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Practice reconfigurations around heat pumps in and beyond Dutch households

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ABSTRACT

Domestic heating systems need to change to meet climate targets. We draw on practice theoretical concepts to understand what is needed to integrate heat pumps in Dutch households. From a design orientation, we view households as creative actors integrating technologies into daily life. We report on an ethnographic study of the disruptions and resulting reconfigurations that occur when heat pumps are introduced in Dutch households. Our findings reveal a variety of practice reconfigurations around heat pumps. We also find that these reconfigurations are related to and may influence other practices, including professional practices. We discuss our findings in relation to policy, technology development, and design, and conclude that the required reconfigurations in Dutch household practices could be supported, and that innovative practice reconfigurations emerging from internal household dynamics could contribute to sustainability transitions.

1. Introduction

It is no longer news that our ways of living must change in the face of climate crises. In the Global North, however, the household seems to be a protected place where everyday life can and should continue on its steady path toward greater comfort and convenience (Shove, 2003). In this paradigm, more efficient, and smarter technologies, for example for indoor climate control, can be introduced; they can be ‘fit and forgotten’ (as Parrish et al. describe this paradigm (2021)) while simultaneously resolving our dependencies on fossil resources. In this paper, we join a body of scholarship and media that questions this paradigm of continuity. We provide evidence of how everyday practices in the household are reconfigured as part of sustainability transitions, and ask whether and how these reconfigurations can be addressed as barriers or as innovations in the context of sustainability transitions.

New heating and other indoor climate control technologies are recognized as necessary for transitions towards a low-carbon and climate-resilient society (IEA, 2013). In the Netherlands, the heating of spaces and domestic hot water accounts for 81 % of the total energy demand of residential buildings (IEA, 2020), and is therefore an attractive target for reduction. The large-scale introduction of heat pumps for residential buildings should reduce CO_2 emissions and save energy while providing comfortable indoor climate in homes (van Leeuwen et al., 2017). They replace the commonly used gas boiler systems (van der Bent et al., 2022). This transformation of indoor climate systems should help achieve the goal of an energy-neutral Dutch residential building stock by 2050 (Tigchelaar et al., 2019). However, as of now, Dutch heat pump uptake lags behind the projected trajectory, and the spread of heat pump use is slow,

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especially compared to other countries in the EU (Toleikyte et al., 2023).

Heat pumps end up in households. The transition towards sustainable heating is a sociotechnical transition. It includes not only the technical dimension of implementing heat pumps, but also changes to other domains and infrastructures (Boess, 2022; Markard et al., 2012; Smith et al., 2005). The field of transition studies has recognized that households are crucial in these transitions (Raven et al., 2021). In relation to heat pumps, for example, the motivations and social and informational needs in the decision to acquire sustainable technologies are extensively studied (Ebrahimigharehbaghi et al., 2019). Households (as users of technologies) are also increasingly seen as sources of innovation, modification, and redesign of technologies and other solutions (Ornetzeder and Rohracher, 2006). Meanwhile, in the literature on sustainable technologies, household interactions (or 'occupant behaviors') tend to be considered a threat to the energy efficiency of buildings with sustainable technology (Caird et al., 2012; Roy and Caird, 2013). Unexpected behaviors of residents might contribute to a performance gap between predicted and actual energy consumption, and thus reduce the success of heat pump transitions (Guerra-Santin, 2013; Pettersen et al., 2017).

Increasingly, practice theoretical approaches are employed to better understand the relevance and roles of households in sustainability transitions (Svennevik, 2022). Such work has identified the introduction of heat pumps into households as 'processes of local reinvention' (Jalas et al., 2017). When a heat pump enters the household, practices of heating, cooling, and many other interlinked practices are disrupted and reconfigured. In this paper, we adopt a view of everyday practices as a primary site of change in transitions (Warde, 2005), in this case: the heat pump transition in the Netherlands. This means that (1) we study changes (or 'reconfigurations' as we will come to describe these changes) of household practices around heat pumps to understand what is required to successfully incorporate them in everyday life, and (2) consider these reconfigurations as potentially innovative. These reconfigurations might need support to further the Dutch heat pump transition, but they might also present novel solutions to challenges encountered in everyday practices with technologies. In the present study we complement practice theoretical commitments with concepts from practice-oriented design research (Pettersen, 2015; Scott et al., 2012) to discuss practice disruptions and reconfigurations, the role of innovation and transitions (Jalas et al., 2017).

We ask the following questions: (1) How does practice theory help us see required practice reconfigurations around heat pumps, and the innovative potential of these reconfigurations? (2) Which reconfigurations can be observed when heat pumps enter Dutch households and what is the innovative potential of these reconfigurations in impacting sustainability transitions? (3) How do these reconfigurations currently interact with the Dutch heat pump transition, what hinders the required reconfigurations, and to what extent is their innovative potential realized?

We answer these questions by, first, introducing concepts and approaches from practice theory and practice-oriented design research. Secondly, we report on an ethnographic investigation into the introduction of heat pumps in 11 Dutch households. And third, we discuss how the ethnographically observed dynamics relate to larger-scale heat pump transition dynamics, and to practices outside the household. This study was conducted with an orientation to design, and as part of a larger design research project. Design research approaches have been highlighted for their potential contributions to transitions research (Wiegmann et al., 2023). Design research is an approach to gathering knowledge driven by field problems (in our case: the observation that heat pumps and associated technologies were not being used in the intended manner, in particular when existing buildings were retrofitted with heat pumps (van Beek et al., 2023). Typically, in design research, knowledge is gained through an iterative process that involves evaluating implemented solutions and proposing improvements. In line with this approach, the present study aimed to identify areas where technology and processes in heat pump design and installation retrofitting could be improved.

Answering the questions posed above is valuable for studies on sustainability transitions as it can help to address a gap in our understanding of the role of households and in particular the ways in which household practices change as part of and in response to sustainability transitions (Raven et al., 2021). Such an understanding can foster and accelerate changes in sustainability transitions at the level of households, as consumers of resources, as users of sustainable technologies, and as sources of innovation. Specifically, for the Dutch energy transition context, answering these questions contributes to the potential success of the introduction of heat pumps, as this success depends on how they become embedded in household practices (Eon et al., 2017; Korsnes et al., 2018). Households also have the ability to innovate and contribute new solutions (Jalas et al., 2017). Engaging with these questions also further expands our understanding of the role of design decisions and interventions in transitions, and thereby to the ongoing alignment between studies of transitions and design (Gaziulusoy and Öztekin, 2019; Loorbach, 2022). Besides developing a design-inspired understanding of household dynamics, answering these questions also helps designers. They can target the evaluation and improvements of interventions more specifically towards transition goals, which makes answering these questions also valuable to the field of design research.

The remainder of this paper is structured as follows: We first introduce the context by providing an overview of the relevant features of heat pump systems, and their role within the Dutch energy transition (Section 2). We then discuss existing work that has investigated the relevance of the household and the introduction of new technologies in the household (Section 3). We explain how concepts from practice theory and practice-oriented design research inform our understanding of these household dynamics (Section 4). Informed by this framework, we report our findings from an ethnographic study of 11 households with a heat pump (Section 5), discuss these findings against existing literature, and highlight implications for technology development and design, as well as for policy and research (Sections 6 and 7).

2. A brief introduction to heat pumps in the Dutch energy transition

2.1. Features of heat pumps relevant to households in the Netherlands

A heat pump boosts low-temperature heat in the ground, air, or water to temperatures suitable for heating a building and/or domestic hot water (Roy and Caird, 2013). The energy (in the form of heat) that is transferred to the house can be up to four times higher than the energy (in the form of electricity) required to run the pump (a metric known as the Coefficient of Performance (COP)).

The current Dutch building stock is largely fitted with gas-fired condensing boiler systems which heat both domestic hot water and the water flowing through radiators emitting heat in every room (Kieft et al., 2021). While these gas-fired condensing boilers heat water to a temperature between 55 °C and 85 °C, heat pumps offer a different approach to domestic heating, as they normally produce heat at much lower temperatures (below 45 °C). Heat pumps operate most effectively in well-insulated buildings with larger low-temperature heat emitters, preferably under-floor heating or convector radiators, which heat indoor air slowly and evenly, rather than quickly. Sometimes, additional fans are placed within convectors in the rooms that move hot air through the spaces more quickly, providing thermal comfort to the occupants without the need for high supply temperatures. In a building with an air-tight insulated outer shell, consideration of building ventilation becomes increasingly important to ensure healthy indoor air quality (Balvers et al., 2008). The adequate performance of mechanical ventilation systems requires regular cleaning and exchange of air filters.

Finally, a relevant feature of most heat pumps is their limited capacity to produce domestic hot water. Systems deal with this by heating the hot water slowly (often during the night) to 55 °C and storing it in a storage tank until needed. Typical storage tanks have a capacity of 100–200 L. A 2008 study in the UK found that the mean domestic hot water consumption per household is 122 liters a day (Measurement of Domestic Hot Water Consumption in Dwellings, 2008).

The above factors are listed to indicate how heat pumps interact with household dynamics, and to show that the features of a heat pump require many other changes to the technological composition of the household (bringing with them 'smart home' features like automated ventilation and scheduled hot water production).

2.2. Heat pumps in the Dutch energy transition

Like in many other European countries, heat pumps are considered a key factor in improving the energy performance of housing in the Netherlands, contributing to less energy use and more sustainable sources of domestic heating (Kieft et al., 2021). This transition is motivated by European policy, which sets requirements for decarbonization to member states, as well as an interest in moving away from natural gas as an energy source due to ending exploitation of a gas field in the north of the country, and the reduction of natural gas import from Russia following the war in Ukraine.

According to a report from the European Commission's Joint Research Centre, the Dutch demand for heat pumps increased significantly in 2022, but the market is still small (Toleikyte et al., 2023). By the end of 2023, only 7 % of owner-occupied single-family households had a heat pump (Kloosterman et al., 2023). Although, as the authors note, this number is likely to be an underestimation, there is still a striking difference with other European member states like Finland where 74 % of detached houses had one or several heat pumps installed by the end of 2022 (Hyysalo and Juntunen, 2024). This difference has been explained with reference to low prices of gas, compared to electricity prices in the Netherlands (making gas-based boiler systems financially equally or more attractive) (Hyysalo, 2021, p. 144). Such economic motivations are also likely the explanation behind the market increase in 2022, following rising gas prices. Next to differences in energy prices, existing research has focused on technological innovation systems to explain what is holding back the Dutch heat pump transition (Kieft et al., 2021). In this paper, however, we focus on the household.

Policy in this transition targeting households primarily focuses on them as consumers doing energy-efficient renovations and acquiring technologies such as heat pumps (Broers et al., 2019; Ebrahimigharehbaghi et al., 2019). Policy measures typically target building standards for new buildings, further subsidies for energy-efficient technologies, or taxes on energy carriers (Boonekamp, 2007).

There is an increasing awareness that, beyond this initial purchase decision, the use phase is critical, as energy-saving measures do not always have the intended result in terms of energy performance. However, post-occupancy evaluation of energy performance in buildings is rare. When it happens, it has been found that energy labels do not accurately reflect actual energy use in Dutch households (Majcen et al., 2013; van der Bent et al., 2022), a phenomenon also described as the performance gap. Currently, the observation of this performance gap has not resulted in coherent and targeted policy measures. In short, it appears that, in the Dutch heat pump transition, households are primarily approached as a closed box (Raven et al., 2021), they are considered as decision makers and resource consumers, without much attention to their internal dynamics.

3. Related work: introducing new technologies in the household and sustainability transitions

In this section, we give a brief overview of related work on the relationship between sustainability transitions and the introduction of technologies into households. We focus on 'open-box' conceptualizations of the household, which means that they address household dynamics (Raven et al., 2021). We then summarize some literature that specifically addresses the introduction of heat pumps and household dynamics.

3.1. Introducing new technologies in the household as part of transitions

It has long been recognized that the introduction of new sustainable technologies in the household has consequences for everyday domestic life. Domestic routines and meanings change when new technologies are introduced in the household (Gram-Hanssen, 2008). Concepts like 'domestication' or 'appropriation' describe how material and non-material aspects (such as daily routines) shape one another (Aiesha, 2016; Aune, 2007). Researchers pay attention to the "construction of micro-networks" of humans, knowledge, practices, and things (such as technical devices) (Aune, 2007). Applying this concept of domestication, studies of smart home technologies, for example, found that these technologies are both technically and socially disruptive (rather than continuous and smooth) and require adaptation and familiarization from householders (Hargreaves et al., 2018). Other studies noted that the dynamics between household members are relevant to how sustainable technologies become domesticated (Skjølsvold et al., 2018). Different household members are asymmetrically involved in domestication (Juntunen, 2012), sometimes leading to conflicts. Other studies found that households' understanding of everyday life changes when interacting with new technology (Korsnes et al., 2018), and that they become skilled practitioners in the use of new technologies, but that these skills need to develop over time (Gunn and Clausen, 2013).

This dynamic relationship between households and the technologies introduced can have innovative outcomes when users tinker with new technologies (Ornetzeder and Rohracher, 2006), engage in experimentation (Jalas et al., 2017), and invent useful adaptations (Hyysalo et al., 2013). These studies more explicitly link local domestication processes to sustainability transitions by emphasizing bottom-up innovation. However, these studies are almost exclusively concerned with the outcomes and their innovative character. The more detailed level of internal household practices and how they change appears underexplored.

3.2. Introduction of heat pumps in the household as part of transitions

The specific features of heat pumps (as presented in Section 2) have implications for household dynamics. Early research (Wrapson and Devine-Wright, 2014) from the UK found that early adopter households often use a mix of heating technologies, requiring 'juggling'. Similarly, a 2012 Finnish study (Juntunen, 2012) found that early adopters have a strong trial or experiment attitude. In addition, a recent overview (Hyysalo, 2021, p. 107) mentions reports of Finnish users adapting to heat pumps by keeping room doors open, changing furniture layout, or changing routines related to emptying iced-up meltwater from the heat pump. Judson et al. (2015) interviewed older tenants in English social housing that had been retrofitted with air-to-water heat pumps and found a strong legacy of existing systems, which impacts how residents experience and interact with air-source-to-water heat pumps. Additionally, residents became dependent on a new constellation of providers, such as social landlords and utility companies when the system did not perform as expected. Nyborg (2015) observed inventive uses such as Danish households' ability to modify a relay in a heat pump to shut the heat pump down completely at night. Hyysalo et al. (2013) described inventions that users made to their heat pumps and other heating technologies. The users significantly improved these technologies to match their specific situation and shared their innovations through internet forums. The authors accord this experimentation and innovation a role in sustainability transitions (Hyysalo, 2021; Jalas et al., 2017). An extensive study of user activities in the generalization of technologies found that there are a range of activities that have facilitated the spread of heat pumps in Finland (Hyysalo and Juntunen, 2024). These activities include not just changes to daily habits, but alterations to the equipment of their social and technical context.

In this more specific literature, we again notice an understanding of the difficulties of adapting to heat pumps, as well as an appreciation of the inventiveness and resourcefulness of households. However, this research is focused on other (non-Dutch) contexts. Heating practices significantly differ between (European) cultures (Sovacool et al., 2021), which means that the Dutch heating transition is likely to have different dynamics. These studies also do not address how local adaptations and resulting innovations relate to one another.

4. Reconfigurations in practice

Studies looking at the introduction of new technologies in the household often draw on theories of practice. These theories emphasize that material arrangements (such as new technologies) reconfigure practical understandings, meanings, and conventions, and thus influence how practices are performed (Shove and Walker, 2010). These reconfigurations are the focus of the present study.

Theories of practice (increasingly present in transitions literature) have also found some traction in the field of design and design research (Ingram et al., 2007; Kuijer, 2018; Pettersen, 2015; Shove et al., 2007) and the adjacent field of human-computer interaction ('HCI') (Kuijer and Giaccardi, 2018; Pierce et al., 2013). This adaptation of practice theory to design has been loosely grouped under the title *practice-oriented design research* (Jalas et al., 2017; Pettersen, 2015). Here, the practice theoretical framework is adapted to study everyday practices in detail and discover ways to influence these practices through design processes and designed interventions.

In this research, we adopt a practice theoretical lens to understand how household dynamics change with heat pumps. In our design-oriented approach, we pay specific attention to ideas from practice-oriented design research. First, practice-oriented design research assumes that individuals practicing everyday life are creative in their adaptation to new situations (Shove et al., 2007). This makes designers collaborators in redesigning everyday practices, rather than authors of new solutions (Botero and Hyysalo, 2013; Scott et al., 2012). We adopt this stance in the context of sustainability transitions by paying explicit attention to creative and unexpected (or 'un-designed') solutions in everyday practices. Second, practice theory pays explicit attention to the situatedness and history of practices. Any new practice or change in practices has its roots in existing practices which are newly linked or reconfigured (Kuijer, 2014). We adopt this notion in the context of transitions research by analyzing new household dynamics with an explicit reference to previous practices. Third, design research (particularly HCI) has extended the practice theoretical framework to include the participation of technologies in practices (van Beek et al., 2023; Kuijer, 2019; Kuijer and Giaccardi, 2018). This constitutes the lens we adopt here. In it, 'co-performance', automated or 'smart' technologies participate in practices, not just as material elements but as performers that take on tasks (such as regulating indoor temperature or observing the weather) previously performed by humans. We use this lens to highlight how practices are delegated from humans to technologies (heat pumps and other technologies) and vice versa, and how this affects sustainable outcomes.

With this lens in place, we outline some more specific concepts (practice reconfigurations, everyday crises of routine, and innovations-in-waiting) that we will use in the rest of this paper.

By *practice reconfigurations*, we mean any change in practices (Shove et al., 2012). Following our interest in (changes on) the meso-level of household dynamics (Raven et al., 2021), we focus only on (reconfigured) performances of practices within specific households, and not on practices at a societal level. Changes can occur in internal practice elements (e.g., order of action, or participating practitioners) or in the way they connect with other practices (e.g., which other practices they make possible). We elaborate further below how practice reconfigurations typically solve something for practitioners in everyday life. They make the practice more appropriate to the local context ('to make it work and make sense') (Kuijer and Giaccardi, 2018). This does not necessarily mean that these reconfigurations are beneficial towards transition goals (such as conserving energy, or diffusion of sustainable technologies). They might be neutral, positive, or negative.

Reckwitz (2002) describes *everyday crises of routine* as "constellations of interpretative indeterminacy". The concept refers to situations where a practice is disrupted, established ways of doing things are de-routinized, people do not know how to go on, which leads to a "crisis of routine" (Shove et al., 2007, p. 34). Such a crisis can be a minor inconvenience in daily life which is then quickly resolved (by reconfiguring practices) or a more serious barrier to the continuation of routines. When applied to material arrangements (such as the implementation of heat pumps), such disruptions can be seen as a consequence of the introduction of new technologies (Shove et al., 2007, p. 34), for example at the moment of handover (Behar, 2016). These disruptions (and everyday crises of routine) form starting points for new practices and might be interesting, and perhaps even necessary, situations in moving towards sustainable practices (Kuijer et al., 2013; Viaene et al., 2021).

When such a crisis of routine occurs, people generally figure out a way to go on. They improvise and invent a new practice on the spot. These reconfigurations can be considered to be "*innovations-in-waiting*", or 'proto-practices' (Shove and Pantzar, 2005, p. 48). The innovations are not yet fully realized as they are not integrated into fully formed practices. In practice-oriented design research, proto-practices or innovations-in-waiting are not seen as stopgap solutions for a difficult situation, but rather as an opportunity for the formation of desirable (more contextually appropriate or more sustainable) future practices (Kuijer et al., 2013). These innovations-in-waiting could be repeated and diffused in other ways beyond this specific situation. We therefore pay attention to such potential occurrences.

5. Methods: investigating practice reconfigurations through ethnography

Our empirical study is an ethnographic investigation of reconfigurations in eleven Dutch households that have, within the past six years, begun living with heat pumps (Fig. 1).

5.1. Participating households

The research consisted of ethnographic site visits to eleven households across the Netherlands (Table 1). Nine of these households were renters and were invited to participate through contacts at social housing and rental organizations. Two were owner-occupied and were recruited through word-of-mouth in the researchers' social environment. The sample balances older and younger people, couples, families, and single dwellers. The buildings are both apartments and terraced houses. The sample of participants and building

Fig. 1. An impression of the participating homes (Left to right, top to bottom: an air-to-water heat pump, air filters being replaced, a display showing domestic hot water consumption and budget, low-temperature heating convectors).

Table 1
Participating households and their situations in 'living labs' (locations A and B).

Residents (pseudonyms)	Technologies	Building and situation characteristics
Herbert & Johanna Louise, one dog Rudolph, Alice & two teenagers, one dog Gemma, Gideon & four children, one dog Laura, Michael & two teenage children, one dog Robert & Barbara	Ground-to-water heat pump, automated balanced ventilation system with heat recovery controlled by CO_2 and relative humidity sensor readings, thermostat in most rooms controlling underfloor heating and convectors with additional fans, domestic hot water boiler with scheduled reheating, automated exterior blinds controlled by outdoor temperature and wind sensor readings.	Terraced house, completed 2020, social housing (location A)
Sebastian, Marion, & one baby, one dog	Retrofitted, air-to-water heat pump, automated ventilation system controlled by humidity sensor readings, several self-built energy management features	Resident-owned, terraced house, 1980s, heat pump retrofitted by owner in past 6 years
Ella, two cats	Ground-to-water heat pump, advanced programmable thermostat, underfloor heating in all rooms, automated balanced ventilation system controlled by CO_2 sensors	Resident-owned, apartment, 2010s
Dustin (pet sitting a dog during interview)	Air-to-air heat pump shared between two apartments, ducted	Rented, apartment, 2010s (location B)
Julia & Mick	Turbine air-to-water heat pump (out of order), now heated by gas-boiler, non-programmable thermostat, automated ventilation system controlled by CO_2 sensors	Rented, terraced house, 1970s replications (location B)
Bas	Air-to-water heat pump, non-programmable thermostat controls, decentralized automated ventilation system controlled by CO_2 sensors	Rented, terraced house, 1970s replications (location B)

characteristics is diverse and reflects the Dutch context.

Locations A and B in Table 1 are characterized as different experimental 'living lab' settings (Keyson et al., 2017) where stakeholders test new and sustainable technologies in inhabited environments. This makes them particularly interesting to be included in this study: innovative reconfigurations might occur in these settings. The six households listed first in Table 1 are part of a set of newly built homes located in the North of the Netherlands (location A). A social housing organization commissioned these buildings as zero-energy buildings to test several smart home technologies in social housing. Features like sun shading, indoor lights, and thermostats are automated, and can be controlled and monitored by an external home automation technology company. The three households listed at the bottom of Table 1 are recently built homes located in the South-West of the Netherlands (location B). They are realized as part of an effort of researchers and technical companies to investigate the potential of new sustainable technologies. The terraced houses in location B are replicated common Dutch 1970s residential buildings specially built to investigate retrofit possibilities. The buildings and technology performances in location B are monitored by researchers who collect, e.g., energy consumption data and heat pump performance numbers and administer quantitative indoor comfort surveys.

5.2. Data collection and analysis

Analyzing household dynamics requires methods that can capture the complexity of transition processes on the level of everyday practices. Ethnographic research has been suggested as a method that reveals detail on real-time sociotechnical phenomena such as the uncertainty and complexity of transition processes (Murto et al., 2020). It can be used to link practice theoretical approaches to the everyday, especially in relation to design, because it allows for careful attention to material and to improvisation (Pink and Mackley, 2015). Ethnographic methods have been applied previously to energy retrofitting (Murto et al., 2019) and to living with smart technologies in homes (Pink et al., 2013; Strengers et al., 2022). Walkthroughs, where a home 'guided tour' is complemented with reenactments of daily routines and technology interactions (Boess and Silvester, 2020; Fetterman, 2019), have proven particularly useful in exploring sensory aspects of everyday life, and to remember and imagine technology interactions (Pink, 2007, 2015).

We used both video-recorded walkthroughs and follow-up interviews so that technologies and material configurations are included in the analysis (Pink et al., 2016), rather than limiting ourselves to participants' statements in interviews. In the ethnographic interview, we aimed for depth of communication and mutual intelligibility on the topic of inquiry by asking for clarification and elaboration (O'Reilly, 2004). We also tested tentative interpretations with our participants.

The first author collected the data in March and April 2022. Following signed consent, data was collected through a video-recorded home tour including reenactments of interactions and daily routines, combined with a semi-structured interview. Together, these lasted around 1,5 h. Interviews and walkthroughs were digitally recorded and, where possible, transcribed for analysis. Written notes were made during and after the visits. In addition, the first author conducted informal background interviews with involved technical project leaders. Transcripts, video recordings, and ethnographic notes were analyzed and coded in themes by the authors, with the aid of Atlas.TI software (ATLAS.ti Scientific Software Development GmbH, 2022).

During the interviews, the topic of reconfigurations was discussed, specifically by asking how practices had changed, what participants found challenging about living with the new technologies, as well as through focused and contextual follow-up questions that arose. In the subsequent analysis, we identified reconfigurations by looking for instances where participants described situations or their experiences as exceptional, non-standard, non-routine, or non-mainstream. We identified crises where the participants described challenges in these situations. Innovations-in-waiting were identified by looking for new practices, invented in response to these challenges. We also took note of instances where participants expressed uncertainty or where we ourselves felt that the situations or experiences were non-standard.

6. Findings: practice reconfigurations

We found three types of reconfigurations in the households following the introduction of a heat pump. The three types are: reconfigurations of understandings (6.1), material reconfigurations (6.2), and reconfigurations in routines (6.3). In sections 6.1–6.3, after each description of instances of reconfigurations, we highlight and speculate on how they have an impact in the household beyond the specific instance. We also evaluate whether these reconfigurations seem desirable in the light of sustainable transition goals. The impact of a reconfiguration might be its reproduction elsewhere ('the recruitment of other practitioners' (Shove et al., 2012, p. 70)). The impact might also be in other ways in which practices link together and thereby impact one another. In section 6.4, we widen the perspective and indicate how observed reconfigurations impact relations with other households and professionals. We group our findings in a similar way as previous work has done (Skjølsvold et al., 2017). As will be shown in the findings, the three types of reconfigurations are intertwined and associated, but each grouping highlights an area of impact.

The findings highlight reconfigurations (and thereby emphasize change) and should not be read as a comprehensive record of all types of household interaction with heat pumps. One of our participants, Bas, for example, tells us: *"Everything is the same, except that the heat is made differently."* Our specific focus on reconfigurations means that continued practices and less dynamic situations are not included in what follows.

6.1. Reconfigurations of understandings

The introduction of a heat pump requires and allows for reconfigurations of knowledge and competences in dealing with indoor climate and technologies.

6.1.1. Newly developed understandings

Rudolph explains how the slow and gradual heating from the low-temperature heat pump means that the family needs to think more about their short-term future needs in everyday life. *"If you know that you will be sitting still in the evening, you have to start thinking about that at five. And put it up, then it will be warm by eight."* Other examples from our data indicate that households become sensitized to features of the heat pump affecting everyday practices. Gemma became aware of her household's hot water consumption from frequently being confronted with the limits of the domestic hot water production of the heat pump. *"And then we started paying closer attention. (…) "So doing the dishes also counts. (…) We have to make some calculations."*

6.1.2. New local knowledge through experimentation

Rudolph and Alice experiment with the building they live in. They leave the bedroom windows open for one night, document and compare the temperatures as shown on their alarm clocks in the evening and the morning, and find that the open windows indeed make a difference. Alice: *"It only made a difference of one degree."* Rudolph: *"Yes, but the heat pump has to pump to keep it at that temperature."* The family gains a new understanding of the effects of open windows and how this relates to heat pump performance. This type of reconfiguration of competences is anchored in experimentation and tinkering as also found by Skjølsvold et al. (2017). While this experiment initially increases energy consumption, this reconfiguration of knowledge can also contribute to sustainable practices by preventing future unnecessary window openings, while retaining window opening when this is appropriate (e.g., summer nights when the heat pump will not become active). The successful integration of such an experiment in regular practices may depend on confirmation that the reasoning is right – and this could be supported by affirming feedback from technology developers.

In another household, Laura discoveres a way to know when the underfloor heating is on. Laura explains how the dog in their household starts panting due to warmth from the underfloor heating. This crisis in (the pets') routines led the dog to lie on the couch in winter, rather than on the floor, since he finds the heated floor to be uncomfortable. This newly acquired understanding could potentially lead Laura to a more conservative use of the underfloor heating, leaving it off when not required and when the dog finds it uncomfortable. Multiple households in our research refer to their pets' behavior as helping them understand the operation of the underfloor heating. However, it is unclear how these competences could transfer to other situations and households (without pets).

6.1.3. Broader impacts of reconfigurations of understandings

These examples illustrate that the introduction of a heat pump required residents to develop new knowledge, and how this change enabled a reconfiguration of competences and knowledge. A typical feature of these reconfigurations is that they are developed experimentally and are driven by unresolved challenges in everyday life. This theme highlights how new configurations of competences both facilitate and are required for technologies to be taken up in everyday practices. While these experiments might have initial adverse effects (consuming more energy), they could lead to energy savings in the long run. The question remains if the thus acquired knowledge is correct, and how such local competences could transfer beyond the boundaries of the household.

6.2. Material reconfigurations

The introduction of a heat pump is itself a reconfiguration of the material setting. Following the specific introduction moment, the presence of a heat pump also caters to other rearrangements of material environments. We identify these in this theme.

6.2.1. Material reconfigurations that resolve heat pump inconveniences

The introduction of the heat pump introduced inconveniences in the household that the residents did not have to deal with before. Several participants in our research explain how they modified the material setting to resolve these inconveniences. Alice and Rudolph, for example, recount with pride how they had previously adapted the top floor to a room for their son to sleep and work. However, the ventilation system is also located here. "*But this system makes a lot of noise. So, we put in a lot of sound insulation.*" This material reconfiguration resolved this crisis in their routines (Fig. 2). Louise explains how she has been instructed to keep the polyvinyl flooring, which she does not like, to make sure the underfloor heating performs well. *"I think it is too hard."* She has covered the floor with a rug in the main seating area to resolve this issue (Fig. 3) and explains how she is still busy with wall decorations to 'soften the room'. Alice and Rudolph again talk about their son working from home on the top floor of the house. *"He likes the holiday temperatures, you know. 25, 26 (*degrees Celsius*)"* These higher temperatures cannot be provided by the low-temperature heat pump and delivery system. Instead, the family has installed an additional electric heater on this floor.

In some cases, material settings were reconfigured as part of attempts to compensate for technical inefficiencies and optimize performance. Sebastian has installed a backup system to compensate for and counter some of the problems with the heat pump performance: *"Yeah, I have a backup* 3 kW *heater. I installed it as an experiment to see if I could effectively reduce the defrost effect and increase the overall COP* [Coefficient of Performance, a measure of heat pump efficiency]. *(…) In any case, it gives some peace of mind for extreme winters."* Since Sebastian is active in online forums where tips for improving heat pump performance are circulated, this local material reconfiguration also reconfigures others' understandings and has a further impact beyond the specific situation.

6.2.2. Material reconfigurations taking advantage of technical features

The introduction of a heat pump and a better ventilation system in the household allowed participants in our research to take advantage of the systems' features in surprising ways. Julia and Mick combined a portable dehumidifier they already had with the stable temperature and humidity in their new house and in such a way created a room for drying clothes. *"Our previous house was very humid, so we had a dehumidifier. Now we turn it on, we just close the doors, and in two hours it's perfectly dry."* A similar resourceful way of drying clothes was found elsewhere. As the heat pump emits heat with low water temperatures, the buildings in location A have an additional electric radiator in the bathroom for some additional comfort. Many participants mentioned that they never turn on this radiator. However, Laura explains how she takes advantage of this radiator. *"We don't have a clothes dryer, I don't need that, once in a while I put pants on this [the heater] and then it dries very quickly."*

6.2.3. Broader impacts of material reconfigurations

These examples illustrate how the introduction of a heat pump leads to a reconfiguration of material settings. They illuminate how practices (e.g., heating, washing clothes, etc.) are closely interwoven, and are thus not easy to change. Residents applied reconfigurations to resolve inconveniences, continue household everyday life as before, improve on system performance, or take advantage of system features. These reconfigurations were often resourceful (Kuijer et al., 2017): the residents made efficient and creative use of the resources (for example: dehumidifiers) available to them. We found reconfigurations that were not yet aligned with transition goals and consuming more energy, such as additional heaters. We also found reconfigurations that enable more sustainable practices. For example, using the electric radiator to occasionally dry clothes reduced the potential need to buy a tumble dryer, which might quickly be used more often. Thus, such local reconfigurations hold the potential for households to live more sustainably, to overcome obstacles, and to integrate the heat pump into everyday life.

6.3. Reconfigurations of routines

Beyond the expected routines required for making the heat pump work (such as turning up the thermostat when it gets cold), we found other reconfigurations of routines. We observed how they relate to previous arrangements of routines, and how they might be new or shared.

Fig. 2. Rudolph shows the sound insulation that reduces the noise from the ventilation system.

Fig. 3. Louise's rug that softens the room.

6.3.1. Existing routines repurposed, old routines becoming obsolete, and gradual reconfigurations

Participants explained how their routines were slowly reconfigured in response to the changed conditions in the home. Gemma used to live in a poorly insulated home with inadequate heating where the family wore shoes and thick jumpers inside the house. That has changed: "*I really shouldn't walk in a thick jumper around the house. That'll get me way too hot.*" Now, she is trying to implement a new household rule to not wear shoes inside, to save her cleaning time. Here, the reconfiguration in comfort practices clearly impacts other practices, like cleaning. This reconfiguration might thus realize beneficial, if small, effects on energy consumption.

Julia explains a similar gradual reconfiguration of routines. As their previous house was much less insulated, Julia and Mick had a routine of wearing multiple layers of clothes and keeping the thermostat low to reduce energy consumption. Julia indicates how a material configuration still caters to a routine from their previous house: the couch still has a *"big fluffy blanket"*. Maintaining the routine of using this blanket allows them to still keep the thermostat low and not have to turn it up for a more sedentary evening activity during which one is likely to feel more need for warmth.

Participants also explain how reconfigurations in routines were slowly optimized to become appropriate to energy efficiency. Ella has been advised to keep the windows and doors of her apartment closed when the heating is on. However, since she has cats, she likes them to hang out on the balcony, but still walk in and out. She finds a balance, by opening the balcony doors slightly in the morning, just enough for the cats to pass through, while not letting too much cold air in (Fig. 4).

6.3.2. Broader impact of routine configurations

Like material reconfigurations, reconfigurations in routines are ways to resolve crises in routines, mainly motivated by continuing household everyday life as it was before the introduction of a heat pump. Routines tend to change slowly and might persist even though the situation that prompted them to develop has disappeared. The examples above indicate routines (like sitting under fluffy blankets) which find new purpose in new situations. This reveals both the rigidity of practices that do not immediately adapt to new technologies such as heat pumps, and the cross-fertilization of practices (Warde, 2005). The latter enables appropriate reconfigurations ('that work and make sense') to be applied elsewhere.

6.4. Reconfigurations impacting practices beyond the household

In this section, we describe our observations of the ways in which reconfigurations impact practices beyond the boundaries of the household. These observations suggest potential routes for innovations-in-waiting to have a broader impact and become applied or established innovations.

6.4.1. Impacting other households

Reconfigurations in practice were found to have an impact beyond the household when a resident's technological or household expertise was applied outside of the home. Rudolph, for example, appears to play a leading role in making his optimizing reconfigurations known to neighbors. He demonstrates in his own household how the domestic hot water budget can be increased by

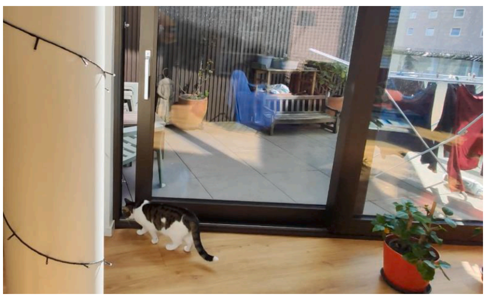

Fig. 4. An opening in a door that is just wide enough to allow a cat to pass through, without losing too much heat.

changing a setting. *"If you read the manuals, you can change it from economic to comfort setting. And most people don't know that."* This setting makes the boiler heat the domestic hot water more frequently, and thus gives the family enough hot water during the day, instead of occasionally ending up with a cold shower. Rudolph then explains how he applied the same setting to Louise's system and suggested it to other families in the neighborhood. *"You have to turn off the economy setting, especially with four kids."* Ella, another participant in our research, has also received advice from him. She explains how she trusts the technical expertise of one of her neighbors in the same building to help her reprogram the thermostat which she struggles to understand (Fig. 5).

Another way reconfigurations have effects beyond the household is through observable norms. This becomes clear in a conversation between Alice and Rudolph during our visit. Alice likes to open up the windows for fresh air. But Rudolph thinks that this is unlikely to help. *"It is (already) well-ventilated, but that's something you don't understand."* Alice responds: *"No, I don't like the feeling of it."* Alice then supports her claim that open windows are an appropriate practice by pointing out that many neighbors do the same. *"I see a lot of windows open in the neighborhood."*

Herbert is enthusiastic about the novelty of his house, which is visible from the outside and known to other town residents: "When I'm doing gardening in front of the house, people ask for information. That happened already four or five times. (…) I can only tell (them) that we don't have gas, and that electricity generation happens during the day." Here, the dwelling's 'living lab' character enables impact beyond the household and might incentivize other town residents to implement similar measures.

More technical and experimental reconfigurations were also found to impact other households. Sebastian is active on an online forum with other owners of this specific model of heat pumps. He is currently waiting to receive a printed circuit board (PCB) that another forum member is developing, which will regulate the heat pump performance in ways that will reduce defrosting effects. This, in the end, should reduce costs and environmental impact.

In summary, we found that reconfigurations within households impact other households by being observable and thereby normalized, and by sharing competences and information with neighbors. In addition, even specific material reconfigurations (such as modifying heat pump performance with a controller PCB) can be shared beyond the household (notably: without a role for professionals). This last case also highlights the role of digitally mediated communities in the impact of innovations, as also reported in the Finnish context by Hyysalo et al. (2013, 2021). Another relevant observation from this data is that the reconfigurations reported here reproduce (rather than innovate on) traditional configurations of gender and technology, contrasting perceived as masculine technological explanations against perceived as feminine social knowledge (de Wilde, 2020; Oudshoorn et al., 2004).

6.4.2. Impacting professional practices

In addition to their 'horizontal' impact on other households, reconfigurations also 'vertically' impact professional practices. Louise, for example, recalls how there seemed to be a fault in the heat pump system in her home, and different technicians visited repeatedly for repair. In conversation with a technician, she has temporarily set the thermostat to 24 °C. Then the technician rerouted some piping, after which the room finally gets warm enough. She has taken photos of the thermostat as documentation and proof of these settings. This experimental reconfiguration (setting the thermostat to 24) is closely connected with professional practices and impacts future installation decisions by technicians.

In a similar response to inadequate system performance, Ella has made a temporary material reconfiguration. In her bathroom, the underfloor heating does not heat the room adequately. She has used a thermometer to determine how hot the room can get. Now, she has marked on the bathroom floor (Fig. 6) where it gets warm and where it does not. She intends to call on the installers of the heat pump to repair the problem by installing a new radiator, connected to the underfloor heating.

During the research period, the building contractor is constructing similar houses across the street. Gideon explains how reconfigurations in his household are closely connected with the professional practices there. Gideon has shared with the building professionals how the air filters in the ventilation system have quickly become black (Fig. 7). In this way, together with the contractor, they found out that the dust from the building site settles on the air filters. This information has led the maintenance company to distribute air filters more frequently during the time of construction, thus impacting professional practices.

In summary, reconfigurations happening in the home are both embedded in, and triggered by professional practices. Professional and local household expertise come together to shape these 'innovations-in-waiting'.

Fig. 5. Ella's interactions with the thermostat.

Fig. 6. Ella's bathroom floor markings indicate where the floor gets warm and where it does not.

Fig. 7. Gideon shows the dust that settles on the air filters.

7. Discussion and implications

Heat pumps are expected to play a key role in sustainability transitions in the Netherlands and beyond. The introduction of a heat pump has effects beyond simply replacing a material element (the heating technology): it reconfigures household practices. We have categorized changes in households as reconfigurations of understandings, material reconfigurations, and reconfigurations of routine. We have shown how these experimental reconfigurations or innovations-in-waiting (such as reasoned window opening) can have impacts both aligned with, and deviating from transition goals (i.e., reducing energy consumption). We also found that these reconfigurations have potential impacts beyond the household (e.g., by being observable by neighbors).

We used concepts from practice theory (such as reconfigurations) and practice-oriented design research (innovations-in-waiting) to study the introduction of heat pumps on the meso-level of households in transitions. The study has resulted in two aspects to highlight. First, we have highlighted that the required reconfigurations align heat pumps with existing household practices in the participating households. These reconfigurations represent potential barriers to heat pump adoption in the Netherlands, as practices are densely interwoven (e.g., heating and care for pets), and households might shy away from technologies requiring effort to integrate into their lives. Specific required reconfigurations are understandings (such as understanding how the heat pump works, and skills of planning ahead), material (such as noise insulation, additional heaters for colder areas or extra warmth needs), and routines (such as daily choices in clothing or door- and window opening). In the next section, we highlight some ways in which technology development and policy might respond to, support, or take away the required reconfigurations. Second, the study highlights how these reconfigurations hold the potential to both reduce everyday annoyances and, in some cases, decrease the environmental footprint of household practices. Our research demonstrates that the impact of innovative reconfigurations beyond the boundaries of the household is not realized straightforwardly or predictably. Innovations-in-waiting are not always positive toward transition goals, and they are vulnerable and in need of support (Keller et al., 2022).

The results showed that there is diversity in responses to crises (from adapting window opening routines to developing controller PCBs). We regard all of these as local reinventions of technologies (Jalas et al., 2017), but there is a need to further unpack how these reconfigurations develop and relate to a diversity in citizen competences, and how they relate to innovations from other settings (e.g., off-the-shelf controller PCBs). We have also noted a diversity in households and among household members. Gender roles may have a role in shaping who is innovating and how. Some of the diversity in willingness and ability to innovate might be attributed to matters of ownership and control over the home. Renter households, for example, had few options to modify their home in a material sense, but their innovations-in-waiting seemed to have more impact beyond the household due to their involvement with a constellation of providers of energy, maintenance, etc. (Judson et al., 2015). Our results also showed an important role for neighborhoods in the impact of innovations-in-waiting. This can be attributed on one hand to close spatial and social proximity, but also to the similarity of technologies installed in these houses, which made innovations more directly applicable.

The understanding of reconfigurations detailed in this paper aligns with earlier calls for 'opening-the-box' of the household (Raven et al., 2021). We have contributed to a view of households, not as receivers of a technology, but as creative actors giving technologies a place in everyday life. This view implies seeing heat pump innovation as a (non-linear) process, rather than a one-time purchase (Aune, 2007). Our view relates the internal dynamics of the household more closely with other scales and places (or interlinked practices in practice theoretical terms), in this case, most notably: the neighborhood, and professional practices of technology rollout in the Dutch energy transition. This is in contrast with current framings of the household within energy transition policy (which is often concerned with increasing technology uptake) and with current design and technology development practices (often focused on making sure technology is used in the 'right way'). Instead, our framing suggests a different site where transitions take place — the household — and thereby a different source of innovation. Households could be recognized, supported, and further studied as a resource in realizing the ambition of energy transitions in the Netherlands and elsewhere.

7.1. Implications for policy

Our findings suggest that besides the current policy focus on technology roll-out, policy could also target household practices (Spurling et al., 2013). The required practice reconfigurations (in understandings, material, and routines) required in the Netherlands could potentially be supported through policy interventions. Reconfigurations of understanding for example could be supported with policies promoting the distribution of information material or with campaigns of learning from innovations-in-waiting. Material reconfigurations could be made easier when heat pump replacement is considered to be part of integrated renovation (for example, replacing not just heat insulation, but also sound insulation). Reconfigurations of routines could be supported with dynamic electricity tariffs, making the performance of energy-intensive routines more attractive at certain times of the day. Future research could compare the dominant heating and heat pump-related practices (and thus the required practice reconfigurations) in the Netherlands with other contexts. In Nordic European countries, for example, heat pumps are more widespread (Hyysalo, 2021, p. 144). Comparisons with these contexts could reveal configurations of practices that have been found to be appropriate to home heating with heat pumps (e.g., stable indoor temperatures).

Supporting such reconfigurations is a necessary ingredient of policy and technological interventions. However, the design of such interventions should also account for the dynamics of transitions. Social practices, technology uptake, and the goals of societal transitions are all shifting targets. Likewise, supporting a heat pump transition in late-follower countries like the Netherlands will have to be different from the more minimal support required in the early phases of heat pump transitions in early-adopter countries like Finland. The consequence of this is that the necessary support for heat pumps will likely not be the same now as it will be in the future. When heat pumps become more accepted as normal heat generators, different measures will be required. The focus might shift towards convincing later adopters. Likewise, when transition goals shift from the diffusion of heat pumps to an overall reduction of energy use or to the optimization of demand patterns over time, different interventions are required again.

The understanding of everyday practice and innovation developed in this paper also implies an active role for households in realizing the Dutch energy transition, as the sites where change happens. Existing research in the field of transition management has developed diverse strategies and approaches to enable and promote such bottom-up innovation. One might think of niche development where innovations are protected (Loorbach et al., 2017), promoting experimentation (Sengers et al., 2019) or sharing and amplifying innovations through policy (Vezzoli et al., 2008). More concretely, policy could support the dissemination of innovative reconfigurations through demonstration homes, guided tours around local houses with improvements, or even vocational courses to share expertise, as also suggested by Jalas et al. (2017).

Another potential avenue for policy measures lies in the further integration of the spheres of technology installation and energy provision, which incentivizes monitoring of what happens after installation. This is currently already experimented with in the Netherlands and elsewhere through energy performance contracting mechanisms (Guerra-Santin et al., 2022). This research confirmed an important role for professionals as intermediaries, which was also found in previous research on technology implementation (Behar, 2016). More innovative households and their innovations could be championed by intermediaries such as installers (Martiskainen and Kivimaa, 2018; Owen and Mitchell, 2015), energy coaches, and advisors who have an on-the-ground view of technology-household interactions (Bouzarovski et al., 2023) or by citizen initiatives such as the "Duurzame Huizen Route", an annual open day for sustainable houses (*Duurzame Huizen Route*, n.d.).

As also observed in our data, living labs, or other 'out-of-the-ordinary' settings, can stimulate the willingness and acceptance of households to engage in experimental reconfigurations, while simultaneously making reconfigurations more visible. These living labs are sites where experimental governance, technical innovation, and the change of daily practices are all brought together to participate in the co-creation of new integrated solutions (Keyson et al., 2017; Liedtke et al., 2012). These living labs can also serve to monitor and evaluate experimental reconfigurations and their impact.

Other potential avenues for the dissemination of innovative practice reconfigurations benefit from social and spatial proximity and cohesion, such as in neighborhoods. These avenues can extend or be combined with community-based programs to retrofit (Karvonen, 2013). Such programs support (further) engagement between occupants, housing providers, community groups, local authorities, and construction professionals. They can be helpful in disseminating innovative practice reconfigurations, not only in the initial retrofit decision, but also in the later appropriation of the technologies. Similar supportive roles could be taken by energy communities or local energy co-operatives (Lode et al., 2022).

7.2. Implications for technology development and design

The findings from this research highlight how technology development and technology use are interrelated practices. This implies a change to the traditional model of new product development which rarely attends to what happens after launch (Ingram et al., 2007). We agree with previous research that innovation involves an iterative loop between design and use (Hyysalo, 2021; Khalid and Sunikka-Blank, 2020; Usenyuk-Kravchuk et al., 2022), a loop which, in our view, can be tightened. This broadens the scope of design from purely material elements such as technologies, to inter-household configurations of understandings, routines, and material settings. Jalas et al. (2017, p. 78) have championed practice-oriented design research for its potential to support local changes in practices in the context of transitions. Practice-oriented design research reorients design from a narrow focus on products and technologies (e.g., improving the efficiency of heat pumps), to practices (routinized ways of enacting everyday life). The role of designers is then to facilitate the local adaptation of, and to create a better fit with, new technologies by supporting the remodeling of everyday routines (Pettersen, 2015; Scott et al., 2012).

Our findings show that innovation is a collective accomplishment of both technologies (and their designers) and users. This means that creativity and authorship are (partially) relocated from professional design practices to everyday practices in the household (e.g., the repurposing of a dehumidifier). This invites designers to examine the characteristics of successful and desirable reconfigurations as potential solutions that could be implemented or supported elsewhere. Designers can contribute by surfacing, articulating, and supporting these potentially successful, or innovative alternatives (Botero and Hyysalo, 2013). A wide range of design tools is available for this (trigger products, low-fidelity prototypes, design of communication tools, etc.) (Giaccardi and Nicenboim, 2018; Kuijer, 2014).

Features of the technologies themselves could also have a role in supporting and enabling creativity in household practices (e.g., the possibility to connect a controller PCB to a heat pump). This echoes previous suggestions that reconfigurations (and thus the local appropriation of technologies) can be enabled by modular and ambiguous designs of technology (Boon et al., 2018; Usenyuk-Kravchuk et al., 2022). Such an approach could also stimulate a risk-taking attitude among end-users, leading to more innovative practices. We noticed that residents reflect on reconfigurations as a way to evaluate their appropriateness (or ‘local adequacy’ (Usenyuk-Kravchuk et al., 2022)) and sustainability. In this way, professionals could support innovative and successful reconfigurations by designing technologies that support reflection in practices (Backlund et al., 2006; Ghajargar et al., 2018).

Finally, professional design cannot be seen as separate from the society in which its resulting objects are used. What is a normal and appropriate way of living with technology is continually reconfigured by inventive users (as we have seen in this study). These reconfigurations in turn influence how and which products are developed and put on the market (de Laet and Mol, 2000; Usenyuk-Kravchuk et al., 2022). In other words, there is a recursive relation between design and use (Kuijer and Giaccardi, 2018). This observation suggests, first, a practice of design that is sensitive to diversity in product use (or misuse). Second, it suggests that this sensitivity can be improved by including the people “destined to use a system to play a critical role in designing it” (Schuler and Namioka, 1993). Third, this participation can be made more responsive when designers tinker and explore reconfigurations together with end-users (Scott et al., 2012).

8. Conclusions

This study set out to find out how everyday life in Dutch households is reconfigured when heat pumps are introduced and to consider the impact of these reconfigurations beyond the situations at hand. We found reconfigurations in understandings, material settings, and routines. We also found that these ‘innovations-in-waiting’ impact peer households and professional practices, and could do so even more. The findings have yielded implications for policy and technology development. The latter could embrace supporting the required reconfigurations in Dutch household practices and exploring the further potential for innovative practice reconfigurations to contribute to sustainability transitions. Our analysis is exploratory and based on a small number of participating households. The findings suggest future work on approaches that can uncover, spark, and diffuse further innovations-in-waiting.

CRediT authorship contribution statement

Evert van Beek: Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Stella Boess:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Alessandro Bozzon:** Writing – review & editing, Supervision. **Elisa Giaccardi:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Evert van Beek reports financial support was provided by Netherlands Enterprise Agency.

Data availability

The data that has been used is confidential.

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