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ABSTRACT

Designing interactive technology to support and reduce domestic energy consumption has occupied HCI researchers for decades. This paper extends this body of HCI research by using postphenomenology as an analytical lens to understand how the digital energy assistant' Watts' mediates domestic district heating. We base our inquiry on empirical insights from a two-year study. We conducted informal meetings, focus groups with seven households before Watts' distribution, two rounds of semi-structured interviews with seven household representatives using Watts, and 304 questionnaire respondents. We illustrate findings in three postphenomenological dimensions - practical, ontological, and epistemological - showing a two-sidedness of technology-mediated domestic district heating. For instance, Watts enables some to reduce heating by magnifying certain new aspects of consumption, but also constrains others from doing the same by concealing the "raw" consumption data. Finally, we discuss four tensions of Watts mediation and how postphenomenology can complement HCI studies on domestic energy consumption.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in HCI**.

KEYWORDS

postphenomenology, district heating, sustainability

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1 INTRODUCTION

Studying and designing digital technology to facilitate more sustainable energy consumption in the home is an ongoing challenge in the HCI research community. For years, HCI scholars have been occupied with the research and design of digital technologies to create or promote sustainable behavior. This interest aligns well with contemporary social movements that call for reducing consumer consumption in sectors such as electricity, transportation, and heating. Most HCI studies focus on electricity consumption, and particularly on how to change consuming behaviour through e.g., eco-feedback and eco-forecasting technology [16]. However, a critique of many of these studies is that they fail to account for their long-term effects and the complexity of everyday life [53]. To this end, an emerging interest in the HCI community is to extend our understandings by bringing in novel theories and perspectives as a lens [20]. As argued by Frauenberger, this is a move towards asking less about what features make particular technology work and more about the configurations in which it works [15]. Inspired by such perspectives, we turned our attention to *postphenomenology*.

Postphenomenology sees technology as a *mediator* that shapes how humans experience and act in the world. As such, postphenomenology aims to account for human-technology-world relations. It rejects the notion that technologies are passive means for realizing human needs, stresses empirical work as the basis for analysis, and that mediation depends on specific technologies [20]. Although initially presented by Don Ihde [23], several scholars (e.g., [5, 32, 59]) have expanded on his original concepts. These concepts are applicable as postphenomenological lenses for understanding technology mediation, which is evident in a number of HCI papers (e.g., [5, 12, 15, 21, 25, 41, 57, 59, 61]. However, while postphenomenology has provided powerful concepts to HCI researchers as a lens to understand technology mediation, the area of application has been relatively narrow. In HCI, postphenomenological perspectives and contributions within domestic energy consumption and conservation is still unexplored.

This paper extends and complements contemporary HCI research on domestic energy consumption using postphenomenology as an analytical lens. We derive empirical insights from a two-year study of district heating where we have investigated the energy

assistant *Watts* a smartphone app designed to give single-family households feedback on heating consumption. The purpose is to understand how Watts (technology) mediates people's (human) experience and interactions with district heating in the home (world). We report from a mixed-methods study with focus group interviews with seven households before Watts distribution, two rounds of semi-structured interviews with seven households using Watts, and 304 respondents to a deployed questionnaire.

As the basis for our analysis, we are inspired by Ihde's notion of the two-sidedness of technological mediation: how technology accentuates certain aspects of the world, but in return, downplays others. In our analysis, we expand the notion of two-sidedness by using the *four dimensions of technology mediation* [32] to direct the paper's analysis and discussion. Three of those dimensions were used to structure the analysis and present the findings (practical, ontological, and epistemological) explaining the two-sidedness and complexity of how Watts mediates domestic district heating consumption. We illustrate two contributions to HCI research in our discussion. First, we use illustrate four tensions from our fidings using the fourth *ethical* dimension from Kirans framework. Second, we address how our work contributes to HCI research on domestic energy consumption.

2 RELATED WORK

In this section, we first unfold HCI literature in domestic energy consumption gradually moving our attention towards district heating. Second, as a complementary perspective to existing studies within domestic energy consumption, we present postphenomenology as a lens for understanding digital technology mediation in district heating.

2.1 Domestic Energy consumption in HCI

For over a decade, HCI has seen a tremendous increase in research aiming to investigate digital technology to support and reduce domestic energy consumption [6]. Within HCI research on energy consumption, persuasive technology has been a central concept for guiding interaction design [11] focusing on changing consumer behavior, for example, through eco-feedback [53]. Eco-feedback refers to "technology that provides feedback on individual or group behaviors with a goal of reducing environmental impact" [16]. Within eco-feedback, several different modalities have been studied, for example, art and ambiance (e.g., [18, 46]), physical materials (e.g., [18, 44, 62]), or lighting (e.g., [31, 41]). More recently, HCI research has also complemented eco-feedback with concepts such as eco-forecasting (e.g., [27, 33, 45]) in realizing that an overview of past consumption might not be enough to help people plan and change their behavior. Despite these attempts, HCI studies report that eco-feedback often does not change consumer behavior for reasons such as people already having established practices that do not fit with the intended behavior change [19, 50], or technology assuming every user has the knowledge and willingness to act [52].

Different consumer sectors have been studied such as electricity (e.g., [8, 10, 33, 34], transportation (e.g., [7, 29, 54]), water (e.g., [17, 40]), and heat (e.g., [3, 13, 26, 31, 35, 37, 63]). In this body of literature, researchers have been especially interested in changing behavior in electricity use and central heating [19]. A less studied sector which is related to central heating is *district heating* which is widely spread in many Nordic countries. Opposite central heating, the literature in district heating focuses less on behavior change and more on efficiency or one-time investments (like upgrading or renovating the house) aiming at long-term effects [56]. As sole examples, Hasselqvist et al. [19] investigates potential designs by outlining requirements for interactive systems supporting one-time actions. Kvist Svangren et al. [37] investigate one-time actions and argue that there is a need for more specific advice as each household is unique.

Lately, the HCI community has been expanding their focus on technology by bringing new theories and perspectives to understand the complexity of human-technology relations [20]. For example, drawing on theories of scripting, Jensen et al. [28] illustrates three different personas of energy users based on a holistic understanding of a home setting. Drawing on social practice theory, Jensen et al. [29] shows how Electric Vehicle (EV) drivers use their cars to make driving a more meaningful, sustainable, and desirable practice. Similarly, in design research, Raptis et al. [44] draws on aesthetic, functional, and conceptual provocations to bring forward tacit knowledge on energy consumption practices. For heating, Madsen and Gram-Hanssen [39] uses practice theory to show that comfortable temperature is perceived differently in different practices.

In this paper, we extend the HCI literature on domestic energy consumption using *postphenomenology* as a lens to study district heating. We turn our attention to postphenomenology as we are motivated to explain how digital technology is not only a collection of functionalities that can be designed to serve people, but rather relational [12] in the sense that technology shape us and we shape technology. As a case, we study district heating which have received limited attention in HCI.

2.2 Postphenomenology and HCI

Postphenomenology brings together approaches from more traditional technology philosophies like phenomenology, American pragmatism, and Science and Technology Studies [47]. However, postphenomenology moves beyond these in at least three ways [25]. First, it emphasizes that people's experiences and technology cannot be seen as distinct entities but are inseparable, continuously shaping each other and influencing the perceptions and experiences of the world [23, 24, 60]. To this end, the world can be understood as a situational context such as the home or a more abstract idea such as people's understanding of themselves [20]. Second, postphenomenology stress empiricism by exploring how concrete material artifacts affect human experience and action [47]. In this context, empirical work is derived from actual experiences with certain technologies, including first-person experiences, self-conducted studies, and other empirical work by others [20]. Finally, postphenomenology is based on a relational ontology: a philosophical stance stating that entities do not have a-priori qualities but become through relationships with others.

Although much work has already investigated behavior change, many studies stress technology (e.g., eco-feedback) as a means to achieve behavior change. However, postphenomenology is slightly

different in this regard. No matter the behavioral outcome, postphenomenology stress that a change in the human-technology relationship (i.e., introducing Watts to customers) will introduce a change to something. We seek with our work in this paper to achieve a more detailed outlay of this relationship in detail.

In his original work, Ihde presents four concepts that explains types of technology mediation [23]: Some artifacts are transparent to users and can be seen as extensions of ourselves (*Embodiment*), some require little or no interaction (*Background*), some presents information that needs interpretation (*Hermeneutic*), and some might be confronted as quasi-living beings with whom people interact (*Alterity*). While these have proven useful in many cases, recently, others scholars have presented extensions of these concepts (i.e., Verbeek also add *Cyborg*, *Immersive*, and *Augmentation* [59]). Following this work, in HCI studies, different areas have been investigated using postphenomenology as a lens (e.g., [5, 12, 15, 21, 25, 41, 57, 59, 61]). As examples, the study of obstetric ultrasound by Verbeek [58] shows the technology's mediating effects on parents' perceptions of the fetus and how, in effect, this shapes how they make future decisions. Similarly, investigating electricity use, Pierce and Paulos [42] used postphenomenology and design to challenge our typical electricity experience by making us experience it 'as a thing itself' instead.

In this paper, we adopt postphenomenology as an analytical lens as we aim to understand the mediating role of an energy assistant – Watts – an recently introduced app designed to give households feedback on their district heating. To this end, we use a specific framework: Kirans four dimensions of mediation [32]. We elaborate further on this framework in Section 3.3.1 of this paper.

3 STUDY

In this section, we first unfold the case of district heating as an energy sector along with the energy assistant Watts and how it relates to district heating. Second, we describe data collection, and finally, we describe data analysis.

3.1 District Heating and the energy assistant Watts

District heating is a widely adopted way to heat households in Nordic countries. District heating can be described as a closed system of pipes with pressurized hot water that can heat individual buildings, neighborhoods, or towns [38]. The consumers are served from a centralized plant or several distributed heat-producing units. When hot water enters the household, radiators or floor heater units cool down the supplied water and heat the air around it. The temperature is regulated by thermostats on each unit. The cooled water is eventually returned to the plant for reheating. Traditionally, inside every house with district heating, a meter gives feedback displaying aggregated total consumption data, real-time consumption, and temperature levels for the whole household. The meter is usually installed out of sight for example, where the pipes enter the building below ground. Besides meters, consumers receive quarterly accumulated consumption feedback either on paper (letter) or on email. House owners are not free to choose a supplier (and prices) but are bound to the one that manages the physical infrastructure.

In 2020, the district heating provider of Aalborg in Denmark, Aalborg Forsyning (AFS) municipality of, started digitalizing heat metering and consumption feedback. This was part of a larger goal of lowering demand side consumption to be able to deliver fully renewable and more efficient heating, also known as 4th generation district heating [38]. This process involved the roll-out of the smartphone application *Watts*, an energy assistant (in AFS own words), that can inform people about household district heating with the belief that this would lower consumption. The roll-out was conducted in stages, gradually offering more and more households access. Watts was offered to more than 40.000 households. Watts digitalize the quarterly accumulated paper consumption feedback (a utility bill) to having consumption data available anytime on the phone. Besides accumulated consumption over time, Watts also introduces novel information to users that were not accessible before. First, it presents a *budget*, which indicates whether or not household consumption is above or below normal values for similar households within a particular chosen range (day/month/quarter/year) (See Figure 1 - 1). Second, it presents an *hourly* overview of household consumption (See Figure 1 - 3). Users can choose several predefined units they want their consumption data to be displayed in, e.g., money or energy (kWh). Values are calculated based on a combination of the household's previous years' consumption, similar households data, and seasonal data. Finally, Watts also introduces *alarms* that preemptively can warn householders if consumption increases unexpectedly. These are implemented as colors codes, green is below the estimated budget, orange is close to the estimated budget, and red is budget exceeded (See Figure 1 - 3). Additionally, a pop-up on the phone will appear for alarms informing of a severe deviation from the budget.

3.2 Data Collection

Over the two year period, we collected data from several sources. We initiated our study with informal meetings and formal interviews with representatives from the utility company Aalborg Forsyning (AFS). The informal meetings became a monthly occurrence and their purpose was to learn more about domestic district heating.

3.2.1 Focus Groups - Mediation before Watts. We wanted to learn how consumers relate to district heating before the introduction of Watts. For this purpose, we conducted focus group interviews with seven representatives who had not yet taken Watts into use. Participants lived in single-family houses in the same geographical area (i.e., serviced by AFS) and had the same prices on heat. We recruited households at a meeting on investments in energy savings organized by a homeowners' association in Aalborg (see Table 1). For better retrospection about heating, focus groups were held within the heating season (November). Before focus group interviews, we informed participants that they could bring material they found relevant to their heat consumption. Thus, the participants brought various materials, including bills, consumption data, and correspondences between participants and AFS. We used these materials to start discussions. We also presented participants with general discussion themes following [36], such as "energy reduction" and "environmental concerns." We developed these themes

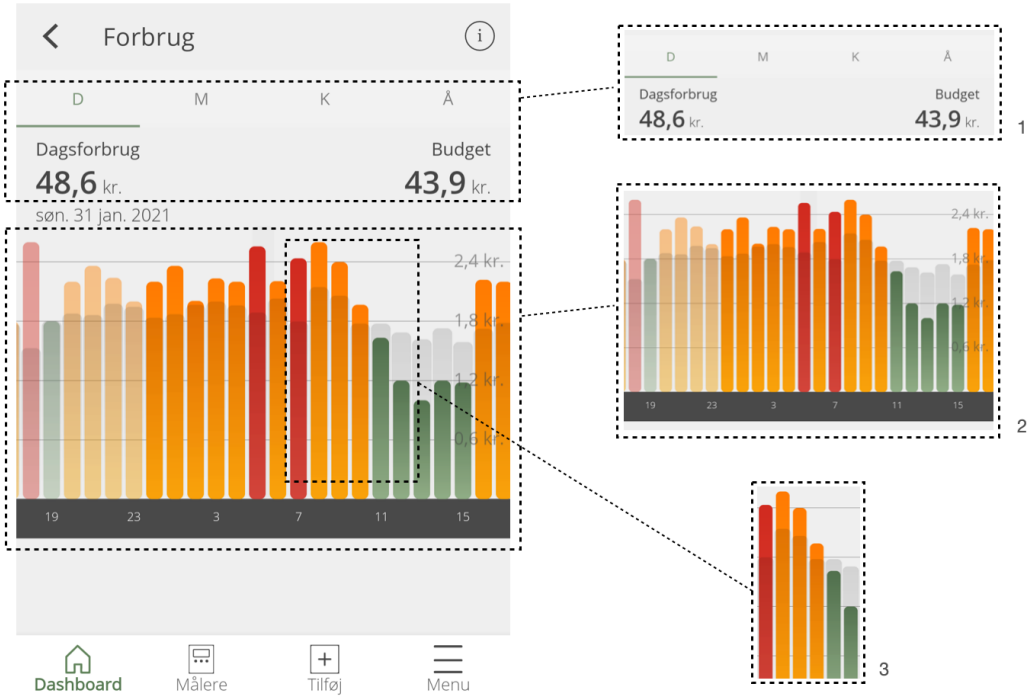

Figure 1: Left: Overview of the primary consumption feedback in the Watts app. Right: 1) Estimated budget for day (D), month (M), quarter (K), and year (Å). It shows current consumption as selected (Dagsforbrug) and estimated budget - 2) Hourly consumption chart (colored columns) with estimated budget for each hour (greyed out columns) - 3) Colors marks consumption according to budget (Red will trigger an alarm on the phone).

from prior insights. We asked follow-up questions starting with *how, what, where, why* [64]. The focus group interviews were video recorded, and researchers took extensive notes. We gathered a total of six hours of video recordings, two hours of audio, and several pages of researcher notes.

3.2.2 Interviews and Questionnaire - Mediation with Watts. To understand how people use Watts and experience their heat consumption, we used a mixed-methods approach combining two rounds of semi-structured interviews (7 months apart) and a questionnaire. We conducted the initial interviews in the fall (October), questionnaires in winter (January - February), and the second round of semi-structured interviews in spring (April-May). We conducted the initial semi-structured interviews [36] with seven household representatives (see Table 1). We recruited participants via email distributed to early Watts users from 200 seperate households. Initially, we selected eight representatives of the 21 households who signed up; however, one participant declined to participate. The households were selected based on house build year, participant age, job function, household composition (i.e., number of adults /children), and self-assessed Watts usage. The interviews addressed the use of Watts and how that had influenced their view on their heating. Due to local lockdowns, we conducted the interviews over the telephone or online (Skype or MS Teams). Questions in the interview guide were based on the previously gathered data and regarded the use of Watts and experiences with heating. In total, seven hours of audio were collected, along with several pages of researcher notes.

Based on the insights from the initial interview, we developed a questionnaire that we distributed to 2000 single-family households in the municipality. The questionnaire contained both open and close-ended questions on the use of Watts, consumption behavior (e.g., which type of feedback consumers found most useful, whether it had changed their consumption behavior, and open-ended elaborations of these). The questionnaire received a total of 304 responses.

Finally, we conducted follow-up semi-structured interviews with the previously interviewed households to understand how their heating experiences and behavior had changed over time. As previously, we interviewed the participants over the telephone and online and developed the interview guide [36] on the previously collected data from initial interviews and questionnaires. Differently, we asked participants to write down their experiences with Watts whenever it has surprised them or strengthened their knowledge about district heating. This exercise was relevant because it helped the participants to collect and recollect their experiences. We collected six hours of audio, along with several pages of notes.

3.3 Data Analysis

3.3.1 Theoretical lens. Providing both analytical and designerly concepts, in this paper, we take an outset in the *four dimensions of technological mediation* [32]. Kiran [32] takes an outset in the

	Name	Gender	Age	Occupation	HH Adults (Children)	Estimated Watts Usage
Focus Groups	Bill	M	70	Retired	2	*N/A*
	Robert	M	48	Researcher	2 (2)	*N/A*
	Michael	M	53	BlackSmith	2 (2)	*N/A*
	Thomas	M	41	Communication Worker	2 (1)	*N/A*
	Daniel	M	64	Factory Worker	2	*N/A*
	Alison	F	72	Retired	1	*N/A*
	Paul	M	53	Contracter	2 (1)	*N/A*
Interviews	Steve	M	39	Researcher	2 (2)	Bi-annually
	Jack	M	45	Construction Designer	2 (2)	Monthly
	Peter	M	51	Taxi Driver	2 (2)	Monthly
	Nick	M	37	Municipal Worker	2 (3)	Weekly
	Karen	F	76	Retired (Secretary)	2	Monthly
	Monica	F	46	Municipal Worker	2 (1)	Daily
	John	M	50	Utility Worker	1	Monthly

Table 1: Overview of focus group and interview household representatives. Names are anonymized.

posphenomenological idea that; *in any shaping, there also has to be a downplaying movement* Ihde [23]. The four dimensions consist of dual concepts. First is an *ontological* dimension describing the technologies' ability to *reveal* and *conceal* the world. The revealing regards the technologies ability to mediate a "new" world and all its possibilities. The downplaying movement of the ontological dimension, the concealing, regards the consequent inability to see other possible ways of seeing the world (i.e., using a typewriter reveals the efficiency of machine typing but may conceal the possibility that there may be different solutions regarding writing). Second is the *epistemological* dimension, and it is concerned with technology-mediated perception and knowledge about the world. Technology can *magnify* and *reduce* what we know about the world; it can augment or diminish our experiences, thus shaping how we obtain knowledge about the world (i.e., an X-ray magnifies specific properties of the body like bones, but reduce others like skin and muscles). Third is the *practical* dimension exploring how technology mediates our actions and behavior in the world by *enabling* or *constraining* behavior. This dimension refers to the things we do in the world and can be influenced by other dimensions e.g., people's interpretations of the world might enable them to act in specific ways, but that might then constrain alternative actions. For example, we might be enabled to drive fast in a new car with lots of horsepower, the car might actually afford it by revealing or magnifying specific aspects to us, but that might also constrain us from driving eco-friendly way, although this might entirely be possible. Finally, the fourth dimension is the *ethical* one, which is more reflective, goes beyond the other three dimensions, and assesses how technology can be *involving* and *alienating*. To this end, assessing the involvement and alienation through technology mediation can set a course and serve as inspiration for designing new technology.

3.3.2 Analysis process. To analyze the collected data, four authors followed the approach of directed content analysis mentioned in [22] using the ontological, epistemological, and practical dimensions mentioned in [32] as an initial coding scheme. The ethical dimension was used to discuss the outcome of the analysis process. First, we went through the data selecting exemplary quotes and coded these according to the three dimensions (e.g., a quote from the questionnaire, "Lowering heating when it is nighttime", was coded under the practical dimension). Second, because each dimension is two-sided [32] (e.g., enabling and constraining in practical dimension), we further divided the identified quotes into two sub-themes (e.g., the quote "Lowering heating when it is nighttime," as a type of enabling). In this process, four authors met several times and discussed three dimensions and the findings until a consensus was reached. In this manner, we focused on the documents' specifics and uniqueness, the identified quotes, and the sub-themes until analytical saturation was reached. Saturation was reached when all quotes deemed relevant to the three dimensions were clustered under a theme and a sub-theme.

4 FINDINGS

Watts aimed to enable district heating reductions by giving householders access to new information about their household consumption, and our findings indicate that for some householders, it does mediate in such away. However, our findings also show that Watts does more than just enable heat reductions. In this section, we show how Watts reveals and conceals what householders know about consumption (ontological), how it magnifies and reduces certain aspects of consumption (epistemological), and finally, how it both enables or constraints actions at consumption (practical). We illustrate our findings using quotes from the entire dataset, using the same names for our participants as in Table 1. We annotate individual quotes from the data (FG, Q, I1, I2, for focus group, questionnaire, first interview, second interview, respectively).

4.1 Ontological dimension

The ontological dimension refers to what *becomes* the world through technology (Figure 2). The *world* in this case refers to *domestic heating*, while what the word becomes signifies how the world is *revealed* or *concealed* through technological mediation.

4.1.1 Revealing. Before Watts, the district heating system was mainly physical with little digital interaction. Our initial focus

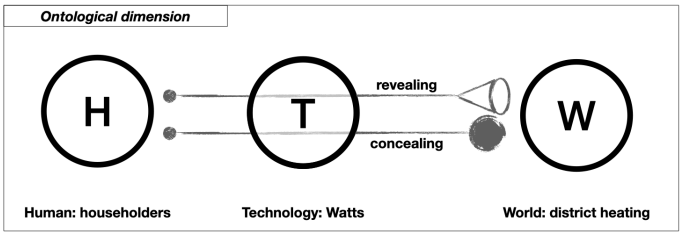

Figure 2: Ontological dimension. What becomes the world (revealed or concealed) to human beings through technology.

group interviews showed that district heating concerned the consumption of the whole house for most householders. The consumption only appeared every three months through a bill (typically in the form of a letter). However, mediated by Watts, new aspects of district heating were revealed to the householders. First, the district heating system was transformed from being largely 'unified' to a 'divided' system. Some householders realized that each device, room, or practice consumes heating differently. For example, Watts had revealed the different individual radiator consumption for interviewee Nick:

> *"I had a suspicion before that the radiators in the living room were using more than they should. I couldn't do that before because the number was accumulated on the entire household."* - **Nick (I2)**

Besides revealing new parts of own household, Watts also revealed district heating consumption in other households. For example, Jack was using Watts to monitor his elderly mothers' consumption. He was monitoring manually for years; it was a bit of a hassle as she lived in a house he rented out to her across town. Although he kept visiting her, he was now able to do monitoring through Watts. In addition, the application revealed a potential for non-invasive monitoring of the consumption for potential new owners when his elderly mother eventually moved out.

Second, the district heating system became continually 'visible' instead of becoming apparent every three months when the bill arrived. For example, Monica **(I1)**. realized that she could monitor the heat consumption of each individual part of the world at any moment: *"I can see if it goes up* [the hourly consumption]*, that it was at that moment we turned the radiators up or cooked and used some hot water."*. Similar to Monica, other householders too explored the constant revealing of the world to them. As a result, they could keep an eye on potential large consumption that could accumulate for months before the bill would arrive.

Third, through the mediation of Watts, district heating was revealed as a world subjected to a breakdown. For many householders, district heating was perceived as always operating in a 'flawless' manner; thus, not requiring any attention. Even the few interviewed participants who would occasionally manually read their meter to keep track of consumption did that usually only once a month. Before Watts, breakdowns had revealed themselves too late:

> *"Right now, we have a very annoying case open with the energy provider. In the last year, we've used 1600m3, whereas in the year before that we've used 800m3. So that's a doubling* [...] *There's no clear answer why, but the energy provider seems to think it's a faulty valve."* - **Bill (FG)**

Through Watts, though, many householders realized that district heating can break down (e.g., increased consumption through broken water pipes, faulty thermostats, etc.), which urged them to take action (see practical dimension). For this reason, the alarm functionality of Watts displaying different colors of consumption and giving notifications.

Finally, we identified a few cases where district heating would reveal itself too often (e.g., through constant consumption alarm notifications). For some, Watts feedback was perceived as disturbing, unnecessary, or giving "too much information" as it mediates a demand for constant attention:

> *"I don't want to know what's going on all the time. I don't want to do anything about it, and I certainly don't want technology that constantly beeps. I have enough of that in everyday life"* - **Michael (FG)**

For others, like Steve **(I1)**, Watts became a constant reminder that his household was consuming too much heating; he was constantly being confronted that his consumption was "red" because this was not his own experience. This experience urged him to stop using Watts: *"I don't bother looking at it* [Watts] *when the numbers are red because I don't experience my consumption like that."*.

4.1.2 Concealing. Pulling in a different direction, Watts also conceals aspects of district heating in the sense that householders cannot know, e.g., alternatives ways of heating. For example, some interviewees explained that they seldom used old ways of knowing about district heating consumption. The old way of (usually) going down the basement and checking the consumption meter, the practice of writing consumption data on notebooks, or listening to radiator sounds had been concealed as digital took over:

> *"I usually had this thing where I would read the meter every three months in the basement and write it down in a book. That has now moved onto my phone instead, so I'm able to follow it there."* - **Peter (I1)**

Furthermore, as district heating was mediated by Watts, certain aspects of consumption have been concealed. For example, while district heating mediated by Watts is highly dependent on large amounts of data for creating a budget - such as previous years' consumption, weather forecast, and consumption data from similar households - these details are concealed from householders. This was present both in our questionnaire data such as *"the budget is a bit off. I don't really understand why, I've used roughly the same"*, and *"I don't understand the budget, it seems random"*, as well as our

interviews. For example, Nick still had not figured out how to read the budget:

> *"Its kind of hard to see what 'normal'* [budget] *is, and therefore it's hard to see through it. That's also why I still read the meters manually to keep track of if what Watts tells me is true."* - **Nick (I2)**

For Nick, the problem was that Watts concealed from him that the world was constituted with other types of data, too, besides consumption. Therefore, Watts' recommendations often contradicted his paper consumption notes. And this urged him to believe that there is a fault within the technology. Similarly, some participants argued that knowing about green alternatives was concealed. Instead, they used consumption budgets as an indicator for what to do. For example, Nick **(I2)** was still using his fireplace because they had no knowledge through Watts about environmental impact: *"I can't really see the environmental benefits of using one or the other, but I can see that I'm red or green in the app, and that's what I use to guide what I use"*.

4.2 Epistemological dimension

The epistemological dimension refers to what human beings *know* about the world through technological mediation and how certain world's aspects are either *magnified* or *reduced* (Figure 3).

4.2.1 Magnifying. Watts magnified individual appliances or activities such as thermostats and showers, thus enhancing the consumers' knowledge about district heating. As also mentioned in the ontological dimension, the introduction of hourly consumption allowed to divide consumption to separate appliances providing new ways to perceive consumption:

> *"Now you can actually see the consumption and track it down to individual rooms by looking at the hourly consumption."* – **Nick (I2)**

For Nick, Watts mediated a new experience of being able to "track down" consumption which was not an intended experience; Watts does not have a specific function to show the consumption on a single appliance. Nevertheless, through a trial and error approach, mediated through the Watts, Nick conceived new knowledge about heating.

Second, Watts magnified knowing what good and bad consumption are, which was typically interpreted through the different color schemes of the app (red, orange, and green). However, some householders interpreted the color schemes as indications of good and bad behavior, but also to see where to improve:

> *"Yeah, it's nifty, because I usually can see on the color whether we're good or bad that day and if we need to improve. If it's red, I probably have to turn down the thermostats or something. Before, you didn't really have a clue."* – **Peter (I1)**

As mentioned in the ontological dimension, the district heating system and household consumption were largely invisible before Watts. Thus, having a new experience with district heating also reflected in the other dimension as it revealed to consumers new knowledge and enabled them to act accordingly.

Similar to budgets, magnifications of *"money spent"* was perceived as good or bad consumption. Thus, Watts did not only inform the consumers of their consumption. The application shaped the way people think and talk about their consumption by magnifying specific consumption units. Many participants in the focus groups and initial interviews referred to district heating consumption in terms of flow and temperature. However, over time new interpretations of consumption had come into focus like 'Kr.' and 'kWh', which is introduced units in Watts but not part of the old way of receiving consumption feedback as argued by Monica:

> *"I have been following the consumption for some time, and it takes a little getting used to, you know, going from flow to kWh. But it is nice, it says more about the actual energy used, I think."* – **Monica (I2)**

To Monica, this was primarily a learning process that took some time to get used to, but to her, the new units were more tangible and representative of the world. Furthermore, based on her experience with district heating before Watts, she argued that representation became more appropriate by magnifying these types of consumption units. Monica stated that the temperature of district heating water is often not the same for different households, and flow-based consumption (m3) does not take this into account, whereas energy-based (kWh) does. Thus, to Monica, magnifying one unit of consumption and reducing the other mediated an experience of fairness.

4.2.2 Reducing. Opposite of magnifying, Watts reduced particular ways of interpreting district heating consumption. For example, although Watts magnifies consumption monitoring, it also reduces the need for monitoring consumption problems simultaneously. Although most interviewed householders had not monitored problems directly before they expressed that they felt more "safe" having something that would reduce the need to decipher bills or meters:

> *"Now you know what's going on. It's kind of like a watch guard that monitors the home for you, and that's very comforting"* – **Monica (I2)**

Even the participants monitoring their consumption "manually" expressed that they would feel safer with something monitoring for them. This was the most crucial aspect of using Watts to most participants because it replaced their role as consumption problem monitors, and they felt comfortable that it would warn them. To an extent, this also goes back to the ontological dimension as Watts visualizing district heating as "something" rather than being invisible.

Another observation was that Watts reduced the number of ways consumption could be represented before creating a simpler overview, which was perceived as useful for some householders. For example, Steve argued:

> *"There are at least four numbers, one for flow, one for temperature in, temperature out, and delta value* [on the physical meter]. *What is that even? In Watts, here on the phone, there are two: money and kWh. That works so much better!"* – **Steve (I2)**

Even though reducing consumption representations was perceived helpful for some, at the same time though, other householders disliked it. Some already had their ways of interpreting the data available to them. In Watts, however, this data was put in the background - reduced to an algorithm calculating good and

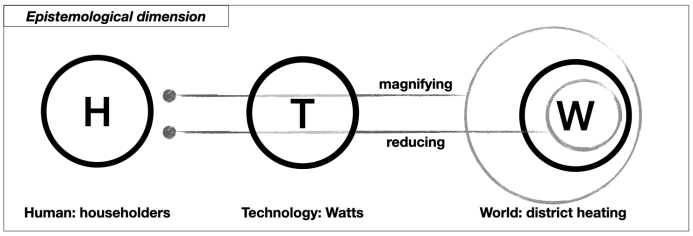

Figure 3: Epistemological dimension. What human beings know about the world (magnified or reduced) through technology.

bad consumption. This created challenges for some when trying to combine old representations of district heating consumption with new ones:

> *"I don't understand why they've chosen to show the consumption as money spent. Down on my meter, it's written in m3 and temperature, but there's no simple way to show that in Watts unless you, of course, download the raw data, but then I might as well read it myself"* – **Nick (I2)**

Nick was frustrated that he couldn't get the data he was used to interacting with because Watts reduced it. Similarly, Robert (FG), who liked to "nerd" numbers, had a customized spreadsheet containing exact data for his house. He was skeptical about the Watts since he experienced that the "raw" data was less visible or accessible than before Watts; he wanted to "dive" into complex data and have a complete overview. Thus, for a user like Robert, Watts gave the experience of incompleteness, reducing the knowledge that he is used to having regarding district heating. On the other side, people that had no or minimal knowledge of district heating had a similar experience, for example to **Karen (I1)**: *"I don't know what to do, you know, that was my late husbands' job. It all seems new to me, and I thought maybe the app* [Watts] *could give me some information. But it doesn't show me what it is or what to do."* As she did not have any prior knowledge of district heating; she knew little about her consumption in general, which was indicated when she confused district heating with cold water and electricity. To a user like Karen, Watts appeared to be too "nerdy", thus reducing the learning experience with district heating.

4.3 Practical dimension

The practical dimension refers to what human beings do in the world through technology (Figure 4). The *world* in our study is *domestic heating*. Within this practical dimension, technological mediation can be *enabling* people to achieve certain goals, or *constraining* them.

4.3.1 Enabling. The questionnaire showed 35 respondents who reported their heat consumption had changed since they started using Watts. We found that both heat consumption reductions and increases were enabled through Watts. Examples mentioned in the questionnaire include *"lowering heating when it's nighttime"*, *"using less hot water"*, *"turning off water heaters when not home"*. In these examples, Watts enabled daily (almost constantly) acting at the world (district heating) enabling Monica and her family to make heat reductions a game:

> *"You bet it has worked, at least in our home! It's almost a game for us, you know, getting to the next level by using less than the day before getting the cost down even lower than before in the app"* - **Monica (I1)**

Monica and her family made small daily interventions to reduce consumption. For example, she convinced her family to take shorter showers or put on sweaters if it was cold in the morning as she knew the sun later warm up the house. Watts revealed consumption to her several times a day, and through this, her heat reducing acts were kept in check.

However, opposite Monica, very few householders were enabled to act constantly. Many of them opted for more comfortable ways of acting. Thus, a second way Watts enabled some householders to reduce their heat consumption was investments. Examples identified in the questionnaire were *"changing to newer / automated thermostats"*, *"adding more insulation to the house or pipes"*, or *"investing in a new heat exchanger"*. For most of the interviewed participants, one-time investments were preferred since they required minimum ongoing interactions. Thus, it was a convenient way to save money and bring down overall consumption. Jack, a construction engineer and father of two explained:

> *"Watts have revealed to me some places where I need to do something where I've had a suspicion* [...] *for example, investing in smart thermostats to replace the old ones to lower temperatures at night* [...] *It would be way more convenient to buy something that could be more efficient, and then you wouldn't have to think about it again for some time. If you didn't have a lot to do, then maybe you would have time to fiddle around, but I don't."* - **Jack (I1)**

In his own words, Jack was *"a little geeky"*, knew about heating due to his job, and despite that, he was too busy or unwilling to act daily. Watts was magnifying places in his house where he used most heat, thus, enabling Jack to make one-time investments - the more expensive but more comfortable way of reducing heat consumption.

Finally, we have also identified a third way of being enabled. Some householders were also enabled through Watts to consume more heat to achieve the desired comfort. This mediation contradicts Watt's purpose as technology designed for reducing heat consumption and being more sustainable. For instance, Steve described how extra consumption was a sacrifice he was willing to make to ensure a healthy indoor climate:

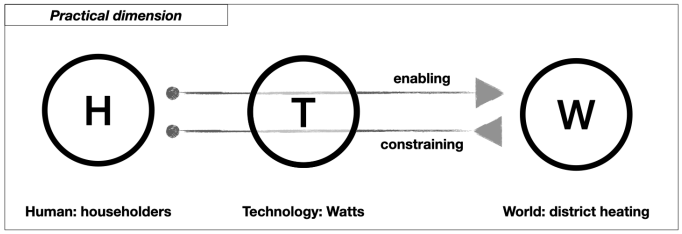

Figure 4: Practical dimension. What human beings are enabled or constrained to do at the world through technology.

> *"I would almost say that we value good indoor climate much higher than money. Well, I have to say that, because when we open the windows to get fresh air, we leave the radiators on. I can see that in the app, but I also knew that, and I'm willing to sacrifice that extra money on it"* - **Steve (I2)**

Watts' was perceived by Steve as serving the purpose of monitoring the monetary expenses, thus, justifying his extra consumption. Being more sustainable was somehow ignored, and as such, being more comfortable or having fresh air was prioritized. Other examples of being enabled to act unsustainable were identified in the questionnaire data and included *"using the fireplace more"* and "[checking Watts]*to see when I should switch to my pellet stove"*, which are concealed in the Watts as alternatives to district heating.

4.3.2 Constraining. Watts also constrained participants from acting on their district heating. From our questionnaire data, we have identified that several respondents (29) were constrained in acting. Going in-depth in our interviews, we have determined that they were constrained by Watts mediating limited knowledge on how to act or the consequences of their actions. For example, interviewee John found out that one of the rooms in his house had a higher consumption than the others, but was unsure what to do about it:

> *"I'm not sure what to do when it says that I'm close to the budget limit. Well, I could get some more insulation in the attic, but then again, that probably only saves me a little money. So, how many years before that has earned itself back? Also, I'm not really sure that more insulation won't lead to a worse indoor climate. That's individual from house to house, you know."* - **John (I2)**

Second, being a single-user application, Watts constrained the primary user from taking action when the consumption regarded the other household members. Thus, we have identified several cases where the primary users felt enabled to act through Watts magnifying instances of district heating (e.g., too long showers). Still, since the same parts of district heating were not revealed or magnified for the rest of the household, they were constrained from acting. For example, interviewee Nick with a family of 5 (3 teenage boys), argued:

> *"Yeah, so you know, I've noticed in Watts that my wife and boys are taking very long baths and I don't like to think about how much money that actually wastes each year* [...] *I've sort of accepted that now, as some things you cannot change because when I confronted them, they were 'like don't mess with our showers that's where we relax"* - **Nick (I2)**

Similar constraints were also reported from other interviewees like Monica, who stated, *"I sometimes turn down thermostats, but then the others, of course, turn them back up again"*. Combating such behaviour, Jack considered being a shower head that automatically reduces water consumption instead of convincing the family to take shorter showers.

Third, we found that householders' old heating practices and familiarity with consumption were constraining them from taking action through Watts. The questionnaire showed that only 11 respondents used the Watts daily, whereas the majority used it weekly (23) or monthly (32). Our interview showed that Watts only revealed and magnified certain parts of consumption. It constrained some householders from continuing to engage because it was deemed uninteresting or superfluous. For example, **Steve (I2)** who had initially downloaded and opened Watts and familiarised himself with the households' consumption and billing. However, as he experienced that Watts didn't reveal anything new to him; he had lost interest.

Finally, we also identified situations where householders were constrained from taking action due to the technological constraints. An elderly man Roger (aged 86), called us from his landline phone during the questionnaire roll-out. Although he wasn't officially part of the formal data collection, he had received the invitation and asked: *"how do I answer if I don't have a computer!?"*. After an elaborating conversation, it became clear that he didn't own a smartphone. He further explained that he often felt excluded from using such technology because he didn't think he could learn it. Although not using Watts, he experienced an inability to act because the technology was introduced to him.

5 DISCUSSION

So far, we unpacked postphenomenological dimensions of the technological mediation of Watts in district heating. We have described how Watts mediates people and the world through the two-sided practical, ontological, and epistemological dimensions as defined in [32]. In our effort to discuss these findings in relation to sustainable HCI, we will first turn to the ethical dimension of Kiran [32] framework, looking across the three dimensions. Second, we discuss our reflections on using postphenomenology as a lens in sustainable HCI.

5.1 Bridging dimensions: The ethical dimension of mediating district heating

According to Kiran [32], the ethical dimension emerges from the other three. It looks at the relationships of people, technology, and the world as a whole, in yet another two-sidedness: *inclusion* and *alienation*. To this end, we realize that the meaning of alienation can have several meanings within HCI (i.e., powerlessness, meaninglessness, etc.). As a way of conveying less ambiguity, when we use alienation in the following sections, we simply refer to the feeling of exclusion as also illustrated in the findings. Within those two, we have identified four tensions that should be considered for design within sustainable HCI.

The first tension relates to being included through Watts to either be sustainable or not concerning district heating consumption. We found several examples of how Watts *included* householders in their heating consumption, and in this, they were successful in lowering consumption, for example, by changing practices or through investing in insulation. This mainly occurred because Watts revealed new opportunities for action (e.g., specific consumption problems) and *magnified* new ways of interpreting consumption. Similar findings have been identified in the HCI literature before, for example, by Froehlich et al. [16] for behavioral change for electricity or by Kvist Svangren et al. [37] for one-time investments in district heating. Unlike other studies, our study further indicates that for district heating, practice change can be achieved for some through mediation, given the right human-technology-world relationships. However, not all types of *inclusion* have a positive, sustainable effect. We also found that Watts often *enables* using more or the wrong types of heating. Examples of these are using the fireplace more if district heating consumption is high (which is unsustainable compared to district heating) or using Watts to justify using more heat. In the HCI literature, such negative aspects of *inclusion* have been identified before, for example, when electric car drivers drive more [29]. Such studies show that many people think they are sustainable (it's more efficient, right?), but they are actually using more [52]. In our study, the instances occurred because for some householders, Watts *conceals* sustainable alternatives, and instead *magnifies* certain aspects like money spent and budgets. Similarly, Brynjarsdottir et al. [9] brings forth the same challenge, especially for persuasive technologies that often tend to focus on measurable units (i.e., money or kWh used) and, as a consequence, fail to show the broader implications (i.e., environmental impact) of one's actions.

The second tension is related to the amount of presented information. Presenting too little information about consumption *alienated* some householders as they didn't trust the authenticity or origins of the data. Presenting too little, Watts *constrained* some householders from acting or knowing about district heating. This occurred because Watts *magnified* types of consumption (e.g., unfamiliar types of measurements) did not align with the standard measurement (on their own meters), which led them to distrust the correctness of the data. Similar findings on feedback displays are reported in HCI, for example, trusting that companies don't misuse data [14, 55]. Additionally, some were also *alienated* because Watts *constrained* them from acting by not presenting possible solutions to the identified problems. This type of alienation can be positive, assuming that a household is already acting sustainably and there are no serious problems. Still, it can also be very negative if this is not the case. Furthermore, some householders had a need to maintain their engagement in old practices on checking the infrastructure (i.e., reading the meter and checking the status of pipes). Those participants felt *alienated* because these parts of the world were *concealed* and *reduced* by Watts. New technology not aligning with existing electricity or heating consuming practices has also been widely regarded as a barrier to sustainable change in HCI (e.g., [19, 50, 52]). To this end, Kiran [32] argues that practices often conceal alternative behavior.

The third tension is related to presenting too much information to people. For most householders, revealings and magnifications of consumption were seen as a positive aspect of Watts and invited them to be *involved* in district heating. However, to others, *revealing* or *magnifying* too much information, or too often, or seemingly too much non-relevant information about consumption similarly *alienated* them, as it over-*magnified* the world. In presenting too much information, two reasons for alienation emerged from our findings. For some, being presented constantly with data *constrained* them from using Watts. They felt annoyed from being reminded of the things they did wrong and the fact that comfort was more important to them than the world of district heating. In the HCI literature, constantly having to monitor consumption to act accordingly has similarly shown alienating effects. For instance, people don't adjust their thermostats because they don't want to compromise comfort [26] or behavior change becomes undesirable over time [30, 49, 53]. Beyond constant reminders, some were also *alienated* because Watts was invading their privacy due to its constant *magnification* of hourly consumption. Individual family members were uncomfortable with being monitored; thus, it *constrained* actions towards district heating. Similar privacy challenges have been brought up in HCI (e.g., monitoring elderly patients at home [1], monitoring family electricity consumption [33], or car location [55]).

Finally, the fourth tension is related to who is *involved* in Watts' mediation of district heating and who is *alienated*. For the reasons presented above, many participants were *included*. However, other participants felt *alienated* because they could not comply with Watts' technological assumptions. For example, one householder did not own a smartphone or a laptop. This *constrained* him from using Watts and acting upon district heating. This digital divide has similarly been brought up as an ethical consideration for HCI as it potentially excludes parts of the population and leads to social inequality [1]. Similarly, we had a few cases where householders were not *included* because they lacked the necessary literacy in both energy use and building materials and solutions. Since Watts *reduces* these parts of the world, it is not possible for these householders to act sustainably even if they want to. Building literacy has similarly been identified in HCI studies as a foundation for many technologies meant to change practices, and empirical studies show the importance of literacy for reducing consumption, e.g., through knowing which devices that consume [33], or knowing how to renovate a house [37].

5.2 Postphenomenology in domestic energy consumption

The two-sidedness of technological mediation seems paradoxical. Can we really create an interactive technology that make people sustainable or is there simply no size fits all? Continuing our discussion, we outline three considerations on how postphenomenology can be incorporated into a contemporary discourse on domestic resource consumption within HCI.

First, is important to keep in mind, that the two-sidedness of sustainable technology in many cases pull in opposite directions. While many studies are focused on utility (i.e., does this technology or feature make people sustainable?) they often forget that there are other consequences of introducing technology that often goes against the designs initial intent. For example, while Watts certainly empower some people to become sustainable. However, it also empower other people to become more comfortable at the cost of sustainability. This is also true for many other products (i.e., electric cars that make people drive more because they feel more sustainable [29]). We argue that explicitly looking for such two-sidedness, or tensions as we discuss above, can be helpful to keep in mind when designing with a specific purpose, user group, or technology in mind.

Second, postphenomenology can contribute to broadening sustainable HCI's explanatory vocabulary. From a postphenomenological perspective, the above four tensions emerged from a deployment and an empirical study of a particular technology along with using Kiran's four dimensions [32] as a lens. To this end, we brought forward both new findings and some that have been identified in prior research within sustainable HCI. Our findings confirm that many of the tensions for district heating are the same as in other domestic resource consumption domains (e.g., water, electricity, transportation). Looking to the literature, these tensions are most likely ignored by designers because they assume that all householders will behave according to an "ideal" user (e.g., like the Resource man [52]). In explaining this, we argue that our four tensions can be used as an explanatory vocabulary accounting for the ontological, epistemological, and practical dimensions of mediation. We urge designers of sustainable technology to prioritize the four tensions during their design processes. For example, we argue that there should not only be a focus on how to empower the people that are already sustainable but also looking into how potential unsustainable behavior can be prevented. To this end, it is important to note that inclusion should be a priority for those where it makes sense (e.g., forcing people to use certain technologies is rarely wise).

Third, since HCI research is concerned with the design and evaluation of various technologies, we believe that postphenomenology provides useful concepts that complement and even go beyond existing approaches (e.g., social practice theory [39, 48], scripting [2, 27, 43], or provocative design [4, 44]). Such existing approaches all have their own focus and impact on design. However, in the pursuit of design, we often find ourselves on novel ground and having little prior knowledge about what works in a particular area. Therefore, as recently argued by [51], predicting an outcome of a design is hard because when introducing a new design into the world, the initial state changes, and earlier understandings do not apply anymore. As such, designing for specific energy-reducing behaviors (a common research agenda in HCI research), persuasively or coercively, is not uncomplicated. We believe that shifting our focus to a relational ontology [12], we believe that it is precisely the two-sided dimensions offered by postphenomenology as a lens that may guide researchers and designers to shape the outcomes of technological mediation better. Following this, we argue design needs feedback to help shape it better, for example, through iterative crafting of designs that allows both scholars and practitioners to study and create more interactive designs.

6 CONCLUSIONS

Sustainable HCI has increasingly been looking to other fields for theories that deepen our understanding of domestic energy consumption. The aim is to understand how Watts (technology) mediates people's (human) experience and interactions with domestic district heating (world). We base our inquiry on empirical insights from a two-year study. We have conducted informal meetings, focus groups with seven households before Watts' distribution, two rounds of semi-structured interviews with seven household representatives using Watts, and 304 questionnaire respondents. We adopt a specific postpehnomenologic framework for our analysis that suggests that all technological mediation consists of dimensions containing both shaping and downplaying movements. We illustrate our findings in three postphenomenological dimensions – *practical, ontological, epistemological.*

We discuss our findings under two headings providing two contributions of using postphenomenology as a lens in sustainable HCI. First, we discuss four tensions of how Watts includes or excludes people from sustainable energy consumption using postphenomenology to elaborate further. Second, we discuss three implications of how postphenomenology can be used as a lens in domestic energy consumption to design better technologies for more people. 1) We should use postphenomenology as it broadens the contemporary vocabulary of HCI research. 2) We should have the two-sidedness of technology in mind in research and design, as it is often forgotten because many studies are focused on utility and neglect the broader implications, and 3), we argue that we cannot predict technology outcomes in the design phase alone, it is best understood and (re)designed as an iterative process in-situ.

Our study has some limitations. Firstly, it should be noted that we only recruited participants from single-family houses. Secondly, our participants were still early users and had only tried the first version of Watts. Thirdly, the use and price of district heating vary across geographical locations. We realize that these circumstances influence householders' experience and use of district heating, and thus, the human-technology-world relations under such circumstances would differ. As such, we do not claim that our results can be generalized across wider populations or countries, although investigations covering these limitations would be interesting in future work.

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