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The everyday enactment of interfaces: a study of crises and conflicts in the more-than-human home

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ABSTRACT
By 2027 more than 530 M homes will likely adopt at least one type of automated system. This means that a growing number of residents will be living with automated technology in the home, everyday. But living with smart homes is full of conflicts between what residents find appropriate and what technology does instead. Previous research, centering end-user needs, has often focused on smooth living experiences through graphical user interfaces and improved predictions. In this research, we take the more-than-human lens of co-performance to put crises in everyday practices in view, and to conceptualize a new notion of interface. Based on ethnographic data from 11 households, our findings illustrate how crises reveal conflicting ideas of appropriateness, how residents reconfigure their co-performances with technology in response to everyday crises, and how new interfaces are enacted as a result. We conclude by illuminating how researchers and designers should not look at the conflicts and crises emerging in the more-than-human home as something of which to get rid. Instead, they are opportunities for residents and buildings to respond to one another in the context of everyday life and to enact interfaces that were not pre-designed into the building.

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Co-performance; interface; smart buildings; more-than-human design; smart home; internet of things

1. Introduction

With the introduction of automated and connected technologies, we no longer just live *inside* our houses – we live and perform tasks together *with* them daily. In this paper we will argue for a need to better understand this relationship. We will contribute to an understanding that goes beyond user-centered approaches, and that focusses on the relationship between humans and technology as it develops through crises in everyday practice. Drawing on more-than-human concepts, this paper will propose the notion of enacted interfaces (new dynamic matches of people and things) as a way to conceptualize this relationship and how it develops. We develop these ideas further based on qualitative data from smart households in the Netherlands. Such an understanding is required to realize smart housing that acts sustainably and appropriately to the situation at hand.

By 2027, it is expected that more than 530 M homes, that is, 23% of all households worldwide, will adopt at least one type of smart system (Ablondi, 2022). This is initiated by multiple actors for various reasons: Residents and housing owners increasingly seek automated support to ease various domestic tasks and save resources (Jiang et al., 2004; Strengers et al., 2020). In addition, many governments and municipalities have begun to incentivize the adoption of smart systems as key

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technological solutions to sustainable energy transitions (De Groote et al., 2017), with the goal of optimizing energy consumption and indoor climate (Mofidi & Akbari, 2020).

But, for smart home technologies to achieve their promises of sustainable energy consumption and support in domestic tasks (and prevent e.g., consumer rejection), these automations need to act appropriately to the situation at hand. Modern approaches, adopting a user-centered design (UCD) perspective, prioritize human needs (such as fresh air and up-to-date information) to design automated, smart technologies to accommodate to those needs in an energy efficient manner (Agee et al., 2021). From this perspective the goal is to simplify, smooth out, and purposefully reduce the required interactions of residents with their homes ("set and forget") (Harper-Slaboszewicz et al., 2012). UCD is dedicated to preventing conflicts between humans and technology, especially by designing better graphical interfaces (Zhang et al., 2009), better prediction of human needs (Bouchabou et al., 2021), or better collaboration mechanisms (Huang, 2019). The assumption is that automation will perform appropriate actions in the background, meeting the users' intentions and actions without friction, and thereby achieving the promises of sustainable energy consumption and support in domestic tasks.

However, reality is messier (Strengers, 2014). From a resident's perspective, living with a smart building includes breakdowns, compromises, and conflicts (Davidoff et al., 2006; Hargreaves et al., 2018). In addition, governments, clients and commissioners find that building performance does not always save energy as predicted and hoped (van den Brom et al., 2018). For instance, lights turn on in the wrong room (Geeng & Roesner, 2019) or technologies that are essential for health, such as ventilation, do not always function optimally (Boess, 2022). Through the lens of user-centered design, crises – i.e., situations of "interpretative indeterminacy" where users do not know how to go on (Reckwitz, 2002, p. 255) – are something to be avoided, because they stand in the way of a smooth user experience. To UCD these crises indicate inadequate anticipation and faulty predictions of human needs by designers, and ultimately signify that automations did not act in a way that was appropriate to the situation.

This unfavored perception of "crises in routines" contrasts with recent insights on everyday practice, where appropriate performance cannot be established beforehand (Kuijer & Giaccardi, 2018). In this article we adopt a lens informed by co-performance which puts the *appropriateness* of human and non-human performances in view. Through this more-than-human lens, it is not end-user needs that are highlighted. Instead, the focus is on how residents and the smart home perform everyday life together, on how appropriateness is negotiated and redefined through daily performances, and on the everyday crises of routine that form a critical part of how these co-performances develop and change (Kuijer & Giaccardi, 2018).

In this paper, we apply this more-than-human lens to smart buildings. We inquire into the relationship of smart building technologies with their residents. Using this lens, we collect qualitative data using ethnographic walkthroughs in 11 smart households in the Netherlands, which we analyze with a focus on crises in routines, and what they reveal about conflicts between what people find appropriate and do when managing indoor climate and other everyday tasks, and what smart buildings do instead. We show how, studying smart households through this lens, yields relevant insights to design. These insights include a reappraisal of crises as opportunities for novel, more appropriate co-performances of humans and technologies. They facilitate the reconfiguring of human-machine relations to bring the system to interact and behave appropriately from a resident perspective.

We will also argue that our lens implies a different, more-than-human, notion of interface; from a static "human-centered" touch point to a new "matching" that is dynamically enacted in the co-performance between residents and smart buildings. We wrap up with implications for the design of sustainable smart more-than-human buildings, where designers attend to, and possibly stimulate, the enactment of interfaces that do not smooth out crises and conflicts, but allow humans and non-humans to be responsive to one another (Giaccardi & Redström, 2020).

2. Related work

2.1. *Smart homes and smart building interaction*

Housing is a crucial component of life on earth. It provides people, animals and things with shelter and security, it stages live, work, and social interactions, and carries social meaning (Knox, 1987). The residential built environment also has a large share in energy consumption and greenhouse gas emissions, consuming 40% of EU's energy (Dascalaki et al., 2012). Driven by societal and technological developments in industrialized countries, making housing "smart" is now increasingly considered as an opportunity to do housing better. The interest in smart housing is motivated by efforts to reduce energy consumption in response to the climate crisis, by technological developments that promise convenience for residents and building owners, and by a growth in senior population driving a demand for aging in place.

Yet, for smart housing to achieve its goal of reduced energy consumption and support in domestic tasks, smart technologies need to find a place in the complicated reality of situated everyday households.

The concept of smart buildings (or smart housing, smart home, etc.) is loosely defined by the inclusion of some form of automation of heating, ventilation and other "building services", networked capabilities, sensors and actuators, and a user interface displaying e.g., energy consumption (Agee et al., 2021). The smart building is also considered a key element in smart grids and smart cities where communication and energy management takes place in larger networked infrastructures (Kim et al., 2022). In this paper, we will refer to buildings as smart when they include most or all of these forms of automation or connection.

As more buildings are automated and connected, human-building interaction (HBI) becomes more complicated and has received increased interest (Shen et al., 2016). This has led researchers to suggest a more prominent role for the Human – Computer Interaction (HCI) community in the housing industry (Alavi et al., 2016). Simultaneously, researchers have developed arguments to adopt human-centered design principles, and import methods from HCI, in the traditional housing industry (Shen et al., 2016). In the next section we detail what this human (or user) centered design approach entails.

2.2. *Users in the center, technology in the background*

Within the housing industry (architecture, engineering, and construction), at least in Western countries, the traditional approach has been to employ a linear design and delivery approach, prioritizing cost-driven technology centered design (Agee et al., 2021). But, as noted above, with the interest in human-building interaction comes a call for centering humans in the design of smart housing. Drawing on Norman's seminal work (Norman, 2013), the imperative is "to maximize human well-being and the operational performance of smart buildings" (Agee et al., 2021). User-centered design is then directed to objectives such as human needs (thermal comfort), user understanding (readable symbols in interfaces), functionality and user experiences (joy). In design practice, it entails e.g., the development of personas, affinity diagramming, and iterative design approaches.

It is no surprise that the housing industry is seeking inspiration from the field of HCI to get a grasp on user-centered design. In studying computers and humans and how they interact, HCI has a longer tradition of explicitly centering the human user in the design of automated and connected technology. This tradition is characterized by a critical stance toward technology being pushed by industries. The principles of the UCD approach have recently been summarized in four objectives inspired by Norman's work: meeting user needs, making products understandable and usable, making products that perform desired tasks, and making the experience of using a product positive and enjoyable (Agee et al., 2021). Below we discuss some human-centered work on smart homes from the field of HCI and how these objectives are operationalized in the design of smart housing.

In line with these principles of human- and user-centered design (UCD), one dominant line of work in the design for user interaction with smart homes is focused on *predicting* and anticipating user needs. User centered designers develop personas and affinity diagrams to predict smart home user routines, preferences, and lifestyles in the design process (Agee et al., 2021; Luo & Zhang, 2022). Once these future user characteristics are surmised, *control* is typically considered a priority user need which is then to be accommodated in design. A recent literature review seeks out "tools for smart home control," for example (Caivano et al., 2018). This is confirmed by a literature review listing 11 prominent definitions of smart homes and finding that much of smart home technology narrative circulates around the notion of "control" (Dahlgren et al., 2021; Sovacool & Furszyfer Del Rio, 2020).

HCI for smart homes, in line with visions of ubiquitous computing (Weiser, 1991), assigns to technologies a *background* role. This is done by, for example, predicting or inferring human needs in the background. Increasingly, automated recognition of human activity is seen as key to the future smart home (Bouchabou et al., 2021). Advanced algorithms and sensors should enable even better predictions of what users need in their homes (Lim & Tan, 2019). The activity of (in particular, older) residents can be understood and recognized which then enables the smart home to provide its assistance where needed (Bouchabou et al., 2021)

Of course, smart home technologies are also imagined to provide a positive *experience* for the user. Rather than being sold on technological prowess, user-centered design recognizes that users are interested in pleasure and joy in daily life (Wilson et al., 2015). This aligns with work that centers user experience and emphasizes that for the user, the meaning of the home concerns emotions (Eggen et al., 2014).

Throughout this literature, we can observe a key role for *user interfaces* in the human-centered smart housing. This "operational panel" (Zhao et al., 2016) should enable an easy initial setup, while providing the users with understandable feedback (especially about energy consumption), to improve transparency (Paternò et al., 2022) and intelligibility (Castelli et al., 2017), all to meet user needs without friction. Information should enable residents to control (and hopefully reduce) energy consumption in the home (Marikyan et al., 2019). The interface itself is thus the access point behind which the complexity of a system disappears (Norman, 1986). Once set up, users can forget about the functioning of the system (Zhao et al., 2016).

This literature reflects the premise that is prevalent in HCI for smart homes: the human-centered smart building smoothly fulfills preexisting human needs. In summary: the smart building does its job in an energy efficient way, while any hiccup in everyday life is prevented and removed. The push by technology is replaced by a centering of the human; ergo, technology is cast in a background role.

2.3. *The elusive end-user in the messiness of everyday life*

We have described how user-centered design conceptualizes humans as individual beings with somewhat predictable routines emerging from preexisting needs and desires, while technology fulfills those needs in the background. In this section we describe how everyday life in the smart home, as described in literature, does not conform to this conceptualization. We will contrast literature on the smart home with the characteristics presented above (*predictability, background technologies, positive experiences, user-oriented interfaces*) in our discussion of user-centered approaches to smart buildings.

While seldomly reflected in the visions for the user-centered smart home, life at home is found to be "organic, opportunistic and improvisational" (Davidoff et al., 2006). Keeping the home in order, doing laundry, and organizing family life is a messy affair (Wilson et al., 2015).

This *unpredictability* presents a challenge for human-centered design of smart buildings which relies on assumptions of routines and schedules. Often, actual behavior does not match these assumptions (e.g., residents use a flexible mobile heating unit, rather than the provided thermostat) (Guerra-Santin et al., 2022). In response, researchers have proposed to increase granularity and accuracy in recognizing and predicting human behavior and intent (Bouchabou et al., 2021). However, it has proven to be difficult and costly to realize technology that knows where it can be of assistance to humans (Lee & Kim, 2020). Human intent is ambiguous and improvisational. Even more problematic to the goal of user-centered design is the question of whether users actually desire this assistance. Users described, for example, that assumptions made by the Nest learning thermostat, whether right or wrong, made it appear as "arrogant" (Yang & Newman, 2013) and that they feared becoming a "prisoner" of smart home technologies (Mennicken & Huang, 2012). The examples show that, within these messy circumstances, what residents do and what they expect from technology cannot be entirely predicted beforehand, and incorrect assumptions (such as the ones made by the Nest thermostat) might very well be detrimental to user *experiences*.

In contrast, existing literature finds that the "right thing to do" arises within the situation at hand, and is negotiated among family members (Koshy et al., 2021). For example, a study with the Nest learning thermostat found that an occasional visit from relatives who prefer lower temperatures is already enough to surface a conflict between assumed and situated needs (Yang & Newman, 2013). These situated and dynamic needs arising from a complex context do not sit well with the inflexibility of automated technology.

Additionally, situation and context are not just external to interactions with technologies, they also include the technologies themselves. These technologies shape and create human aspirations and situated desires in everyday life. This insight is articulated by prospective smart home users who reveal worries about becoming "lazy" when their life is automated (Balta-Ozkan et al., 2013). This capacity of technologies to shape their users, while broadly studied elsewhere (Akrich, 1992), seems absent from the framework of human-centered design where humans are expected to be accommodated (Kalvelage & Dorneich, 2014).

In everyday practices in the smart home, the technology often does not remain in the *background* as is the ambition in UCD, but becomes the center of attention. For example, a nine-month field trial found that smart home technologies disrupt everyday life, and that learning to use these technologies is a demanding and time-consuming task (Hargreaves et al., 2018). This learning requires high costs and effort, such as covering door locks with tape (Desjardins et al., 2020; Mennicken & Huang, 2012).

The display *interface* as presented in the user-centered smart home has an ambiguous role in everyday life. While it does deliver feedback about energy consumption and the current state of the home, and can be helpful (when well designed) to program the smart home, it is far from clear why residents in busy everyday life would further engage with a display on the wall (Buchanan et al., 2015). Encouraging active engagement by e.g., further reprogramming for technological optimization, or demanding attention regarding energy consumption, contradicts UCD's premise where technology should disappear in the background. UCD then assumes the display could serve as a control panel for various functions of the home (Zhao et al., 2016). Still, from the perspective of residents, why would a touch screen display in the living room be a more appropriate contact point for managing blinds than a point close to the window (van Beek & Boess, 2022)?

Crucially, these observations also suggest there is no guarantee that a human-centered smart home will lead to actual energy savings or greater sustainability (Tirado Herrero et al., 2018). The many irregularities in everyday life imply that a smart building might carry out what users want, but at the wrong time or in an inefficient way. This is confirmed by the (unfortunately, rather small amount of) empirical work that investigates the actual energy savings in homes that are smart and provide feedback (Chalal et al., 2020). The risk and reality of smart buildings is that a significant portion of them actually consume more energy than their non-smart counterparts (Tirado Herrero et al., 2018). Moreover, we mentioned that technologies shape human needs instead of merely supporting them. In the realm of energy savings, this phenomenon manifests in raising standards of comfort when a new, more efficient, technology is introduced. In this way, initial energy savings disappear in the long run (Walzberg et al., 2020).

To summarize: Everyday life in the smart home is *messy*, *unpredictable*, and shaped by *many other factors* than the (singular) human user and their needs. The literature presented here problematizes the assumptions and goals of UCD in everyday life with the smart building. By centering the user, design tries to get a grasp on the user and fulfill their needs, but the unpredictability of everyday life and the many confounding factors between design ideals and technology in-use turns the proposed center of design into an unstable hold.

2.4. *More-than-human approaches*

When the human user of the smart building thus appears elusive and UCD is limited, it seems we need a different point of departure for HCI. Increasingly, HCI and design engages with theories, concepts and insights that find anchor points in other than human entities. This includes understandings of humans and technology which emphasize relations, technological agency and assemblages composed of humans and non-humans (Giaccardi & Redström, 2020). Originating from, for example, feminist theories and science and technology studies (Forlano, 2017), these more-than-human notions increasingly find traction within HCI (Coskun et al., 2022). While offering theoretic foundations (Frauenberger, 2019), new considerations (Coulton & Lindley, 2019), ways of knowing (Wakkary, 2020), and even new roles for designers (Yoo et al., 2023), until now, more-than-human approaches have not been applied to everyday interactions with technology "in-the-wild." These approaches thereby remain somewhat distant from the process of designing smart buildings.

To address this gap, we think it is promising to take our starting point in the crises as they occur in everyday practice, which we have described as at odds with the concept of the human-centered smart home. In the next section we argue why the concept of "co-performance" can be drawn on to better understand these crises, and what they tell us about the complex and dynamic relation between people and technologies. This will also enable us to further develop HCI's central notion of "interface" in a field turning toward more-than-human issues.

3. The idea of co-performance

3.1. *A more-than-human perspective on agency*

The concept of co-performance has been introduced as a novel perspective on the role of artificial agency in everyday life (Kuijer & Giaccardi, 2018). Co-performance is based in theories of practice in HCI, which take everyday human activity, organized in practices such as bathing, cooking, and doing laundry, as the basic unit of analysis. Humans perform these practices in the messy and unpredictable settings of everyday life. The concept of co-performance takes this framework further (Kuijer, 2019), and argues that, since computational artifacts such as smart building technologies, are also capable of performing everyday practices, they should be considered as *co-performers*. Robotic lawn mowers and smart thermostats carry out tasks and judgments ("when to heat a room") alongside humans.

The concept of co-performance aims to enable HCI researchers and designers to develop richer accounts of the dynamic role of computational artifacts in everyday life, and related design practices. It has inspired design proposals such as a "co-performing agent" that adapts its role in-use together with users (Kim & Lim, 2019), and a thermostat that learns about comfort-preferences (Huang, 2019). The concept has also been applied to envisioned frictions with learning systems, including smart buildings (Viaene et al., 2021), and suggests a way to deal with tensions and conflicts in automated decision-making (Jin et al., 2022) and to contribute to explainability in AI (Nicenboim et al., 2022; Tsiakas & Murray-Rust, 2022). Finally, the concept has informed a study exploring future summer comfort in the Netherlands (Kuijer & Hensen Centnerová, 2022).

3.2. *Co-performance centers dynamic relations*

Following practice theory, the framework of co-performance considers everyday practice as a dynamic location where change takes place (Kuijer, 2014). For example, the way individuals prepare and consume food is a social practice that is shaped by social norms and incorporates learned skills and material devices such as microwaves. However, every situated, everyday performance of a practice involves choices about what to eat, how to prepare food, and with whom the food is shared. An everyday performance can thus challenge or reinforce existing social norms and expectations, and in doing so, change the broader practice of cooking.

Co-performance recognizes the doings (or performances) of technologies as part of these practices. The everyday performances of microwaves and washing machines participate in performances of cooking and laundry. This implies that it is not just the human performer who can make a change in practices, but agency is located in the *relation* of human and technological performances. Concretely, when one or both performs their part of the practice differently, this can be the beginning of a change in practice. While designers of technology thus shape everyday practices, they often do not intend to change the practice as a unit. Instead, from a user-centered perspective, designers are primarily interested in mere support of common, already performed everyday practices. This influence of everyday practices on design decisions and vice versa, is referred to as the recursiveness of design and use (Kuijer & Giaccardi, 2018).

In the framework of co-performance, everyday practices involve know-how (an idea of how to appropriately perform an action) (Shove, 2016). Human performers enacting practices (e.g., laundry) integrate a know-how of appropriate practice ("judging what exactly is clean laundry"). For artificial co-performers this know-how exists in their specific embodiments and automations ("washing machine programs") (Kuijer, 2019). This technological know-how is based on an underlying reasoning about what is appropriate practice, originating in the design process. But what is appropriate in situated practice, cannot be defined beforehand, but is continuously reinterpreted by humans ("these clothes are not dirty enough to wash now").

This means that, unlike in a user-centered approach where human needs are determined beforehand, appropriate co-performance can only emerge in the dynamic and contested reality of everyday life. It is "in practice" (within relations between humans and technologies) that divisions of roles and tasks, capabilities, and affordances manifest.

3.3. *Crises of co-performances and the enactment of new interfaces*

Ideas of appropriate action can be different between human and technological performers (judging "how much detergent to add to laundry"). When these conflicting judgments manifest in everyday life, this can lead to "everyday crises of routines" (Reckwitz, 2002). A crisis of routine refers to a situation where the human performers do not have a tested, routinized, socially agreed way to proceed ("normally, we don't run out of detergent so soon") (Reckwitz, 2002). In the case of a conflict, from a human perspective, this means that a technology messes up its judgment of appropriate practice ("the washing machine is wasteful, and adds too much detergent"). Humans might, however, be able to respond to these misjudgments, and repair or correct technological performances. In these *reconfigurations*, a new and improved match between human and system performances might be realized (limiting detergent supply in the washing machine), to which technologies again respond (by signaling a detergent supply error).

Noticing these opportunities for response and repair puts us on track of another aspect in which co-performance enables an understanding of everyday practice different from user-centered design. Typically, in HCI and from a user-centered perspective, the technologies in everyday life present themselves through a (designed) interface. The interface is the location or access point (Morales Díaz, 2022) where humans and technologies interact with one another, and where the "problem of matching people to things" (Pickering, 2000) is solved. We have seen how, in the smart building, this often takes the form of a display or "operational panel" (which hides the complexity of the actual technology (Hauser et al., 2023)).

However, adopting a more-than-human perspective, and shifting our focus from the way that technology presents itself (the aesthetics of the interface), to everyday co-performance, we might recognize many other and more dynamic forms of matching people to things. In co-performance, the interface appears not (only) as a pre-designed surface (Janlert & Stolterman, 2015), but as a doing. We might begin to understand interfaces as *enacted* in response to crises and in repair of co-performances. While literature in HCI recognizes that the pervasiveness of computing in everyday life requires renewed thought about the interface (Janlert & Stolterman, 2015), to date, there have been no attempts to further conceptualize the interface from the more-than-human perspective of co-performance.

3.4. *The questions for our empirical study*

With this framework in place, we can continue this paper and turn our attention to everyday practices observed in smart buildings in the Netherlands. In our study, we focus on crises and new matches of humans and technologies enacted in practice. We aim to answer the following questions regarding the smart households in our study. Taking our starting point in crisis of routine, we ask: 1. Which ideas of appropriateness conflict? 2. How are the crises resolved? 3. How is a new matching (or interface) enacted? The key contributions of this paper are a reappraisal of crises in everyday co-performances with smart buildings, and the beginnings of a more-than-human understanding of enacted interfaces in a framework of co-performance. These contributions support the design of smart building technologies that reduce energy consumption while acting appropriate to the situation at hand.

4. Cases and method

4.1. *Participating smart households*

As part of the energy transition in the Netherlands, many building owners are aiming to reduce domestic energy consumption by implementing smart and sustainable building technologies. This includes heat pumps which include several forms of automation and are connected to sensors and smart thermostats meant to optimize heating performance and reduce overall energy consumption. This situation enables us to study smart building technologies in use, and empirically uncover how, in these households, ideas of appropriateness conflict, how crises are resolved, and new interfaces enacted.

The empirical part of this research consisted of ethnographic site visits and involved 11 households living across the Netherlands (Table 1). As this research connects to a project exploring resident-heat pump interactions, recruitment criteria were the presence of a heat pump and some form of smart home technologies. Nine households living in a rented home were invited to participate through contacts at social housing and rental organizations. Two home-owner households were recruited directly by the researchers. The sample presents a balance of older and younger people, couples, families, and single dwellers. The buildings are both apartments and terraced houses, and their characteristics roughly represent the Dutch context. In the rented homes, the smart housing technologies were implemented by social housing organizations or technical partners. In these rented homes, we expect that conflicts might be more prominent, as renters have fewer possibilities to replace or change system performance, and technological judgments are "backed up" by the technical expertise of professionals.

4.2. *Sustainable building services*

Buildings in our research are equipped with air-to-water, air-to-air or ground-to-water heat pumps (Table 1). Heat pumps heating water (and not air directly) work most efficiently with

Table 1. Participating households and the human, animal, and technological performers of practices in everyday life.

Human and non-human living performers (pseudonyms)	Non-human technological performers	Building 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	Six households with each: Automated ventilation system controlled by CO2 and relative humidity sensor readings, thermostat in most rooms controlling underfloor heating, ground-to-water heat pump, domestic hot water boiler with scheduled reheating, automated exterior blinds controlled by outdoor temperature and wind sensor readings, automated light in several areas controlled by movement and light sensor, remote access by building technicians, energy consumption information on a display	Terraced houses, completed 2020, social housing
Sebastian, Marion, & one baby, one dog	Air-to-water heat pump, automated ventilation system controlled by humidity sensor readings, several self-built home automations and energy management features, energy consumption information on a display	Resident-owned, terraced house, 1980s, automation retrofitted by owner
Ella, two cats	Advanced programmable thermostat controlling ground-to-water heat pump, automated ventilation system controlled by CO2 sensors	Resident-owned, apartment, 2010s
Dustin (pet sitting a dog during research period)	Air-to-air heat pump shared between two apartments	Rented, apartment, 2010s
Julia & Mick	Non-programmable thermostat controlled a turbine air-to-water heat pump (out of order), now controls a gas-boiler, automated ventilation system controlled by CO2 sensors	Rented, terraced house, 1970s
Bas	Non-programmable thermostat controls an air-to-water heat pump, automated ventilation system controlled by CO2 sensors	Rented, terraced house, 1970s

a smaller temperature difference between outside air or ground water temperature (the source temperature), and the water that flows through the system which heats the rooms (the supply temperature). For this reason, most heat pump systems are designed to work at relatively low supply temperatures, which heats indoor air slowly and steadily, rather than fast. In addition, high levels of insulation and a large thermal mass of building elements are seen as beneficial for heat pumps, as these factors limit the additional energy required to heat (or cool) the home following fluctuations in outdoor or indoor temperatures.

Both factors (low supply temperatures and high thermal masses) result in stable indoor temperatures which cannot be changed quickly by inhabitants. Several buildings in our research had these high levels of insulation, but others were buildings with older, less insulated designs, retrofitted with a heat pump with a low supply temperature. Sometimes, additional fans are placed within the convectors that move hot air (and thereby heat) quicker through the rooms.

4.3. *Integrated smart technologies*

Since heat pumps in the Netherlands are relatively novel (replacing gas based central heating systems) and often implemented in efforts to save energy through smart technologies (Van Der Bent et al., 2019), they are frequently accompanied by other novel technologies. In the participating households, there were various forms of home management systems, automated sun shading, sensor-controlled mechanical ventilation (supposedly eliminating the need for ventilating through windows), lights with motion sensors, and various forms of connectivity and monitoring (Figure 1) (Table 1).

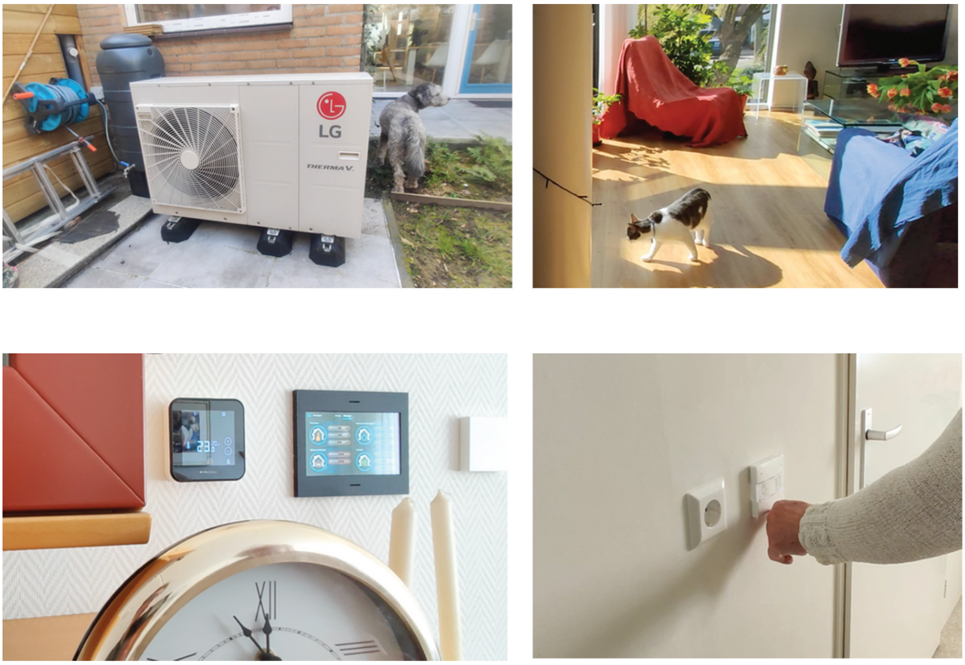

Figure 1. An impression of the smart home (left to right, top to bottom: a heat pump, cats and plants in the living room heated by underfloor heating, a graphical user interface with thermostat and a sensor, an automated light switch on the landing).

4.4. *Data collection and analysis*

4.4.1. *Ethnographic walkthroughs*

To investigate the crises in everyday practices, this research employed an ethnographic approach. Ethnographic methods are a well-established way of doing research in HCI, in particular for investigating how people live with smart technologies in their home (Pink et al., 2013; Strengers et al., 2022). Walkthroughs, where a home tour is complemented with reenactments of daily routines and technology interactions (Boess & Silvester, 2020) have proven useful to explore sensory aspects of everyday life, and to remember and imagine technology interactions (Pink, 2007; Pink et al., 2013). Methods from ethnography fit practice theoretical approaches to the everyday, especially in relation to design, because they allow for careful attention to materiality and to improvisation (Pink & Mackley, 2015). Video recording enabled us to pay attention to technologies and material configurations during the analysis phase, rather than limiting ourselves to participants' statements in interviews (Pink et al., 2016). In the ethnographic interview we aimed for a 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. During the walkthroughs we aimed to establish rapport and trust. This gave us the possibility to ask participants clarifying questions later and share some slices of collected sensor data which could confirm or reject our interpretations.

As we are entering private spaces, where it is not feasible for a researcher to spend a long period of time, we could not observe the crises directly (Hitchings, 2012). Instead, we must rely on participants' memories, which we explored in collaboration with the participants through reenactments. In our research, one or two adult persons (parents) participated in the interview and home tour. This might have limited access to other perspectives, of e.g., children, guests, or pets.

Data collection was carried out by the first author 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 hours. Interviews and walkthroughs were digitally recorded and, where possible, transcribed for analysis. Written notes were made during and after the visits. 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)

4.4.2. *Selecting and analyzing crises*

During the interviews, the topic of crises was discussed, specifically by asking how participant practices had changed, what they found challenging about living with these technologies, as well as more focused and contextual follow-up questions that arose. In the subsequent analysis, we further grouped our findings around emerging themes of crises. To identify them, we looked for instances where participants described their experiences as exceptional, nonstandard, non-routine or non-mainstream. We also took note of situations where participants expressed uncertainty or where we ourselves felt that the situations were nonstandard. Additionally, we identified crises where participants clearly deviated from the designed use. Lastly, we looked for characteristics of improvisation and experimentation, which further aided in our identification of crises. By taking a comprehensive approach to identifying and analyzing crises, we were able to gain a deeper understanding of the challenges and difficulties which participants faced in their experiences.

5. Findings

In our findings, we take our starting point in the crises that we observed. In section 5.1, we describe how these crises reveal *conflicts*: underlying conflicting judgments about appropriate ways of proceeding. In section 5.2, we then examine how these conflicts become everyday opportunities for residents and smart buildings technologies to reconfigure their co-performances with the aim to support outcomes that residents judge as appropriate. Finally, in section 5.3, we describe how new matchings are *enacted* (put into practice) in everyday life and identify the characteristics of such interfaces.

5.1. *Conflicts: when residents and buildings disagree, and how this leads to crises*

In this section, we show instances where the co-performance of human and technological performers did not play out in a way that was appropriate to the situation, according to residents. Although the technological performers in our research have capabilities to perform domestic tasks previously performed by their human co-performers, they did not always do this appropriately in the given situation. This leads to crises in routines. These crises put in view the conflicting judgments that arise between residents and smart building technologies about what is appropriate, meaningful, and useful in specific circumstances. These conflicts concern judgments about, for example, what technology should do when residents leave the house, when to cool the bedroom, when a room requires more lighting, and what are appropriate temperatures in the home. Conflicting judgments of appropriateness also occur among different household members (including pets). Three kinds of conflicting judgments were found. They are described in the following.

5.1.1. *Situated versus decontextualized judgements*

The first kind of conflicting judgment occurred when technology performed in a way that did not match what research participants found appropriate in a specific situation, even though system performance from a decontextualized viewpoint seems appropriate. In Gemma and Gideon’s bedroom, fans in the convector can move air through the room and speed up warming it up or cooling it down. Normally, this system remains in the background: “*We never turn that thing on.*” However, this system is automated in such a way that a fluctuation in temperature can cause the fans to turn on, which speeds up temperature corrections

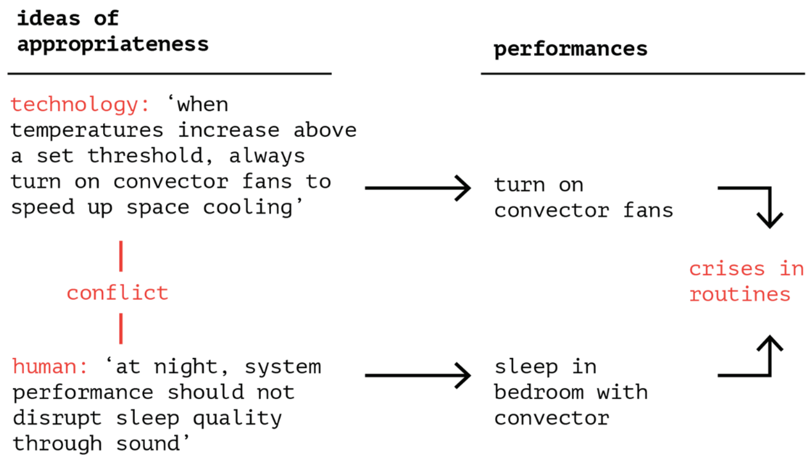

Figure 2. Crises in routines, human and technological performances, and conflicting ideas of appropriateness in Gemma and Gideon's everyday routines.

Figure 3. Gideon demonstrates how the family quickly press the buttons at night in response to the loud noise of the convector fans.

until the setpoint is reached. This can happen anytime of day, including at night (Figure 2). This conflict led to a crisis in routines: *"But sometimes it starts cooling by itself. Starts to blow really loud. And then we quickly press the buttons, and we can go back to sleep."* (Figure 3). In this example, humans, situated in sleeping routines, judge appropriate technological performance different from the technology, which is designed from a decontextualized setting in which fast temperature corrections make sense.

Another instance of conflicting judgment also occurred in Gemma and Gideon's home. The automation in the domestic hot water system will (in its default setting) heat a new batch of water only once every 24 hours. Given the limited boiler capacity, this is not enough for a full day of hot water for their family of six. This sometimes initiated a crisis in showering routines. *"It is kind of a puzzle sometimes. Who's going to take a shower when? (…) We have to make calculations. One time our youngest had a cold-water shower."* They are careful with the amount of hot water they use for doing the dishes to make sure there is enough for the kids to take a shower. *"The boys play soccer on Monday? Then we [parents] can take a shower on Tuesday."* This can be interpreted as differing judgments between humans and building designers about appropriate living situations. Gemma confirmed this interpretation: *"our family is too large for this house."*

5.1.2. *Diverse measures of success*

The second kind of conflicting judgment relates to criteria for success. Some participants live more frugally than was assumed in the building design. This resulted in crises, as for example participant Louise explains: *"I find it strange that I don't have any influence on the temperature. When I leave [the house], I would want to lower the temperature a bit, but it just doesn't do that."* In this case, since the building is well-insulated, lowering the temperature for a short time may not reduce net energy consumption much, and reheating may take a long time. A stable temperature makes sense from a decontextualized designer perspective that views the building in terms of technical functioning and assumed human comfort. However, Louise's routine practices and understandings of sustainability include always striving to save as much energy as possible, resulting in conflicting judgments about the heating of an empty room.

Conflicts can also become visible in the sensory aspects of everyday life. Louise explained her morning routine and points to the home management display: *"Well, here it shows on the display that everything is 'good, good,' and the ventilation is on medium, but I want that ventilation lower, because I can feel the drafts constantly."* This conflict reveals that Louise judged the appropriate response of the ventilation system differently (she does not like the drafts) from the automated technology (which keeps ventilating even though air quality is "good"). Both examples reveal how residents and building services apply different measures and criteria for satisfactory indoor climate.

5.1.2. *Inadequate system sensibilities*

The third kind of conflicting judgment found, relates to the sensibilities of automated building technologies. Robert and Barbara vividly recalled a story involving the nighttime activity of their neighbor's cat. As the sensors for automated lights pick up on the cat walking by, a crisis occurs: the hallway lights wake the human residents, disrupting their sleeping routine. This example illuminates how human (and non-human) judgments of appropriate lighting schedules conflict. The home automation is set up for (and sensitive to) human activity requiring light in the evening, yet becomes inappropriate to the compound routines of a household with pets (which the system can also sense).

5.2. *Reconfigurations: how the crises are resolved*

In the previous section we have shown that crises reveal conflicts. In this section we show that residents take crises as opportunities to actively respond to these conflicts. They do so by reconfiguring (Laakso et al., 2021) everyday life in terms of routines, material settings or by reconfiguring system performances. Residents' responses range from attempts to reprogram the system, to tricking the sensors and manually opening and closing windows. Through these reconfigurations they change the relation between human and technological performances, and by extension their relation to designers and landlords. We found three kinds of reconfigurations.

5.2.1. *Doing it yourself*

Firstly, when a system performed inappropriately, residents in our research responded by partially abandoning the system, or they manually performed tasks which were previously automated. Partial abandonment often seemed to be motivated by a lack of possibilities that renters have to replace technologies or change their performance. Dustin explained how a crisis in heating and cooling routines revealed a conflict in comfortable temperature: *"So, it [the thermostat] is supposed to adjust automatically to the temperature in the room and (. . .) outside. To keep it comfortable for anybody living here. (. . .) I just keep it there, assuming that it's doing something."* However, the system performance could not keep up with what he considered appropriate temperatures. While keeping the automated heating system present in the background, he relied on windows and additional heaters to compensate where system performance fails. "*When it's not enough I can sometimes turn* *the heater on. Or open the windows."* Dustin's response was a reconfiguration of heating and cooling performances, to which he added his manual interventions of heater and windows.

Bas recalled that when he came home in the evening during the first months of his stay, he set the temperature higher, but this did not ensure a comfortable evening on the couch. He explained how he remembers to turn up the thermostat to a set temperature of 22, which he prefers in the evening. *"It tries to get to 22 degrees. I turn it on in the morning. And it takes a long time"*. The reconfiguration in this case is Bas' additional manual adjustment, which he incorporated in his own daily routines to make the smart heating work.

5.2.2. *Reconfiguring material settings*

Secondly, we found that participants in our research reconfigure the material settings of everyday life to resolve crises. In Gideon's smart home, a crisis occurred when the kids couldn't sleep on summer evenings. The automated system judged a change in wind to be enough to open the sunshade. *"It just opened and then immediately closed again. Open, close."* Their response is to bring in an additional manual shade on the inside, which is closed on summer evenings (Figure 4). *"So, 9 out of 10 times, we just do it ourselves."* The residents reconfigured material settings in such a way that the automation will have less impact on sleeping routines.

A crisis in their son's work-from-home routine revealed how Alice and Rudolph have conflicting judgments with their son about what is an appropriate temperature in the home in winter. *"He likes the holiday temperatures, you know. 25, 26 [degrees Celsius]. Like the [elderly] neighbor."* They continued everyday life by installing an additional electric heater in the room where their son works. Here, the reconfiguration of material settings (installing a heater) is linked to a new human routine (turning it on during working hours).

5.2.3. *Re-programming system performances*

Thirdly, we found that the programmability of smart house technologies enables co-performances that deviate from the designed "use" of these systems. Rudolph, for example, explained how their son's sleeping routine came into conflict with the noise made by the ventilation system. Together with his tech-savvy son, he found a hidden control setting that, temporarily, sets the ventilation

Figure 4. Gideon demonstrates the retrofitted manual sunshade with the automated sunshade on the exterior of the window.

system to make less noise. After this, the system will automatically return to normal performance. *"This is actually meant for the engineers. You go to this web page, and you can set it back to zero. [. . .] He kind of hacked the system."* Rudolph and his son have resolved this crisis by (in this case: temporarily) reprogramming the system's ventilation performances.

In Laura's house a crisis occurred when the smart lights turn off after a short period of time. *"Our youngest really likes to sleep with the lights on at the landing upstairs."* In response, the family has circumvented the automation, by turning it off for a while every night. *"So, when he goes to bed, we put it in 'lock' so that it stays on. And if we go back upstairs, we put it back so that it turns on when you walk by."* In this case, the (temporary) reprogramming of automation is closely linked to evening routines.

Sebastian showed how he goes even further in reprogramming automations. His self-installed heat pump system is automated in such a way that it often repeatedly started with a loud noise and then stopped when there is a low need for indoor heat. This disrupted family life and conflicted with ideas of appropriate performance. Sebastian has changed the settings (the "heat curve" and "hysteresis") to resolve the conflict. Here, a more intensive reprogramming of system performance was required to resolve the families' crises and make heat pump performance appropriate.

5.3. *Enacted interfaces: how a new matching between people and technology is put into practice*

So far, we have shown that residents reconfigure their relations to smart building technologies in a variety of ways. They do so to modify the response of smart building technology in specific situations, to one that is more appropriate to their everyday lives. In this section, we describe situations in which these reconfigurations also enact (i.e., put into practice) a new matching of people to things (i.e., an *interface*) which persists in everyday life. In what follows we focus on how the everyday interfaces observed in our study are different from the graphical user interface intended for a "set-and-forget" form of automation, and how everyday interfaces seem to work better in the residents' judgment of appropriateness.

5.3.1. *Constructing new routines*

First, rather than interacting through a graphical user interface, residents in our research align and consolidate co-performances through everyday activities. Opening and closing of windows and doors were frequently mentioned as ways to bring human and technological performances in line with residents' judgments of appropriateness. Herbert, for example, explained how daily routines of window opening and closing replace engagement with the thermostat. He does not touch this thermostat interface *"as we were told"*. Instead, on our following walkthrough, we came to frequently discuss opening and closing windows in different rooms as means to manipulate the temperature. *"Because that's how we like it."* Effectively, the opening of windows is a more trustworthy interface to achieve cooling than the automated system. In a similar defiance of instructions, Robert said: *"My wife opens the windows in the bedroom in the morning. But the advice is that we should actually not do that, because the air is circulated."* Residents find that the instructed use of the windows (keeping them closed), does not lead to what they find appropriate (the feeling of fresh air from open windows). Residents enact a different interface by constructing routines of opening and closing windows.

5.3.2. *Responding to one another*

Secondly, we find that the activities of residents are responses to system performances, which then in turn respond back. Through sequences of such responses repeated in everyday life, these interfaces persist. Gemma recalled that when the automated lighting in the bathroom turns off, she responds by making some movement. This brings the system back to appropriate performance. *"We* *sometimes have to wave to the sensor when on the toilet."* In this case, the interface is not set once, and then forgotten about, but a frequent "back and forth" (or responding) of correcting the performance of the automated lighting enacts an interface that works for Gemma's family.

This "back and forth" was also found in the way indoor temperature was managed. Gemma turned on the underfloor heating using the thermostat, which she leaves at a high temperature until the room becomes too warm. Gemma: *"In winter we sometimes have cold feet, and then we turn on the underfloor heating. But we also quickly turn it off because it gets too hot."* The interface, in this case, is not (just) the thermostat or the display showing the temperature. Much more significant is the response of the floor, and the responding of residents to cold feet. This mutual responding is notably different from the typical intended usage of a thermostat which is set to achieve and maintain a room temperature (Figure 5). Rather, the interface in this case is a repeated mutual responding of residents to heating, and heating to residents.

The interfaces we found in our study are not a single button, passively present in the background to "set-and-forget" the building automation. Rudolph and Alice were frequently presented with a crisis in routines when they entered the scullery that has automated lighting: *"It's great you can walk in with full hands and don't have to think about something. But it doesn't turn on when it is somewhat light* [outside]. *So, you're looking inside a dark cabinet."* In response to this crisis in routines, they have installed a manual sunshade. This device does not replace the system performance but alters its performance by changing the light sensor readings to become appropriate. *"We have added some extra shading which we roll down, so the automatic lighting turns on."* (Figure 6). This material device is not automated, and thus, in a sense, less "smart" than building and residents. However, it is in an important sense part of both human performances (being closed by Alice) and technological co-performance (blocking sensor readings). In this case, the interface, as a new matching, consists of both the material device and the activity of Alice and the lighting.

5.3.3. *Expanding the network of relations*

Thirdly, we found cases where interfaces in our research are embedded in the complicated multiplicity of everyday life. In the home, all kinds of performances are present and interact with one another. Here, the interface does not just match the single human to a technology, but connects many more performers to one another in a network.

Newly enacted interfaces include, for example, the activities of pets and plants. Louise mentioned how her dog plays an essential role in determining the appropriate performance and location of the

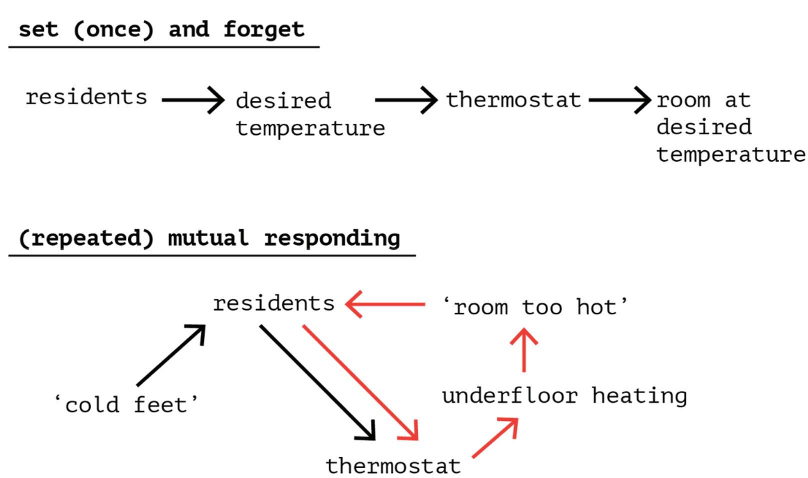

Figure 5. Typical intended usage of a thermostat ('set-and-forget') and a repeated 'back and forth' as recalled by Gemma.

Figure 6. The retrofitted manual sunshade that can be drawn down to alter the light sensor readings.

Figure 7. A plant that lost leaves in Julia's previous house.

underfloor heating: *"Yes, the dog was lying down around this spot."* and *"What was really funny, when she [the dog] came out of the bench, she immediately ran to the water, she normally never does that, so yeah, I think she was thirsty."* Gemma similarly explained how the dog in their household prefers to lie on the couch, rather than on the floor in winter, since he finds the heated floor to be uncomfortable. Here, the newly enacted interface consists of the activities of, and the relations between humans, technologies, and dogs.

Julia mentioned plants as relevant to understanding the building performance. *"Because in the other house, it was very bad. It was very humid and very dark. (...) This one [plant] looks bad now because of that house."* (Figure 7). Their current house has automated ventilation, and thereby takes

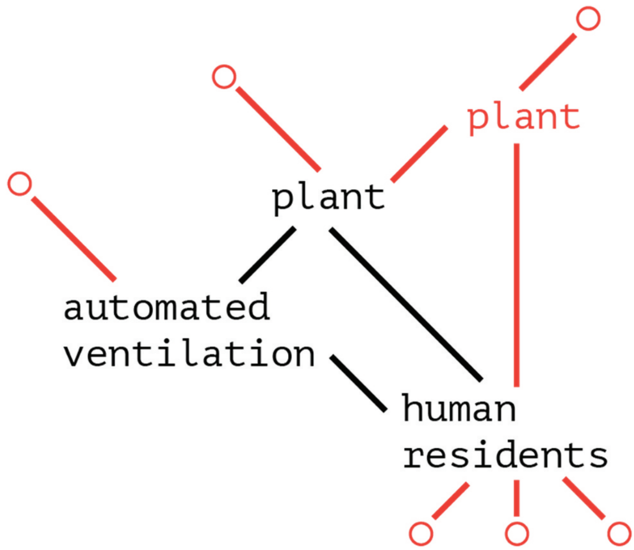

Figure 8. New relations between humans, automated ventilation, plants and beyond.

care of the dehumidification of the indoor air. However, this then required a change in the residents' routines of plant watering. *"The [previous] house was humid, so I didn't need to water them so much. Here they have more light, but I need to water them much more."* In this case, the activity of the plant becomes included in an interface that connects technologies and living entities into a network of relations (Figure 8).

In these examples, residents enact new interfaces by integrating other nonhuman performers into their daily routinized co-performance with the smart building.

5.3.4. *Engaging human bodies*

We found that the engagement of human bodies is another characteristic of the enacted interfaces. Whereas typical (designed) interfaces for automation are displays with a limited modality (often: a touchscreen), the interfaces we describe, engage with more sensory modalities of physical human bodies.

Louise, as noted before, has little trust in what the display interface shows her about system performance. Instead, she invited us to experience system performance by taking off our shoes: "*And can you feel it? I feel immediately some heat around my feet when it heats up.*" Ella also demonstrated how she took a little walk around her house without shoes to feel where the underfloor heating pipes are located. Dustin invited us to share his embodied experiences as he notices the airflow when he sits on the couch in the evening: *"If you come here, you can feel that there is air coming [...]. I don't know if it's cooling or..."* Bas, on the other hand, engages with system performance through the modality of sound. He particularly notices change in system performance during silent moments. *"I can't tell where it comes from. But I hear quite some buzzing and ticking sounds, especially at night."*

These examples highlight that interfaces that matched human and technological performances are not limited to touchscreens. Instead, they are embodied and sensory.

6. Discussion

In the empirical part of our research, we have looked at everyday practice in smart buildings as observed and recounted in our ethnographic walkthroughs. Prompted by earlier research and informed by the more-than-human framework of co-performance, we looked for crises in our empirical research. We have noticed that instead of smooth interactions, crises occur. By further investigating these crises we found that (1) these crises stem from conflicting ideas of appropriateness. What is appropriate, according to residents in situated use, appeared to have not been taken into account by designers in decontextualized decision making. These conflicts are further exacerbated by the different sensibilities and capabilities of humans (e.g., bodily felt temperature) and technological systems (measured room temperature). The differences in the way humans ("not feeling drafts") and technologies ("CO2-levels") measure success further reveal conflicting ideas of appropriateness. We also found that (2) these crises are resolved through reconfigurations. Residents actively engage by taking over roles previously performed by systems, by changing the material configuration of their homes, and by reprogramming smart home technologies. Finally, we found that, as a specific form of reconfiguration, (3) new interfaces are enacted. These interfaces are persistent matchings of humans and technologies which are enacted through new routines of humans and technologies. These interfaces take the shape of sequential responses. We found that they may involve a network of non-human performers, and engage human bodies.

Smart homes are increasingly present in everyday life. We are not the first to study everyday practice in smart homes, nor are we the first to adopt ideas from practice theory (Jensen et al., 2018). Such earlier studies have also found that conflicts occur in the smart home (Mennicken & Huang, 2012). However, we are the first to use a lens of co-performance in such a study.

Our approach offers an alternative to user-centered approaches to smart homes. We consider human-building interaction (Alavi et al., 2016) not with technology in the center, nor from a user-centered perspective focusing on assumed end-user needs, but starting from what is in between – the relation between humans and technologies and how this relation can evolve to become more appropriate from a resident perspective. Taking this more-than-human approach highlights ideas of appropriate everyday practice embedded in human and technological performances, and how their respective capabilities and sensibilities enable them to respond when ideas of appropriateness come into conflict. By probing beyond static user needs and predictable interactions, our approach highlights that new interfaces are enacted by residents and smart buildings, which leads to them settling on a more appropriate co-performance.

Existing work that takes more-than-human perspectives in the fields of HCI and design has predominantly decentered the human (user) in favor of posthumanist conceptual and theoretical frameworks, and then used these theories and concepts to speculate on alternative roles and practices in design and HCI (e.g., Coskun et al., 2022; Forlano, 2017; Giaccardi & Redström, 2020; see also Nicenboim et al., 2023, this issue). The work presented in this paper uses co-performance as a more-than-human lens to add empirical nuance to theoretical inquiry. This empirical focus has enabled us to probe how more-than-human concepts can be useful in analysis of existing practices, not just in speculative design practices. More importantly, though currently absent from dominant (user-centered) conceptualizations of the design process, we were able to observe that more-than-human design practices do take place in everyday life. Practices of negotiation, responsiveness, and reconfiguration (Giaccardi & Redström, 2020), engagement of non-humans (such as sensors, but also cats) (Wakkary, 2021), and the creation of spaces where humans and non-humans come together (Frauenberger, 2019) could all be observed in the smart home when taking a more-than-human orientation. Such an orientation positions the act of designing outside the formally designated design work by professionals and reflects our acknowledgment of end-user appropriation as a creative activity (Fischer et al., 2004; Kuijer et al., 2017; Wakkary & Maestri, 2007). This orientation also suggests an initial framework and vocabulary for how more-than-human design practice can tap into practices of use, experimentation, and resourcefulness of human and nonhuman performers alike.

On this premise, we briefly expand on the relevance of our findings for HCI and sustainable design, and discuss implications of a more-than-human approach for the design of smart homes and automated performers in a broader sense.

6.1. *A reappraisal of crises as productive events*

We have seen that a user-centered approach to smart homes often aims to smooth out conflicts and crises within everyday life. Our study indicates that conflicts can be expected since it is impossible for designers to predict or fully anticipate what is appropriate in everyday practice. Our findings also show how these conflicts lead to crises in routines in everyday life, as smart building technologies do something different from what residents find appropriate. Yet, these crises also enable reconfigurations which then improve co-performances from a resident perspective. These reconfigurations are forms of situated adaptation (or "appropriation" (Sørensen et al., 2000)) of smart technologies that make their performance appropriate to residents within everyday life. Human performers (end users) are (as of now) unique in their capabilities to initiate resolutions of these conflicts in improvisatory and resourceful ways. However, are there lessons to be learned for design? Designers of smart home technologies might support this appropriation by designing technologies that are more flexible and configurable and thus more open to improvisation (Kuijer et al., 2017). This appropriation can also be supported by professional human actors such as technicians or building owners who are involved in the use phase (Boess, 2022). These professionals could be supportive to residents in the resolution of crises by being open to learning about crises from residents, advising from a more technical point of view or adapting hidden system settings to make them more appropriate for residents. In addition, the (connected) smart building lends itself well to the extension of design activities (like optimization of settings) into the use-phase which enables designers to be involved more in everyday practice than possible before (Giaccardi, 2019).

More generally, this reappraisal of everyday crises as possibilities for reconfiguration entails a different positioning of design practice in terms of how it shapes technological performance in use-time. The challenge for design is then not one of discovering the intentions of residents (e.g., having warm feet) and then enabling the technology to act upon these intentions, like user centered design has been trying to do (Agee et al., 2021). Rather, the challenge could be how to both learn from and possibly even stage crises in design time, and to then design with the reconfigurations and interfaces that emerge. We also propose an alternative to existing design research which is focused on changing user behavior for sustainability goals (Coskun et al., 2022; Lockton et al., 2013). Our intent is not to design for pre-determined resident behaviors. Instead, the challenge is to design a certain openness and configurability into smart buildings to relate and respond to human and other entities within the home.

This openness also implies a positive outlook toward improvisation and experimentation with technologies in everyday life (Giaccardi et al., 2016; Jalas et al., 2017). Rather than focusing on increased human control over technologies, *this paradigm challenges designers to offer human performers opportunities to experiment, learn and explore in a meaningful way with technologies*. This means that residents and smart buildings might perform more flexible roles where tasks can be dynamically delegated from humans to technologies and vice versa (e.g., users deciding "I'll do it myself" or systems requesting manual interventions in automated performances).

6.2. *Interfaces enacted in practice*

The notion of interface is malleable, and the current more-than-human turn in HCI and design has not yet articulated a conceptualization of the interface. Almost 30 years ago, Cooper and Bowers (1995) claimed the user interface as the site of HCI knowledge and practice. They identify the notion of interface as flexible, and only accidentally, in their era, manifesting as a screen. Their analysis of HCI discourse recognizes that the entity of interface is produced through practices (discursive practices in HCI and practices of use) (Cooper & Bowers, 1995, p. 64). Through the lens of co-performance, we have developed and mobilized a contemporary more-than-human understanding of the concept of interface. Rather than limiting ourselves to the "operational panel", we looked at other "solutions to the problem of matching people to things" (Pickering, 2000). In line with an understanding of everyday practice where residents and smart buildings perform everyday life together, we recognized many interfaces that are *enacted* rather than designed. These interfaces are “zones of activity” (Galloway, 2012) that allow humans and non-humans to respond to one another in situations that are not, and cannot be, entirely anticipated by designers (Bødker, 2006). Through improvisations and experiments, residents and technologies figure out new matchings that persist in everyday life.

In contrast to the operational panel, the enacted interfaces are not of the graphical or representational kind, representing the state of the building to its occupants, to improve their understanding. They are also not the means to carry out a specific task or goal (as in (Blair-Early & Zender, 2008; Marcus, 2002)), nor an exchange of information primarily (Molich & Nielsen, 1990). In the smart building, where technologies present themselves more as “fields” around humans, than as tools that humans use, the interface is almost “faceless” (Janlert & Stolterman, 2015). Rather than (just) the surface of a screen, the interface is a site of mutual “effects” and responses of human and technological performances (Galloway, 2012). Interfaces are new relations, enacted through household routines, and in relations with windows, and pets.

These interfaces relate and connect human and non-human performances through embodied couplings, and routines, human and non-human, that match and build on one another. This aligns with Suchman’s proposal to “take the interface not as an a priori or self-evident boundary between bodies and machines but as a relation enacted in particular settings and one, moreover, that shifts over time” (Suchman, 2007, p. 263).

For designers this implies a shift in thinking of interfaces not as nouns but as verbs. They are not about knowledge, insight, and control of a technology (i.e., designers developing the correct representations for users to understand how things work). Instead, interfacing is about the site where human and technological performances affect one another. Designing technologies and technological performances that enable the everyday enactment of this kind of interface is not straightforward. The challenge seems to ask designers to leave some margin: a certain flexibility and configurability in technological performances. Building technologies such as smart thermostats could be made sensitive to other measures of success than the room temperature. In this way, technologies might be able to respond to and develop with redefinitions of what is considered appropriate by residents in the course of everyday life.

To summarize, we have argued and demonstrated that what is an appropriate performance, for both humans and automated technologies, can change over time and therefore interfaces cannot be fully anticipated and materialized at design time. Instead, interfaces come about through the ability of human and technological performances to respond to one another. This suggests that, rather than the design of single touch points, *designers should focus on the cultivation of “responsiveness”, both human and artificial*.

6.3. *Designing sustainable buildings as more-than-human sites of friction*

A smart building promises to consume less energy and be more sustainable because its automations can do the necessary things (“user needs” such as heating, turning lights on) in a more efficient (energy saving) way than users. Our observations highlight that residents do not evaluate and reconfigure technological performances according to their “user needs”, but according to what is appropriate to the situation at hand. What is appropriate is situated, contextualized, and contested. Driven by mere technological possibilities or a genuine orientation toward human needs, a smart building embeds assumptions about what is appropriate everyday practice (how does one live there). Our research suggests that, if the performance of a smart building is optimized simply according to assumed current resident practices (or envisioned alternative practices), projected energy savings and sustainability goals might not be realized. For example, residents consider the opening of windows when heating appropriate practice. This is different from projected use, makes the building lose thermal energy, and consumes more, rather than less, energy.

The challenge thus seems to hinge on uniting the appropriateness and sustainability of building performance. Reading through the complexity presented in our findings, it seems an extraordinary challenge for designers to shape the co-performance in smart buildings in such a way that it is always efficient with energy, while also being appropriate to the situation at hand. The smart buildings in our research could not have been programmed or designed in such a way that they could deal with the contextual, situated nature of appropriateness as described by residents. This reflects insights from literature which consider technological artifacts as (for now) incapable of dealing with tacit, implicit and ambiguous information or social awareness (Kuijer, 2019, p. 208). When inappropriate performances can thus not be prevented, designing sustainable smart buildings becomes a matter of configuring performances that are flexible toward different and changing circumstances in the home, while remaining energy efficient (e.g., the heating could turn off when windows are opened). In this way, conflicts can be resolved and even be fruitful toward the enactment of new interfaces that allow new co-performances.

However, design for sustainable smart buildings does not have to stop at this seemingly neutral position toward everyday practices. Instead, our research emphasizes the ideas of appropriate practice embedded by designers in technological performances, which thereby shape everyday life in the smart building. By going beyond straightforward automation of tasks previously performed by residents, this power of designers can be used to direct or orchestrate sustainable co-performances. For example, a smart thermostat could slowly reduce set temperature over time, requiring active involvement of residents to stay warm, which might reduce energy consumption. Here again, our proposal is different from efforts to change behavior. Instead, we align ourselves more with efforts to provoke, negotiate, engage, and propose and explore alternatives (Jensen et al., 2018; Mazé & Redström, 2008; Pierce & Paulos, 2013).

This might very well go much further than merely the material configuration of building and automation (the linear approach to building design). Designers could devise everyday experiments together with residents (e.g., new routines), be engaged in instructing them during use-time (e.g., suggest to "notice the dog's behavior"), or adapt system performances during the occupancy phase. Rather than avoiding crises, these design activities might foreground conflicting ideas and thereby be influential in making everyday life more sustainable. This extends previous design research, which has e.g., put design efforts in "crafting an argument" for different behaviors toward end-users (Mazé & Redström, 2008). Our suggestion goes further and proposes that end-users are also enabled to "speak back" to the argument proposed by designers.

From a co-performance perspective, the everyday crises we presented, can be seen as conflicts about sustainability between residents and technologies (and, by implication, designers). They come into everyday conflicts about the importance of sustainability, what it means, and what are effective ways to realize it (e.g., when to heat a room). This further foregrounds the home as an "inherently social, political, and contested site" (Dahlgren et al., 2021).

With these considerations in mind, the enacted interface is not just a site of productive friction but can be interpreted as a site of deliberation. *Designers might turn their attention to design for conflict and deliberation and consider how it might turn into a productive dialogue*. More speculatively, this can be considered as a more-than-human form of participatory design through and with technologies (Hee-Jeong Choi et al., 2020) or "particular instances where the dynamic agency of algorithms comes into relation with human actors, citizens, and the public(s), especially when it resists automation". This positions human designers in the role of infrastructuring co-performances (Karasti, 2014), which expects of them an "attentiveness to existing power asymmetries" (Barad, 2007) and an awareness of political agendas and narratives in technology development.

6.4. *Limitations of the study*

Our ethnographic method informed by a practice theoretical framework focused on crises in everyday routines. This focus might have limited our perception of everyday life as it unfolds more smoothly, and we might have overlooked other ways in which human and technological judgments influence one another. In addition, our sample of participating households featured a high number of tenants. Thereby, many decisions regarding design, choice and implementation of smart home technologies were made by professional stakeholders (housing organizations and technical stakeholders), rather than residents acting as consumers. This might have led to a higher acceptance of technological judgments justified by the “expertise” of professional stakeholders; judgments which residents would otherwise not consider appropriate. On the other hand, this different type of relationship between residents and technologies seems to prompt residents to engage more in conflicts with technological judgments, which they, as tenants, did not have the power to change.

By situating our research within the boundaries of the household, we have not engaged with potential future developments on a societal scale that might have a bearing on the appropriateness of everyday practices in the home. One could think of increasing energy prices as examples of developments that change norms. In future research, the crises prompted by such developments could potentially also be studied through the lens of co-performance. We have also limited our scope to the physical walls of the household and thereby not engaged with the many other-than-human agencies and perspectives that emerge when smart buildings are connected to broader networks (Coulton & Lindley, 2019; Redström & Wiltse, 2019).

We relied on the memory of our participants and a shared exploration documented on video. As the data has been gathered principally from the human side of co-performance, we might have missed out on the less visible aspects of technological performances. This limitation could be compensated for in future research by capitalizing on increasing opportunities to gather more insight into past and present technological performances through for example, building monitoring (Guerra-Santin et al., 2017) and the attachment of sensors to devices (Berger et al., 2019).

7. Conclusions

We live with our smart houses, not just inside them. Using the more-than-human lens of co-performance, we hope to have contributed to an understanding of what living together in the more-than-human home looks like. We have argued for a reappraisal of everyday crises in routines as possibilities for improved co-performances. Our empirical research through the lens of co-performance revealed how crises in everyday routines reveal conflicting judgments between human and technological performers of what is appropriate proceeding. We have argued that these crises are opportunities for the reconfiguration of relationships between humans, technologies, and other entities.

Through the lens of co-performance, we have developed and mobilized a more-than-human understanding of the object of HCI, the interface. We have shown that new interfaces between human and non-human performances are relational matchings enacted in use, dynamically subject to change.

We have suggested that researchers and designers look beyond user-centered approaches, and instead focus on more-than-human relations in everyday practice. Rather than stable anchor points, these relations provide a starting point for investigating dynamic and fluid co-performances. We have also suggested that designers could focus on the cultivation of responsiveness, both human and artificial, to enable the enactment of new interfaces and support sustainability and dialogue about this issue in the use phase.

In future research, the enacted interfaces and co-performances could be studied in further detail and from other (non-human) perspectives using sensors and other data gathering devices. Future research could also explore the opportunities of designing technologies and technological performances that enable and promote the everyday enactment of interfaces, which offer human performers opportunities to experiment, learn and explore in a meaningful way with technologies.

8. Ethics statement

This research study has been performed in accordance with the principles stated in the Declaration of Helsinki. Participants in this study have provided written consent to be part of this study. This research has been approved by Human Research Ethics Committee TU Delft under number 1913.

Disclosure statement

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