# Heat-sensitive sonic textiles: fostering awareness of the energy we save by wearing warm fabrics

**Vincenzo Madaghiele**
KTH Royal Instute of Technology
vmad@kth.se

**Arife Dila Demir**
Estonian Academy of Arts
arife.demir@artun.ee

**Sandra Pauletto**
KTH Royal Instute of Technology
pauletto@kth.se

## ABSTRACT

In this paper we describe the development of two heat and movement-sensitive sonic textile prototypes. The prototypes interactively sonify in real-time the bodily temperature of the person who wears them, complementing the user's felt experience of warmth. The main aim is making users aware of the heat exchanges between the body, the fabric, and the surrounding environment through non-intrusive and creative sonic interactions.

After describing the design challenges and the technical development of the prototypes - in terms of textile fabrication, electronics and sound components - we discuss the results of two user experiments. In the first experiment, two different sonification approaches were evaluated allowing us to select the most appropriate for the task. The prototypes' use-experience was explored in the second experiment.

## 1. INTRODUCTION

Human relation to energy is often mediated by technology, and the assumptions behind technology's current design affect the possibilities for future developments. The design of contemporary energy systems for the household tend to assume that energy availability is unlimited. Consumption of resources is often concealed to the users, distancing them from the impact they have on the environment and hiding the complexity of energy systems [1, 2]. As part of a larger project about sonic interactions for energy awareness [1], this study addresses heating in the household, prompting users to reflect on their relationship to heating systems and directing the attention to their body through physical wearable interfaces. In this context, our prototypes aim at promoting awareness about a way of heating, and energy saving, that is alternative and complementary to centralized systems: keeping heat by wearing warm fabrics.

We describe the design of two heat-sensitive sonic textile prototypes, shown in Figure 1, through which users receive real-time sonic feedback about their bodily temperature in a minimalistic sonic-aesthetic experience. Results show that letting users playfully engage with their real-time temperature data through our textile-sonic interface fostered reflection on their bodily awareness and their daily-life habits towards heating. The role of sound as a medium of interaction was integral to the experience, as it allowed close physical contact with the measurement, exposing the complexity of heat exchanges rather then concealing it and placing the focus on the person's body rather then distancing heating to a number on the thermostat.

Figure 1. The two sonic textile prototypes. Artifact I on the left, and Artifact II on the right.

Our main contributions in this paper regard (1) the design methods and the implementation of self-contained, sound-augmented textiles [2], (2) the experimental evaluation of our sonifications, which were based on previous studies on warm characteristic of sounds, and (3) the discussion resulting from our user studies about the role of sound in textile-data interfaces.

## 2. BACKGROUND

Heat exchanges are governed by complex physical phenomena. The human body exchanges heat with the environment through convection, radiation, conduction and

---

[1] `https://soundforenergy.net/`

[2] All of the code used for this paper, including the interaction mappings and the sound models is available at `https://github.com/soundforenergy/Sound-augmented-fabrics/tree/main/SMC_heat-sensitive`

evaporation [3, 4]. Modern centralized heating systems rely on heating spaces by warming up the entire volume of air in a room. However, in the past, different methods have been employed for keeping warmth, often focusing on keeping peoples' bodies warm through clothes and furniture [5]. Despite being low-tech, these approaches can be considered more energy efficient, because it does not rely on electrical sources, and could be an inspiration for contemporary technology design. In fact, it has been argued that the current discourse on energy efficiency can be too focused on optimizing existing electric energy systems, without considering alternative options which do not involve any electricity, but may have a bigger impact on lifestyle [6].

Incremental advancements in technology tend to make it more complex and concealed to users, and this can have the consequence of dislocating *ends* from *means* [7], and actions from their effects [8]. A good example is the case of a fireplace, which provides heating, light as well as an aesthetic experience. In the interaction with a fireplace, energy is *felt* through the physical labour of transporting the wood, which also provides feedback on the amount of resources being consumed in real-time. This is not true for current heating methods, which are designed in such a way that users remain oblivious to the amount of resources that are being consumed, providing the illusion of an unlimited energy availability [9]. In fact, it has been shown that recent advancements towards digitalization and automation in the design of these systems can contribute to hide and legitimize unsustainable behaviour and foster harmful power dynamics in home environments [2,10]. Human-Computer Interaction researchers have proposed design strategies to address these issues, calling for different priorities when designing energy interfaces for control and feedback in the household [11]. Some examples include designing playful interfaces [12] that can encourage creativity and wonder [13], or designing 'threshold devices' that allow users to explore and question the complexity of energy systems rather than concealing it [14]. This project explores creative interfaces that foster playful explorations and, at the same time, expose complexity rather than conceal it. The role of the sonic medium for this purpose and the tensions it unveils are discussed in Section 5.3.

The issue of energy efficiency has been tackled in many ways in sonic interaction design, for example through real-time sonification of the power consumption of different appliances [15] or water consumption in a shower [16]. Water consumption has also been addressed by using sound as a playful control mechanism [17], and the introduction of sounds in the home has been investigated through participatory workshops [18]. Different experiments used sonic augmentation as a technique for providing energy feedback in the household, for example by exploiting the affordances of the living space [19], specific household objects [20], or augmenting some sonic properties of the environment such as reverb [21].

Textile products have been historically used for keeping warmth, while at the same time having the function of decoration and creative expression. Inspired by that, in this project we developed prototypes that aim at fostering awareness towards energy exchanges through low-demanding interactions, while at the same time stimulating creative expression and aesthetic engagement. We do so using heat information, as it has been shown that real-time feedback on physical data has potential to elicit self-reflection about bodily experiences [22], such as the feeling of warmth. The relationship between the physicality of sensors, digital data and the resulting feedback has been recently subject of HCI research [23], specifically as part of wearable interfaces. Sonic textiles have been significantly explored in the musical field, in which wearable electronics have been used to build experimental musical interfaces and controllers [24] and interactive performance garments [25]. To the best of the authors' knowledge, no studies have employed sound interactive fabrics to provide heat feedback so far.

## 3. SYSTEM DESIGN

This paper presents the second design iteration of our sound-augmented textile prototypes. Building on the knowledge presented in our previous work [26], we developed two prototypes with alternative shapes and use cases. With respect to our previous prototype, we have further improved and validated our sonification models through a perceptual test; we have developed two different physical interfaces which incorporate the electronic components in a permanent manner; and finally, we have developed fabric-based speakers which are embedded in the prototypes. Overall these developments have improved the stability, safety and sonic clarity of the prototypes.

### 3.1 Textile fabrication

In our prototyping phase, we aimed at developing a seamless **sonic augmentation** of textile materials. We designed our fabric interfaces to be firm enough to contain necessary electronics as well as soft and comfortable enough to be interacted as we usually do with common textile products such as a blanket. We enhanced the touch-based experiences of a non interactive fabric by implementing sonic interactions based on temperature and movement.

Piezoelectric microphones are ideal for this task, since they do not detect any sound when the surface they are in contact with is not moving, so we used them as both movement sensors and sound sources for our sonifications. We used two piezo disks on each artifact, to make the whole textile surface sound and touch-sensitive. As can be seen from Figure 2, the sound signal from two disks was used as an input for a Bela Mini [27] microcomputer, on which the sound models have been implemented in the Pure Data environment [28]. A LM35 temperature sensor is connected to the Bela, and incorporated in the artifacts pointing inwards, in close contact with the body. The temperature detected by the sensor is used to control the sonification. The Bela is powered by a 3.7V LiPo battery, which can be charged through a USB charger.

As electronic sounds need a speaker to be heard, we built fabric speakers [29,30] that were incorporated in the structure of the textile prototypes. Additionally, this allowed

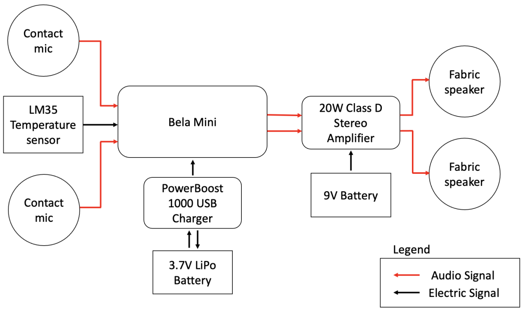

Figure 2. Signal flow and electronic components in our sonic textile prototypes.

Figure 3. Fabric speakers and electronic components have been sewed inside crochet patches

to minimize the amount of solid component on the textiles. Our fabric speakers are composed of a coil made of 0.15mm thick copper wire, which was stitched to a thick piece of plastified paper which acts as a vibrating surface for the speaker. A wire length of 8.3m allows to build a speaker with 8 Ohm resistance. The two ends of the coil are respectively connected to the positive and negative ends of the audio source. The coil is positioned in close contact with a small neodymium magnet (size 25 x 7mm). Before being transmitted to the speakers, the sounds are amplified by a 20W Class D stereo amplifier, powered by a 9V battery. Crochet patches with buttons have been used to secure and cover up the electronic components such as Bela, batteries, sensor and speakers, as in Figure 3. A layer of synthetic fabric was added between the electronic components and the wool for electrical insulation.

Our previous experiments [26] led us to consider different options for the placement of the electronics on the materials. We decided to build two interfaces with different shapes to investigate how people relate to them. The first artifact (Artifact I, on the left in Figure 1), has the shape of a rectangular blanket of size 1.40x2.00m, made of red wool. The electronic components and cables are all positioned on one side of the blanket, giving it a clear direction of use. The two fabric speakers are both positioned on one of the short sides, while the two piezo disks are positioned on opposite ends in order to be sensitive to the whole surface of the blanket. The second artifact (Artifact II, on the right in Figure 1), resembles a long sweater with sleeves or a wearable blanket, and it is made of grey wool. The speakers are positioned on the shoulders of the artifact, while the electronics, besides the amplifier, are on the front part. Specifically, the temperature sensor is positioned on the lower part of the chest, allowing people to easily interact with it and influence its behaviour, and the two piezo disks are positioned under the sleeves, where we noticed they could detect the most movements.

The shape of Artifact II allows us - the designers - to have much more control over the experience, since sensors and speakers have a fixed position when wearing the object. In contrast, the experience with Artifact I is much more open, since it can be used in very different ways and the position of sensors and speakers is unpredictable.

### 3.2 Sonic Interaction design

Our goal was to provide an engaging, low-demand creative and aesthetic experience as well as a straight-forward auditory display of temperature. We therefore aimed to develop a sonic interaction able to combine these aspects, offering a rich and complex auditory experience to the users. Our sonifications were informed by recent research on shared meaning of metaphorical sound descriptions [31, 32]. In particular, by the definition of a *warm* sound from Rosi et al. (2020) [31]:

> *A warm sound seems to be a low-pitched or mid-low-pitched sound. It gives a feeling of spectral richness in the mid-low frequencies. It has a rather soft attack and it is a fairly pleasant sound for the listener, giving a sensation of envelopment.*

We developed two alternative sound models based on the inputs from the piezoelectric microphones and the data from the temperature sensor. The sonic output is activated by the audio sensed by the contact microphone through an envelope follower, which act as an interaction medium in this context. Using piezo microphones in this way means that the interface is silent when the fabric is not moving. When moving, users can intuitively and playfully control the amplitude and the envelope of the sonification without affecting the spectral properties of the sound which communicate the heat information.

Increases in temperature detected by the sensor are mapped to a progressively *warmer* sound. The two sound models that we proposed employ different sonification strategies to achieve the *warmth* sound metaphor.

The first sound model is an **additive synthesizer** (abbreviated as ADD in the following charts and figures), which is composed of a bank of triangle wave oscillators with different amounts of detuning. An increase in temperature is mapped to an increase in amplitude of the lower harmonics, while decreasing the higher ones. The second sound model employs instead a **real-time granular synthesizer** [3] (abbreviated as GRN in the following charts and figures), whose audio inputs are the sounds from the piezo microphones placed on the fabric. In this model an increase in temperature corresponds to a higher octave transposition amount and a shorter live-recording window.

---

[3] This granular synthesizer is based on an implementation by Johannes Kreidler: `http://pd-tutorial.com/english/ch03s07.html`.

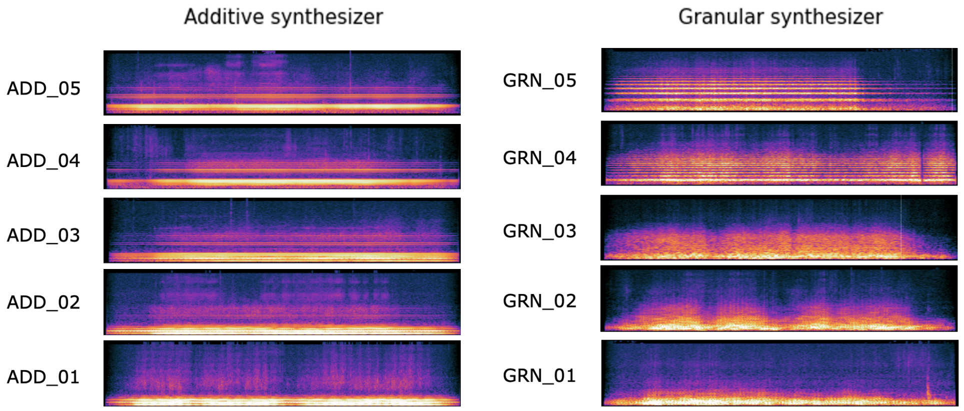

Figure 4. Spectrograms of the two different sound models. The sound tracks are sorted vertically from the *coldest* (ADD_05 and GRN_05) to the *warmest* (ADD_01 and GRN_01)

Moreover, in both sound models an increase in temperature has been mapped to a lower envelope reactivity, resulting in softer attack and slower interaction times. As can be seen from the spectrograms in Figure 4, in both sound models the high-frequency components increase in correspondence of lower temperature, and the attack time decreases; the two models are however quite different in terms of how the energy is distributed in the spectrum.

## 4. METHODOLOGY

We conducted two separate experiments to evaluate the different sides of our prototypes. A quantitative listening test was used to compare the two sound models and validate our assumptions behind the *warmth* sonification metaphor, and a physical user-experience test with the prototypes was used to understand how users relate to them.

### 4.1 Perception experiment

To evaluate if our assumption about the *warmth* of our sonification were correct, we developed an online listening experiment using the platform Psytoolikt [33, 34]. After being asked for demographic information, participants were subjected to a rating task [35], in which they had to rate each sound from *very cold* to *very warm* by moving a horizontal slider, whose position was quantized from 0 to 100. The sonic stimuli participants listened to were sampled from the two sound models, and their order was randomized. There were 15 stimuli for each sound model, sampled at 5 different levels of *warmth*, 3 different envelopes for each level. The sounds have been recorded with a microphone from the fabric speakers on the artifacts [4] .

The participants to the online listening test were recruited through the Prolific platform [5] . The test involved 30 participants and it lasted approximately 10 minutes paid at a hourly rate of 9GBP. The age of participants was between 19 and 54, averaging at 29. Among them, 17 identify as female and 13 as male. Out of all participants, 5 stated that they had no sound or music background, 14 that they have basic knowledge, 10 self-described as intermediate, and 1 participant had advanced musical knowledge.

The results of this perception experiment are shown in the box plots in Figure 5. In both sound models the *warmth* mapping shows on average to be successfully intuitive for participants, confirming that our sound design reflects results from the literature [31, 32]. In general, sound *warmth* seems to be more easily identified in the Granular model (GRN) than the Additive one (ADD), especially looking at the results for *colder* sonic stimuli. These results can be attributed to the change in pitch that happens in the Granular mapping, while in the Additive one the fundamental pitch stays the same, resulting in less easily perceivable changes. Moreover, by looking at Figure 4, it can be argued that the spectral shape of sounds produced by the Granular model changes more than the ones from the Additive model, corresponding to more easily identifiable sounds.

### 4.2 User studies procedure

We devised a qualitative user testing procedure to understand the artifacts' use-experience. Ten participants took part in individual user evaluations with the physical prototypes. The test lasted approximately 40 minutes, and was run in our lab at KTH Royal Institute of Technology. The test procedure combines think-aloud methods [36] and semi-structured interviews [37]. Five participants experienced Artifact I and the other five experienced Artifact II. Given the results of the perception experiment, the qualitative test was carried out only with the Granular synthesizer (GRN) sound model on both prototypes.

The first phase of the test took place in our studio, a closed space with a quiet sonic environment. Before starting the test, participants were asked about their relationship to their home heating system and in which situation

---

[4] The sonic stimuli used for this experiment are available at `https://github.com/soundforenergy/Sound-augmented-fabrics/tree/main/SMC_heat-sensitive/00_Docs/test_sounds`

[5] `https://www.prolific.co/`

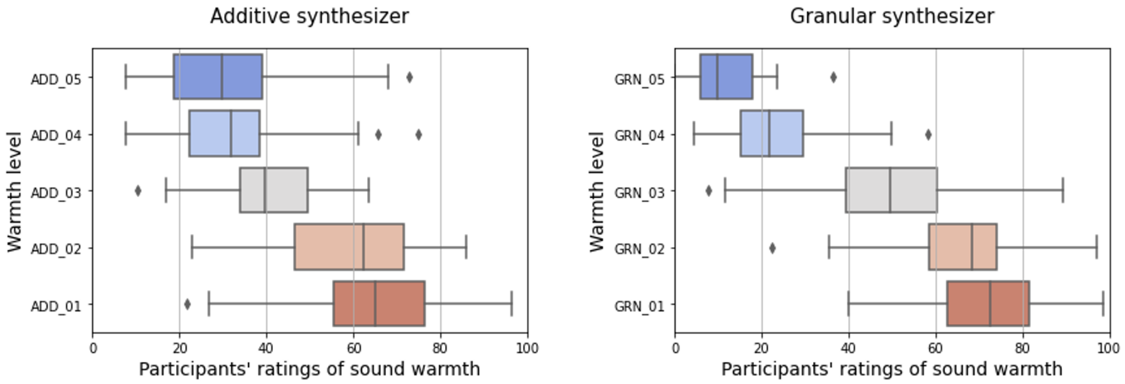

Figure 5. Results of the perception test. Results for each *warmth* level have been averaged over the three stimuli with different envelopes.

they would use clothing as an alternative to increasing the temperature of radiators - either for reasons of costs, lack of control or environmental awareness. Then, they were introduced to the prototypes, and we indicated to them only the position of the temperature sensitive area. They were then invited to freely explore the object and interact with the temperature sensor while listening to the sound. After this they were asked to describe their experience.

The second phase of the test consisted in taking a short walk outside, in the yard of our research institution in the winter while wearing the artifact. After this, participants were again asked to describe their experience. The aim of this part of the test was for users to experience different thermal conditions and explore how the artifacts react in such situation, while at the same time being in a less controlled sonic space. Once back inside the studio, a short semi-structured interview [6] was conducted with participants about the experience. Audio and video of the free exploration task and the interviews were recorded and later analysed by the authors.

## 5. DISCUSSION

In this section we discuss the results of our qualitative user testing. Given the low number of participants, we do not claim that these results can be generalized; however the experience of participants with our prototypes can be of interest for other use cases of sonic augmentations and interactive sonification. In the analysis of the results we were mainly interested in how users interact with the temperature data in the sonic form and how sonic augmentation affects their awareness.

### 5.1 Sense-making

In the first phase of the experiment, we asked participants about their relationship with heating and their use of textiles for warmth. After this, the only information about the object that was given to them was the position of the temperature-sensitive area. This influenced participants' approach to the free exploration, shifting their focus towards the heat-sensitive aspect of the artifact. In order to test the intuitiveness of the sonic augmentation, users were not told that sound would also react to movements.

At the start of the free-exploration task, most participants tried to understand which aspects of the sound were modified by changes in temperature. Here we can identify the first difference between the two prototypes: it was easier to recognize the pitch-temperature mapping for users of Artifact II rather than for those who interacted with Artifact I. This is probably due to the different affordances of the artifacts. The mapping between the sound envelope and movement was considered straight-forward by the users of Artifact II, who did not even consider that the envelope changes could be related to temperature. This is also true for most users of Artifact I; however it generally took a longer trial-and-error process for them to correctly guess the mapping. Some of the participants were not able to identify this aspect at all. For example P4 connected the envelope information to the temperature:

> *The sound can get louder when the blanket is near my body, so that could be an indication that I am in a comfortable and safe and warm environment.* (P4 - Artifact I)

Differently from our previous study, the presence of electronic components did not influence the comfort of most participants. Instead, many users commented positively about the comfort of the interfaces while at the same time being aware of the electronics present in them.

### 5.2 Multimodality and interaction time-scales

Once familiarized with the object, some participants started interacting with the temperature sensor, consciously using movements to activate the sound while touching the heat-sensitive area, for example putting it closer to their body or holding it inside their hands. Participants that used Artifact I explored a vast range of interactions, such as wearing it as a cape (P6 and P9), putting it on their head (P3),

---

[6] A further description of the test procedure is provided as supplementary material at `https://github.com/vincenzomadaghiele/Sound-augmented-fabrics/blob/main/SMC_heat-sensitive/00_Docs/Evaluation%20procedure.pdf`

spreading it on the floor and sitting on it (P6), playing it as a drum (P7). Participants that tried Artifact II were instead more focused on the heat-sensitive component, for example holding the sensor close to their lower chest and stroking the surface (P2), or slowly moving their torso and arms to feel the sonic response as the temperature of their body increased (P1, P3 and P8).

Despite the digital sound models on both objects being exactly the same, sound perception in Artifact I was influenced by the movement of the speakers, and by its changes in shape. These aspects were used creatively by participants, who for example could hold the speakers close to their ears with one hand while exploring the textile surface with the other hand (P7), or shaking the artifact from left to right to experience the spatial change of the sound caused by the fast moving speakers (P9).

The distinction between heat and movement-sensitive aspects of the sound models was influenced by the different time-scales in which the temperature sensor and the piezo disks operate. Movement-based sound changes are much faster and immediate, while heat sound changes are complex, slow and unpredictable, as they are influenced by a variety of factors. This can be confusing for users, because the two sensors affect different aspects of the same sound model and, in the case of the granular model employed in these tests, the piezo input is influencing both the envelope and the spectral properties of the sound, while temperature has most recognizably an effect on pitch, although also changing the spectrum. Since the sound model was not explained in any way to the participants, the different time-scales made it sometimes difficult and frustrating for some to understand the pitch-temperature mapping, as the pitch changed much more slowly than amplitude. Moreover, as some participants pointed out, the test setting might have influenced their experience:

> *If I went home and sat on the sofa for an hour with the blanket on I wouldn't feel frustrated at all.* (P9 - Artifact I)

This is indeed inherent to the design of the artifacts, which are devised for slow, unfocused and continuous use as much as conscious and creative interactions, but were tested in the latter mode rather than the former one.

### 5.3 Sonic interactions with data

Participants were successfully able to distinguish the heat and movement-based sonic interactions, however the entanglement of these two factors in the experience played a significant role in how participants interpreted the prototypes' function. Users had different emotional reactions, ideas and proposed use-cases for the prototypes based on their experience. We identified some common viewpoints towards the sonic interactions, as a result of analysis of their comments during free elicitation and their reflections in the semi-structured interview.

**Sound as persuasion** The persuasive power of sound as a means of communication is well documented in the literature [38–40], and reflected in the experience of users, as they look for a functional purpose of the artifacts. Influenced by the conversation about household heating, participants were prone to interpret the artifacts as functional objects with a clear purpose towards energy efficiency. However, the exact way in which energy efficiency would be achieved - the objects' call-to-action - was not clear to them.

> *Do you want to be noisy? Or do you want to be quiet?* (P5 - Artifact II, directly talking to the object)

This confusion became more defined after the second part of the test, in which the participants realized that the fabrics react to the colder temperature with a *colder* sonic feedback. A clash was identified between what they thought the artifact was trying to promote (turning down the electric heating) and what it was actually communicating (expressing coldness, and therefore a need for further heating).

> *Yeah, I definitely feel myself getting warmer and [pitch] is going kind of lower. But I wonder, does that mean that I need the blanket less?* (P8 - Artifact II)

In this interpretation participants thought the artifacts should persuade them to somehow engage in more sustainable behaviour.

**Sound as complement of bodily experience** Here we place the emphasis on the fact that the sonic feedback can complement and augment the experience of getting warmer or colder, something that participants indeed noticed. In this viewpoint, they assigned a function of increasing self-awareness to the object.

> *Reminds me like: you are really nice and cozy. Even if that's not a prompt to change anything, I feel like it's kind of nice feedback to get. It's just a sound reminder of what my current state is, which is positive.* (P8 - Artifact II)

Some participants referred to not always being conscious of the state of their body, and that receiving a positive feedback about their bodily state might influence their perception of warmth, or making them notice if something needs to be changed.

> *I'm actually happy to know that it's giving me the confirmation that things in my upper body are all right, and being protected and I don't have to worry about it* (P3 - Artifact I)

This idea was especially interesting for P8, who brought up the concept of *interoception* [41], and proposed that a similar approach could be used with different kind of data to increase self-awareness about other bodily states.

**Sound as exposure** It is indeed important to consider the aspect of privacy when designing personal sonic interactions as ears don't have lids [40] and, unless using headphones, sonic feedback is broadcasted publicly from speakers. Despite our strive to achieve a personal sonic experience through low volume and personalized speaker position, some participants were concerned about the fact that other people could hear their personal data.

> *I get that feeling that other people can hear the sound and that makes me a little bit self-conscious, because I am uncomfortable with getting attention to myself in the public. [...] It's giving me the information, and I understand that. But I'd rather prefer it told it to me than making a public announcement out of that.* (P3 - Artifact I)

These participants specified that they wouldn't like others to know information about their bodily temperature, because they considered it intimate and personal.

## 6. CONCLUSIONS

In this paper, we have presented heat-sensitive sonic textiles as creative interfaces that allow users to explore and question their relationship to heating as energy in the home. We describe our methodology to build solid, self-contained prototypes of sonic textiles, and we discuss the design strategies and issues we had to consider for designing low demanding, playful and informative sonic interactions with bodily data.

We developed a perception experiment to evaluate whether our sonifications were interpreted correctly in relation to warmth, and we selected the most successful sound model. We discussed how the decisions we made in terms of both physical and sonic design impact participants' experience with the two prototypes, examining the participants' viewpoints in relating to personal data through sonic interactions.

### Acknowledgments

This project was realized in the context of the Sounds for Energy project (Project No. 51645-1), funded by the Swedish Energy Agency.

## 7. REFERENCES

[1] S. Darby, "The effectiveness of feedback on energy consumption: A review of the literature on metering, billing and direct displays," *A Review for DEFRA of the Literature on Metering, Billing and direct Displays*, pp. 1–21, 2006.

[2] T. Hargreaves, M. Nye, and J. Burgess, "Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term," *Energy Policy*, vol. 52, pp. 126–134, Jan. 2013.

[3] A. Shitzer and R. C. Eberhart, "Heat transfer in medicine and biology," in *Heat Transfer in Medicine and Biology*, 2012.

[4] Thermopedia. Body (human) heat transfer. [Online]. Available: https://thermopedia.com/content/587

[5] K. D. Decker. Restoring the old way of warming: Heating people, not places. [Online]. Available: https://www.lowtechmagazine.com/2015/02/heating-people-not-spaces.html

[6] ——. Bedazzled by energy efficiency. [Online]. Available: https://solar.lowtechmagazine.com/2018/01/bedazzled-by-energy-efficiency.html

[7] A. Borgmann, *Technology and the character of contemporary life: a philosophical inquiry*, 9th ed. Chicago: Univ. of Chicago Press, 1984.

[8] L. Manovich, *The Language of New Media*, ser. Leonardo. MIT Press, 2002.

[9] J. Pierce and E. Paulos, "Materializing energy," in *Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS '10*. Aarhus, Denmark: ACM Press, 2010, p. 113.

[10] T. Hargreaves, "Beyond energy feedback," *Building Research & Information*, vol. 46, no. 3, pp. 332–342, Apr. 2018.

[11] Y. Strengers, M. Hazas, L. Nicholls, J. Kjeldskov, and M. B. Skov, "Pursuing pleasance: Interrogating energy-intensive visions for the smart home," *International Journal of Human-Computer Studies*, vol. 136, p. 102379, 2020.

[12] W. Gaver, "Designing for homo ludens," *I3 Magazine*, vol. 12, 01 2002.

[13] Y. Strengers, "Smart energy in everyday life: are you designing for resource man?" *Interactions*, vol. 21, no. 4, pp. 24–31, Jul. 2014.

[14] M. Michael and W. Gaver, "Home Beyond Home: Dwelling With Threshold Devices," *Space and Culture*, vol. 12, no. 3, pp. 359–370, Aug. 2009.

[15] D. Lockton, F. Bowden, C. Brass, and R. Gheerawo, "Bird-wattching: Exploring sonification of home electricity use with birdsong," in *SoniHED: Conference on Sonification of Health and Environmental Data*, 09 2014.

[16] J. Hammerschmidt, R. Tünnermann, and T. Hermann, "Infodrops: Sonification for enhanced awareness of resource consumption in the shower," in *ICAD*. International Conference on Auditory Display (ICAD), 2013.

[17] Y. Seznec and S. Pauletto, "The singing shower: A melody-sensitive interface for physical interaction and efficient energy consumption," in *Sound and Music Computing Conference, June 2022*, 2022.

[18] ——, "Towards a workshop methodology for involving non-experts in the sonic interaction design process: Connecting household sounds and energy," in *International Conference on Auditory Display*, 2022.

[19] A. R. Menon, B. Hedin, and E. Eriksson, "Expanding Affective Computing Paradigms Through Animistic Design Principles," in *Human-Computer Interaction – INTERACT 2021*, C. Ardito, R. Lanzilotti, A. Malizia, H. Petrie, A. Piccinno, G. Desolda, and K. Inkpen, Eds. Cham: Springer International Publishing, 2021, pp. 115–135.

[20] V. Madaghiele and S. Pauletto, "The sonic carpet: real-time feedback of energy consumption and emission data through sonic interaction design," in *27$^{nd}$ International Conference on Auditory Display (ICAD)*, Online, 06 2022.

[21] K. Groß-Vogt, M. Weger, R. Höldrich, T. Hermann, T. Bovermann, and S. Reichmann, "Augmentation of an institute's kitchen: An ambient auditory display of electric power consumption," *Proceedings of the 24th International Conference on Auditory Display - ICAD 2018*, 2018.

[22] C. Núñez-Pacheco and L. Loke, "Aesthetic resources for technology-mediated bodily self-reflection: the case of eloquent robes," in *Proceedings of the 26th Australian Computer-Human Interaction Conference on Designing Futures: the Future of Design*. Sydney New South Wales Australia: ACM, Dec. 2014, pp. 1–10.

[23] V. Tsaknaki, K. Cotton, P. Karpashevich, and P. Sanches, ""Feeling the Sensor Feeling you": A Soma Design Exploration on Sensing Non-habitual Breathing," in *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. Yokohama Japan: ACM, May 2021, pp. 1–16.

[24] K. Cotton, P. Sanches, V. Tsaknaki, and P. Karpashevich, "The Body Electric: A NIME designed through and with the somatic experience of singing," in *NIME 2021*. Shanghai, China: PubPub, Jun. 2021.

[25] L. Elblaus, V. Tsaknaki, V. Lewandowski, and R. Bresin, "Nebula: An Interactive Garment Designed for Functional Aesthetics," in *Proceedings of the 33rd Annual ACM Conference Extended Abstracts on Human Factors in Computing Systems*. Seoul Republic of Korea: ACM, Apr. 2015, pp. 275–278.

[26] V. Madaghiele and S. Pauletto, "Experimenting techniques for sonic implicit interactions: a real time sonification of body-textile heat exchange with sound augmented fabrics," in *2$^{nd}$ Conference on Sonification of Health and Environmental Data (SoniHed)*, Stockholm, Sweden, 10 2022.

[27] G. Moro, A. Bin, R. H. Jack, C. Heinrichs, and A. P. McPherson, "Making High-Performance Embedded Instruments with Bela and Pure Data," *International Conference of Live Interfaces*, p. 5, 2016.

[28] M. S. Puckette *et al.*, "Pure data," in *ICMC*, 1997.

[29] S. Nabil, L. Jones, and A. Girouard, "Soft Speakers: Digital Embroidering of DIY Customizable Fabric Actuators," in *Proceedings of the Fifteenth International Conference on Tangible, Embedded, and Embodied Interaction*. Salzburg Austria: ACM, Feb. 2021, pp. 1–12.

[30] T. Preindl, C. Honnet, A. Pointner, R. Aigner, J. A. Paradiso, and M. Haller, "Sonoflex: Embroidered Speakers Without Permanent Magnets," in *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*. Virtual Event USA: ACM, Oct. 2020, pp. 675–685.

[31] V. Rosi, O. Houix, N. Misdariis, and P. Susini, "Uncovering the Meaning of Four Semantic Attributes of Sound : Bright, Rough, Round and Warm," *e-Forum Acusticum 2020*, p. 8 pages, 2020.

[32] ——, "Investigating the shared meaning of metaphorical sound attributes: bright, warm, round, and rough," PsyArXiv, preprint, Mar. 2022.

[33] G. Stoet, "Psytoolkit: A novel web-based method for running online questionnaires and reaction-time experiments," *Teaching of Psychology*, vol. 44, no. 1, pp. 24–31, 2017.

[34] ——, "PsyToolkit: A software package for programming psychological experiments using Linux," *Behavior Research Methods*, vol. 42, no. 4, pp. 1096–1104, Nov. 2010.

[35] B. L. Giordano, P. Susini, and R. Bresin, "Perceptual Evaluation of Sound-Producing Objects," *Sonic Interaction design*, p. 47, 2013.

[36] D. W. Eccles and G. Arsal, "The think aloud method: what is it and how do I use it?" *Qualitative Research in Sport, Exercise and Health*, vol. 9, no. 4, pp. 514–531, Aug. 2017.

[37] D. M. Fetterman, *Ethnography: Step-by-Step*. SAGE Publications, 2019.

[38] J. Volcler, *Contrôle : comment s'inventa l'art de la manipulation sonore*. Paris: La Découverte, 2017.

[39] ——, *L'orchestration du quotidien*. Paris: La Découverte, 2022.

[40] S. Voegelin, *Listening to noise and silence: towards a philosophy of sound art*. New York: Continuum, 2010.

[41] A. (Bud) Craig, "Interoception: the sense of the physiological condition of the body," *Current Opinion in Neurobiology*, vol. 13, no. 4, pp. 500–505, 2003.