THESIS FOR THE DEGREE OF LICENTIATE OF ARCHITECTURE

TOWARDS A CIRCULAR HOME

Exploring opportunities for design to support households in sustainable resource use

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ABSTRACT

Our use of natural resources has grown dramatically in recent years, with negative consequences for both the environment and human health. At home, resource use in the form of energy, water, food, and material objects may be related to a wide range of everyday practices as well as changes to, and adaptations of, our home environments. Thus, we as households play an important role in contributing to a less intensive use of resources. Even so, support is needed in the form of solutions that enable both reduced environmental impact and satisfaction with our homes.

The research presented in this thesis aims to identify opportunities for more sustainable resource use at home. This has been addressed through the investigation of home-related resource use relating to households' practices, lifestyles, and decisions concerning the home. The research has also explored design implications to support households in minimising their resource use and analysed households' experiences of sustainability-orientated solutions for the home.

Two field studies have been conducted. Study A investigated daily use and renewal of domestic kitchens and explored design implications to improve kitchens from a circular economy perspective. Qualitative data was collected in the form of interviews and a focus group, complemented by a diary or a short survey. Study B investigated perceptions and acceptance of demand-side management in residential space heating, to support an increased share of renewable energy. This study collected mainly quantitative data through a diary tool, complemented by surveys.

The findings reveal that home-related resource use depends on a multitude of practices, preferences, choices, and contextual factors. In both studies, it seemed that dissatisfaction with the home environment may lead to additional resource use. For instance, kitchen renovations or practices to improve thermal comfort which either use energy or lead to energy being wasted. In the kitchen, design was found to play an important role, both in supporting sustainability in everyday kitchen practices and in allowing needs and preferences to be met over time, with little impact on the environment. Identified opportunities for increasing the circularity of kitchens were: improved technical and functional quality, timeless design, acknowledging emotional values, allowing aesthetical upgrades, allowing functional upgrades and repair, systemic changes and new business models, and increasing awareness of environmental impacts connected to kitchen renewal. Regarding demand-side management in space heating, perception and acceptance were found to depend on factors such as set indoor climate conditions, timing and magnitude of the load shifts, communication, and control.

To conclude, this thesis contributes insights into home-related resource use from a household perspective and highlights opportunities for design to enable greater levels of circularity and renewable energy use at home.

Keywords: circular product design, circular economy, smart energy systems, thermal comfort, demand-side management, social practice theory, design for sustainability

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APPENDED PUBLICATIONS

PAPER A

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Contribution: Hagejärd planned the study together with Ollár, with input from Femenías and Rahe. Hagejärd and Ollár performed the data collection and analysed the data together. Hagejärd lead the work of writing the paper with contributions from Ollár. Femenías and Rahe reviewed the paper.

PAPER B

Hagejärd, S., Dokter, G., Rahe, U., & Femenías, P. (2020, submitted) Exploring household perceptions of demand-side management in district heating. *Under preparation for second review in scientific journal.*

Contribution: Hagejärd planned the study together with Dokter and Rahe. Hagejärd and Dokter carried out the study with assistance from the Chalmers IT team, who developed the website for data collection. Hagejärd analysed the data and wrote the paper. Dokter, Rahe and Femenías reviewed the paper.

ADDITIONAL PUBLICATIONS

The following papers are published in my former name, Andersson.

Andersson, S., & Rahe, U. (2017). Accelerate innovation towards sustainable living: exploring the potential of Living Labs in a recently completed case. *Journal of Design Research*, *15*(3/4), 234–257. https://doi.org/10.1504/JDR.2017.089914

Andersson, S., Ollár, A., Femenías, P., & Rahe, U. (2018). *Retrofitting from the Inside/Insight Perspective: Adapting to Users' Needs with the Kitchen as a Starting Point.* Paper presented at Retrofit Europe, SBE19 Conference. Eindhoven, Netherlands.

Andersson, S., & Rahe, U. (2019). All Doors Lead to the Kitchen – Sustainability and Wellbeing Challenges in a Shared Centrepiece of Living. In T. Ahram, W. Karwowski, & R. Taiar (Eds.), *Human Systems Engineering and Design: Proceedings of the 1st International Conference on Human Systems Engineering and Design (IHSED2018): Future Trends and Applications, October 25–27, 2018, CHU-Université de Reims Champagne-Ardenne, France* (Vol. 876, pp. 111–116). https://doi.org/10.1007/978-3-030-02053-8

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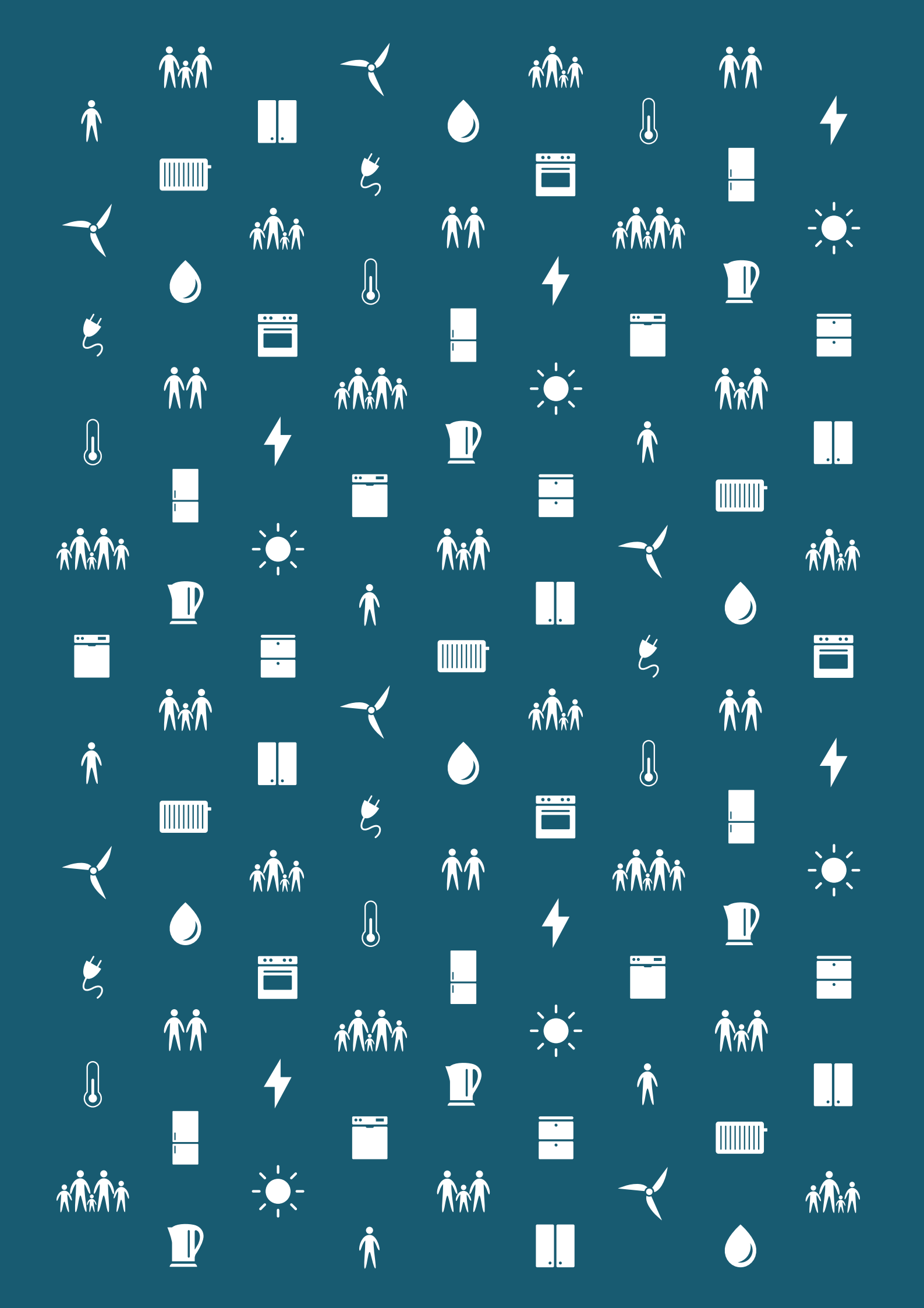


1 INTRODUCTION

This chapter introduces the background to the research presented in this thesis. There then follows a description of the aim and research questions posed. The research context is then presented, followed by an explanation of the limitations of the research and its applications. The chapter ends with an outline of the thesis structure.

1.1 BACKGROUND

The global use of natural resources has grown more than threefold since 1970, causing negative effects on both the environment and human health (Oberle et al., 2019). It has been estimated that household consumption accounts for between 65% and 72% of global greenhouse gas emissions, when both direct and indirect emissions are included (Hertwich & Peters, 2009; Ivanova et al., 2016). Furthermore, household consumption accounts for some 70% of the global land use, 48% of the total raw materials extraction, and 81% of the total use of fresh-water resources (Ivanova et al., 2016).

At home, we use resources in a multitude of everyday life activities, such as cooking, laundry, showering or relaxing in front of the television in a nicely heated living room. Major life events, such as having children, or major decisions, such as renovating the home, may have significant impact on the resource use and environmental footprint of households (Dubois et al., 2019). Through their demand for goods and services, households drive emission patterns and economic development, and also reflect wider societal patterns (Dubois et al., 2019). At the same time, it is difficult for individual households to break free from locked-in patterns of consumption which depend on larger sociotechnical systems (Maréchal, 2010).

A majority of the environmental footprint of households relates to the categories of food, shelter and mobility, with shelter including the operation and maintenance of residences (Hertwich & Peters, 2009). In a net-zero energy building, it has been estimated that furniture accounts for some 10% and appliances up to 25% of the building's overall impacts (Hoxha & Jusselme, 2017). In recent years, the number of

appliances per household has increased (Gram-Hanssen, 2013; Hand, Shove, & Southerton, 2007), while the lifespan of home appliances has declined (Bakker, Wang, Huisman, & den Hollander, 2014; Wang, Huisman, Stevels, & Baldé, 2013). As a consequence, the amount of home appliance waste in Europe has steadily increased, reaching five million tonnes in 2016 (CECED, 2018). Furniture waste totals approximately 10 million tonnes per year in the European Union (European Environmental Bureau, 2017), of which 80-90% is dumped in landfill or incinerated (European Remanufacturing Network, 2015).

Efforts to reduce residential use of resources have so far focused mainly on energy consumption (Kalmykova, Rosado, & Patrício, 2016) through efficiency improvements in technologies and buildings (Gram-Hanssen, 2013). In approaching a future low-carbon society, a growing number of researchers have also highlighted the need to address user behaviour and practices connected to residential resource consumption (Gram-Hanssen, 2013; Janda, 2011). Furthermore, the majority of efforts to bring about behavioural and lifestyle changes have focused almost exclusively on direct emissions (from direct energy use in the home and fuels burned in personal transportation), while indirect emissions from embedded carbon in consumed products and services have received much less attention (Capstick, Lorenzoni, Corner, & Whitmarsh, 2014). This, despite the fact that the majority of the carbon footprint of Western households comes from indirect emissions (Druckman & Jackson, 2009).

This thesis will address residential resource use in a broad sense, including products and material resources, as well as energy, food and water. The included research studies are part of two present research areas constituting different pathways towards more sustainable resource use. These are *circular economy* and *smart energy systems* and will be explained in Chapter 2. Although described as separate approaches, these two areas share the goals of minimising environmental impacts and preventing resource depletion; thus, they complement each other. The specific focuses of the two included research studies are: (1) opportunities for improving the circularity of domestic kitchens and (2) perceptions and acceptance of demand-side management in residential space heating.

Starting with the first theme, in recent years kitchens have become a frequent target for renewal (Hand et al., 2007; Maller, Horne, & Dalton, 2012), with kitchen appliances and furniture contributing a significant share of the climate impact related to apartment renovations (Femenías, Holmström, Jonsdotter, & Thuvander, 2016). Furthermore, household kitchen practices have been identified as one of the most promising areas for behaviour change in the home (Hobman, Stenner, & Frederiks, 2017). Yet, there is currently a lack of research studying design implications to minimise the environmental impact of kitchen renewal and daily kitchen practices.

Regarding the second theme, space heating accounted for almost two-thirds of households' final energy consumption in the European Union in 2018, of which renewable energy sources constituted only 27% (Eurostat, 2020). To increase the share of renewable energy sources (the availability of which depends on current weather conditions and thus varies with time), a relatively small number of research

studies have investigated the potential to improve the flexibility of residential heating demand in district heating systems. Furthermore, little attention has been given to households' experiences and opinions regarding their indoor climate and temperature deviations caused by demand-side management.

1.2 AIM & RESEARCH QUESTIONS

The overall aim of this research is to study opportunities for sustainable resource use within the home. First of all, the aim was to gain deeper knowledge of the different ways in which home-related resource use takes place and how this is influenced by households' practices, lifestyles, and key investment decisions in existing homes. This knowledge was then used as a basis for exploring design implications to support households in minimising their resource use. Consequently, the research also aimed to understand how solutions intended for more sustainable resource use at home are perceived, from the households' point of view.

Furthermore, the included research studies have been guided by more specific aims. In Study A, the aims were to: (1) explore households' everyday resource use in the kitchen, (2) explore typical motivations for renovating the kitchen, and (3) identify design strategies that could enable circular consumption in and around domestic kitchens, with respect to the kitchen itself plus the daily use of kitchens.

Study B aimed to gain better understanding of: (1) the perception of comfort related to indoor temperature conditions at home and (2) the acceptance of demand-side management in residential heating from a household perspective.

The research questions posed in this thesis are:

RQ1: How do households' everyday practices, lifestyles, and decisions influence the ways in which home-related resource use takes place?

RQ2: How could the design of products and services support households in minimising their resource use at home?

RQ3: What influences households' perception and acceptance of solutions aimed at reducing the environmental impact of home-related resource use?

1.3 RESEARCH CONTEXT

The research presented in this thesis is part of two research projects: (1) the Circular Kitchen (CIK), funded by EIT Climate-KIC and industry partners and (2) FIWARE for Smart Energy Platform (FISMEP), funded by ERA-Net Smart Grids Plus via Energimyndigheten.

The CIK project is a collaboration between TU Delft, Chalmers University of Technology, and industrial partners including housing developers, kitchen manufacturers, and appliance producers. The aim is to develop kitchen furniture and appliances (based on circular economy principles and accompanied by circular

business models), to achieve a reduction in resource use, environmental pollution, and greenhouse gas emissions related to kitchens and their daily use. Research which gains insights into households' perspectives and experiences of the kitchen is key to this development.

The FISMEP project aims to enable an efficient, automated and sustainable energy supply through the development of a cloud-based, service-oriented open-source software platform. The project is a collaboration between seven partners from academia and industry in Sweden, Germany and Romania: Chalmers University of Technology, E.ON, City of Malmö, RWTH Aachen University, Flexible Electrische Netze (FEN) Research Campus, University Politehnica of Bucharest, and EnergoBit. The Swedish team focuses on end-user perspectives on energy use in everyday life and the integration of smart grids.

1.4 LIMITATIONS

The research in this thesis was conducted in a Swedish context, focusing mainly on urban areas. Naturally, this limits the extent to which the findings may be generalised to other parts of the world. As explained above, the focus of this thesis is on resource use from a household point of view. The perspectives of other actors relevant to the topic of domestic resource use were beyond the scope of this thesis. Furthermore, in the research projects of which this thesis is a part, the focus was on certain areas of resource use at home. Resource use and the resulting environmental impacts have not been quantified. Rather, the emphasis was on highlighting some interesting aspects of the complex nature of home-related resource use, as well as identifying opportunities for change.

1.5 OUTLINE OF THE THESIS

This thesis is organised as follows. Chapter 2 presents previous research within the two research areas of which this thesis is a part. Chapter 3 describes the theoretical framework that has inspired the research design and analysis of the research findings. Chapter 4 presents my personal background and theoretical perspective, followed by the research approach and methods of the included research studies. A summary of the findings of these studies is then presented in Chapters 5 and 6. A discussion is provided in Chapter 7, followed by conclusions and directions for future work in Chapter 8.

Movable test kitchen used for workshops in the Circular Kitchen project.
Photograph by Svante Örnberg.

2 PATHWAYS TOWARDS SUSTAINABLE RESOURCE USE

This chapter summarises previous research within two areas concerning sustainable resource use. These are circular economy and smart energy systems, and the research in this thesis will build further upon them.

2.1 CIRCULAR ECONOMY

Today, our economy is dominated by a linear model, in which raw materials are extracted and used to manufacture products. These are then sold to and used by consumers, then disposed of when no longer needed. This model causes unnecessary waste, emissions and resource depletion. By contrast, a circular economy 'is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles' (Ellen MacArthur Foundation, 2015, p. 2). Ideally, in a circular economy, waste no longer exists. Non-toxic biological materials are returned to the soil while technical materials are reused and recycled in closed loops. The energy used to power the circular economy should be obtained from renewable sources (Ellen MacArthur Foundation, 2015).

The concept of circular economy integrates features from several theories. As summarised by Geissdoerfer, Savaget, Bocken, & Hultink (2017), 'Some of the most relevant theoretical influences are cradle-to-cradle (McDonough and Braungart, 2002), laws of ecology (Commoner, 1971), looped and performance economy (Stahel, 2010), regenerative design (Lyle, 1994), industrial ecology (Graedel and Allenby, 1995), biomimicry (Benyus, 2002), and the blue economy (Pauli, 2010)' (p. 759), all sharing the idea of closed loops.

According to Ghisellini, Cialani, & Ulgiati (2016), by implementing radically new patterns a circular economy has the potential to achieve improved sustainability and wellbeing in society at minimal material, energy and environmental costs. However, the transition to a circular economy remains at an early stage (Ghisellini et al., 2016).

A first Circular Economy Action Plan was launched by the European Commission in 2015 as part of the European Green Deal – an agenda for sustainable growth (European Commission, 2020). The newest version of this plan proposes actions for such things as making sustainable products the norm in the European Union, making circularity work for people, regions and cities, and ensuring less waste.

Recently, the Swedish government also published a strategy for conversion to a circular economy, comprising four focus areas: (1) circular economy through sustainable production and product design, (2) circular economy through sustainable ways of consuming and using materials, products and services, (3) circular economy through non-toxic and circular cycles, and (4) circular economy as a driving force for business and other actors through measures promoting innovation and circular business models (Regeringskansliet, 2020).

Despite its growing popularity, the circular economy concept is not without its challenges. Korhonen, Honkasalo, & Seppälä (2018) presented six challenge areas that must be addressed if a circular economy is to contribute to environmental sustainability. First of all, recycling requires energy and always generates some waste and by-products, due to the Second Law of Thermodynamics, entropy (Georgescu-Roegen, 1971, as cited in Korhonen et al., 2018). Therefore, reusing, remanufacturing and refurbishing products is more desirable than recycling just for raw-material value (Korhonen et al., 2018), whilst using renewable energy sources in these processes. The second challenge concerns spatial and temporal system boundaries. This involves achieving environmental impact reductions in one part of the system by shifting a problem to another part. Also, extending product lifetimes may cause long-term unsustainability, due to currently unknown negative impacts (Korhonen et al., 2018). Third, economic efficiency increases from the reuse, remanufacturing, and refurbishment of products may cause rebound effects, whereby consumption is boosted due to decreasing product prices. Furthermore, Korhonen et al., (2018) list challenges related to path dependencies and lock-in, governance and management, and the definition of physical flows.

2.1.1 Circular product design

Design plays a key role in facilitating the transition from today's linear 'take-make-dispose' model to a more circular economy (den Hollander, Bakker, & Hultink, 2017; Ellen MacArthur Foundation, 2015). In recent years, various design strategy frameworks have been presented with the aim of guiding designers in developing products and services for a circular economy.

Building on previous work by Stahel (1994, 2010), McDonough & Braungart (2002), and Braungart et al. (2008), Bocken et al. (2016) presented the terminology of slowing, closing, and narrowing resource loops. As the narrowing approach focuses on resource efficiency and reducing the quantity of resources per product, it does not influence the speed of resource flows and could even contribute to further acceleration of linear resource flows. Therefore, Bocken et al. (2016) focus on the other two approaches and present corresponding product design strategies. Slowing

resource loops includes designing long-life products and design for product-life extension. Designing long-life products focuses on increasing the utilisation of products through design for attachment and trust and design for reliability and durability. Design for product-life extension focuses on prolonging the use period of products by introducing service loops. It includes the following strategies: (1) design for ease of maintenance and repair, (2) design for upgradeability and adaptability, (3) design for standardisation and compatibility, and (4) design for disassembly and reassembly. The approach of closing resource loops focuses on facilitating circular flows of materials and includes the following strategies: (1) design for a technological cycle, (2) design for a biological cycle, and (3) design for disassembly and reassembly (as also listed under the slowing-loops approach) (Bocken et al., 2016). They further clarify that combinations of these strategies are possible and that they may support each other. They also acknowledge that understanding the impact of changes in business models and design from a wider perspective makes it essential to apply systems thinking.

Based on a systematic literature review of various design-for-sustainability approaches, Moreno, De los Rios, Rowe, & Charnley (2016) developed a circular design framework including the following design strategies: (1) design for circular supplies, (2) design for resource conservation, (3) design for multiple cycles, (4) design for long-life use of products, and (5) design for systems change. Like Bocken et al. (2016), Moreno et al. (2016) stress the importance of systems thinking in order to progress beyond traditional design processes which follow the current linear economy. However, in an interview study with design professionals, Sumter, de Koning, Bakker, & Balkenende (2020) found no evidence of the systems thinking competency being applied in practice.

Another literature review of sustainable product design, eco-design and circular economy was conducted by den Hollander et al. (2017) as a basis for developing a new typology, which they called 'design for product integrity'. Following the inertia principle introduced by Stahel (2010), den Hollander et al. (2017) define product integrity as 'the extent to which a product remains identical to its original (e.g., as manufactured) state, over time' (p. 519). Design for product integrity involves approaches which resist, postpone, and reverse product obsolescence. Resisting obsolescence includes the strategies of designing for physical as well as emotional durability. This shares similarities with the 'designing long-life products' strategy by Bocken et al. (2016). Postponing obsolescence focuses on enabling extended use of products and includes the strategies of design for maintenance and upgrading. Finally, reversing obsolescence focuses on facilitating recovery and includes the strategies of design for recontextualising, repair, refurbishment, and remanufacture (den Hollander et al., 2017).

However, extended product lifetimes do not necessarily result in lower overall environmental impact. For instance, with the introduction of new, more energy-efficient products, the environmental impact arising from continued use of the former product may exceed the embedded impacts of the new more energy-efficient product, making replacement a better option (Bakker et al., 2014). Therefore, den

Hollander et al. (2017) emphasise the need for product designers to be aware of the environmental consequences of their interventions. They also highlight the inevitable subjectivity connected to determining whether a product has become obsolete or not, which may complicate the selection of design strategies. Furthermore, circular design strategies need to be accompanied by suitable business models (Bocken et al., 2016; den Hollander et al., 2017).

2.1.2 Users in a circular economy

Even if circular design strategies are implemented to prolong the lifespan of a product, ultimately its actual lifecycle depends largely on decisions and actions by its user(s). End-users play a central role in enabling a circular economy because their decisions determine how products are obtained, the extent to which they are used, and what happens to them once they are no longer needed (Selvefors, Rexfelt, Renström, & Strömberg, 2019). Despite this, a majority of the present literature on circular design has focused on technical product aspects rather than how to design products that fit with people's needs, desires, and behavioural patterns (Wastling, Charnley, & Moreno, 2018).

Based on a literature review on consumption in the circular economy, Camacho-Otero, Boks, & Pettersen (2018) conclude that the main part of the existing literature has focused on factors driving and hindering the acceptance of circular solutions, while less attention has been given to issues of how to trigger change on both collective and individual levels to support their diffusion. Furthermore, only a small number of contributions have investigated the integration of user perspectives into the design process (Camacho-Otero et al., 2018).

De los Rios & Charnley (2017) investigated what design skills were necessary to develop products for closed loops. They highlighted the need to understand user expectations and perceptions of value, use experience, and product wear during use. Sumter et al. (2020) identified 'circular user engagement' as one out of seven circular economy competencies for design, explaining that 'the changing relationship with users in a circular economy requires designers working in practice to guide users in the decision-making, use and take-back phase in order to optimally employ certain business models' (p. 12).

Wastling et al. (2018) described a customer's engagement with a product as a three-phase process starting with the point of product acquisition, followed by the use phase, and finally end-of-use, in which the product may be kept, returned to the manufacturer, passed on to someone else, or disposed of. Based on a literature review, case studies, and expert interviews, they developed a framework for designing products and services to encourage 'circular behaviour'. Their model focuses on the use and end-of-use phases and lists key behavioural targets, distinguishing between user ownership and provider ownership of products.

Selvefors et al. (2019) introduced a user-centric perspective on product circularity, in which focus is shifted from issues of production and business models to people's consumption processes. Like Wastling et al. (2018), they divide the consumption

process into three phases, which they call *obtainment, use,* and *riddance.* With product exchange rather than resource recovery in focus, they highlight the following possibilities for reducing resource consumption: 'users can obtain pre-used products from other users instead of buying new products', 'users can avoid disposing of products as trash by passing them on to other users', and 'users can increase product utilisation by passing on unused products to other users' (Selvefors et al., 2019, p. 1016). From this perspective, they outline four design strategies aimed at supporting the development of products and services for circular consumption: design for extended use, design for pre and post-use, design for exchange, and design for multiple use-cycles (Selvefors et al., 2019).

2.2 SMART ENERGY SYSTEMS

The transition from traditional energy systems based largely on fossil fuels and nuclear power to 100% renewable energy systems poses the challenge of integrating a more fluctuating energy supply (Lund, Østergaard, Connolly, & Mathiesen, 2017; Mathiesen et al., 2015). This requires substantial changes in the current energy infrastructures (Lund, 2014), concerning both the generation and consumption side (Mathiesen et al., 2015). Smart energy systems, which incorporate information and communication technologies (ICT) and merge the electricity, heating and transport sectors, have been proposed as a key approach to achieving this transition (Mathiesen et al., 2015). A smart energy system involves the following infrastructures: smart electricity grids, smart thermal grids (district heating and cooling), and smart gas grids (Lund, 2014; Mathiesen et al., 2015). The research presented in this thesis focuses on smart thermal grids and, more specifically, on district heating in multi-residential buildings.

To better match the demand to the available energy supply and achieve greater energy flexibility in buildings, demand-side management strategies have been made the centre of attention. These involve reducing energy use during peak hours (peak shaving), shifting energy use from critical to more favourable periods (load shifting), and increasing energy use during off-peak hours (valley filling) (Reynders et al., 2018).

Demand-side management may be enabled by using home energy management technologies. These have been defined as technologies which 'enable households to manage their energy consumption by providing information about how they use energy and/or by allowing them (or third parties) to control energy consumption in the home' (Ford, Karlin, Sanguinetti, Nersesyan, & Pritoni, 2016, p. 9). Home energy management systems (HEMS) typically include user interfaces, such as energy monitors, smart hardware (including smart plugs, appliances, and thermostats), and software platforms providing data analytics. However, they may also involve electric vehicles, solar panels, and battery storage (McIlvennie, Sanguinetti, & Pritoni, 2020). In a meta-review of research into smart home energy management technologies, McIlvennie et al. (2020) found a dominant focus on technology-centred solutions, while users were often described as passive actors within the system. Also, third-party actors, such as organisations involved in the installation and/or control of the

smart technologies, were mainly portrayed in a passive role through the implementation of dynamic pricing. Often, they were not identified at all.

Furthermore, the environmental benefits of smart home technologies have been questioned (Darby, 2018; Herrero, Nicholls, & Strengers, 2018), with indications that home automation devices might even contribute to increased energy use due to the promotion of more energy-intensive lifestyle visions and expectations of comfort (Strengers, Hazas, Nicholls, Kjeldskov, & Skov, 2020).

Several researchers have highlighted the need to better understand users of smart home technologies (Wilson, Hargreaves, & Hauxwell-Baldwin, 2015) as well as the concept of home (Gram-Hanssen & Darby, 2018). To provide energy flexibility in heating, it has been recognised that deeper insights are needed regarding households' everyday heating practices (Andersen et al., 2019) and to what extent they may accept external control of the indoor climate (Larsen & Johra, 2019). According to Schot, Kanger, & Verbong (2016), users play a crucial role in initiating, accelerating, and stabilising the transition to new energy systems.

2.2.1 Demand-side management & thermal comfort

To date, the potential for achieving greater flexibility in the heating demand of residential buildings connected to district heating has been explored in a relatively small number of research studies. One study by Kärkkäinen et al. (2004), examining two concrete buildings in Finland, indicated that the heat load could be lowered by 20–25% for a period of 2–3 hours, with a resulting temperature variation of up to 2°C. Wernstedt, Davidsson, & Johansson (2007) managed to reduce total energy consumption by 4% in an area of 14 multi-residential buildings connected to a district heating network in Sweden, with no detected reductions in measured indoor temperature. However, depending on building characteristics, the authors estimated that energy savings of more than 10% would be possible with the installed agent system. Kensby, Trüschel, & Dalenbäck (2015) investigated the thermal energy storage potential of five multi-residential buildings in Sweden by introducing multiple cycles of charging and discharging. Their findings imply that temperature variations of less than ±0.5°C are achievable with heat storage of 0.1 kW h/m^2 in a heavy building. Christensen, Li, & Pinson (2020) demonstrated (in a multi-residential building in Denmark) that peak-hour energy use could be lowered by 85%, with minor impact on indoor temperature and total energy consumption levels.

In two recent studies by Sweetnam, Spataru, Barrett, & Carter (2019) and Larsen & Johra (2019), a stronger emphasis was placed on residents' experiences and practices concerning heating control. Sweetnam et al. (2019) conducted a demand shifting field trial including 28 homes of different typologies in the United Kingdom, resulting in an improvement of the load factor from 0.29 to 0.44 and a slight increase of 3% in energy demand. Although the demand shaping caused only minor alterations in indoor temperature, the participant feedback raised some concerns. This highlights the importance of providing information to the residents regarding how the heating system operates, what they can do to maintain their comfort, and

what benefits their participation brings (Sweetnam et al., 2019). In a qualitative study comprising 16 Danish homes of different typologies, Larsen & Johra (2019) found that smart home technologies contributed to convenience in controlling the indoor temperature, whilst giving rise to higher temperature setpoints and comfort requirements. The challenge of increasing comfort expectations has also been highlighted by Strengers (2008), who maintains that comfort expectations are flexible and constantly evolving through such things as the introduction of new technologies, infrastructures, and regulations.

In the study by Larsen & Johra (2019), other potential challenges to increasing flexibility in heating demand were found in practices, such as opening windows, and preferences, such as having a cold bedroom. Furthermore, the study revealed scepticism among the participants regarding operating the feature of increased heating flexibility themselves. Provided it had no negative impact on their comfort, they preferred this to be managed either automatically or by a third party (Larsen & Johra, 2019).

By analysing heat-related practices in Danish households living in detached single-family houses, Hansen, Gram-Hanssen, & Knudsen (2018) found that households in more energy-efficient homes tended to maintain higher indoor temperatures than others. Regardless of the energy efficiency of the houses, they also found that residents with higher education and women tended to wear warmer clothing during winter. Furthermore, the practice of adjusting thermostats was carried out most often by residents with higher education, residents with a partner, and residents who were immigrants or descendants of immigrants. In the same study, Hansen, Madsen, Knudsen, & Gram-Hanssen (2019) found that having a comfortable home indoor environment was more highly valued by women and older residents than other groups. This was further connected to greater amounts of energy used for space heating.

In a survey study in the Netherlands, Guerra Santin (2011) found that seniors tended to maintain higher temperatures at home for longer periods than other user groups. Despite this, the energy consumption of seniors was generally lower than that of families and high-income couples. In families, the higher energy use levels were related to the need for more space and greater use of heavy appliances, while high-income couples were less concerned about their energy use and tended to want convenience at home. Singles and low-income couples were the two groups with the lowest energy consumption. This may be explained by their behaviour being less related to the intensive use of appliances and space as well as temperature comfort.

3 THEORETICAL FRAMEWORK

This chapter describes the theoretical framework that has inspired both the research design and the analysis of the research findings presented in this thesis. Social practice theory and practice-oriented design were chosen because they are useful for understanding the dynamics of resource use and identifying opportunities for change.

3.1 SOCIAL PRACTICE THEORY

One approach to understanding households' resource use, originating in social science, is social practice theory. Practice theory has been proposed as a relevant approach to understanding the 'multiple dynamics of everyday life' (Shove, Pantzar, & Watson, 2012) and for envisioning change beyond the status quo (Kuijer & Bakker, 2015). Furthermore, it has been argued that a practice theory approach supports closer scrutiny of the everyday routines through which people commit to environmentally damaging lifestyles (Hoolohan & Browne, 2020).

Practices are activities in everyday life in which many people engage, following collectively shared ideas about what is desirable and acceptable (Pettersen, 2016). According to Reckwitz (2002), a practice may be understood as 'a routinised type of behaviour which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, "things" and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge'. Individuals are seen as 'carriers' of practices; carrying patterns of bodily behaviour as well as 'routinised ways of understanding, knowing how and desiring' (Reckwitz, 2002, p. 250). Such mental activities are thereby regarded not as individual attributes but as 'necessary elements and qualities of a practice in which the single individual participates' (Reckwitz, 2002, p. 250). Furthermore, practices are social, meaning that they are carried out at different times and places by different 'bodies and minds' (Reckwitz, 2002), or different individuals. This does not mean that a practice necessarily involves any interaction between people.

3.1.1 Elements of practices

Several researchers have proposed various categorisations of elements that, when linked together, form a practice. An overview is given by Gram-Hanssen (2011). One aspect that gives rise to certain disagreement among practice theorists is what role material objects and technologies play in practices (Gram-Hanssen, 2011; Kuijer, 2014). Gram-Hanssen (2011) argues that technologies are an essential element in holding practices together and in contributing to changes within practices. In her empirical study of households' energy use, she summarises the following four elements of practices as most relevant: (1) know-how and embodied habits, (2) institutionalised knowledge and explicit rules, (3) engagements, and (4) technologies (Gram-Hanssen, 2011).

Based on the classification introduced by Reckwitz (2002), Shove and colleagues has developed a simplified version including only three elements: *materials*, *competences,* and *meanings*, sometimes alternatively phrased as *stuff, skills,* and *images* (cf. Shove & Pantzar, 2005; Shove et al., 2012). This model has been widely adopted in design research (cf. Kuijer, 2014; Scott, Bakker, & Quist, 2012) and will be used in this thesis.

Materials (or stuff) include objects, technologies, tools, infrastructures, materials from which objects are made, and even the body itself (Shove et al., 2012). Competences (or skills) refer to multiple forms of understanding and practical knowledge; these include know-how, technique, and shared understandings of what is good or appropriate. Meanings (or images) include mental activities, emotion, and motivational knowledge representing 'the social and symbolic significance of participation at any one moment' (Shove et al., 2012, p. 24).

The elements are influenced and shaped by each other, with some overlap between the categories (Kuijer, 2014). Of equal importance to the elements themselves are also their links. Kuijer (2014) has further developed the images-skills-stuff model by picturing the elements as groupings of elements and the connections between them as a multitude of links.

3.1.2 Dynamics of practices

When speaking about practices, a distinction is made between 'practices-as-entity' and 'practices-as-performance' (Kuijer, 2014, based on Schatzki, 1996). Practice-as-entity represents a guiding structure, containing all elements and links that together form the practice and make it recognisable as such (Kuijer, 2014). Practice-as-performance, on the other hand, is the moment of doing in which a specific combination of elements is integrated into a specific situation. This may be slightly different each time the practice is carried out. Practice-as-entity is thereby formed through a variety of performances through which it becomes gradually established over time and upon which its ongoing existence depends (see Figure 3.1). For instance, the practice of cooking may vary significantly in performances depending on the food, occasion, setting, skill level of the practitioner, appliances and utensils

used for that specific dish, and so on. Still, cooking (as entity) is recognised as one practice which may involve many different elements.

According to Warde (2005), practices 'have some considerable inertia', although they simultaneously 'contain the seeds of constant change' (p. 140-141). Adaptation, improvisation and experimentation by people in various situations contribute to the dynamic nature of practices (Warde, 2005). Shove et al. (2012) maintains that 'practices emerge, persist and disappear as connections between defining elements are made and broken' (p. 35) and that 'practices change when new elements are introduced or when existing elements are combined in new ways' (p. 87). Thus, the elements have 'histories and futures of their own' and are transformed through their integration into practices (Pantzar & Shove, 2010, p. 450). In everyday life, people take part in various practices and, sometimes, these have one or more elements in common. Thus, as one practice changes, there is a chance that another will be affected, due to their shared element(s) (Gram-Hanssen, 2011).

According to Kuijer (2014), some elements and links may be more central in a practice than others (for instance, when they are present in multiple performances). Additionally, some links may be more difficult to break than others.

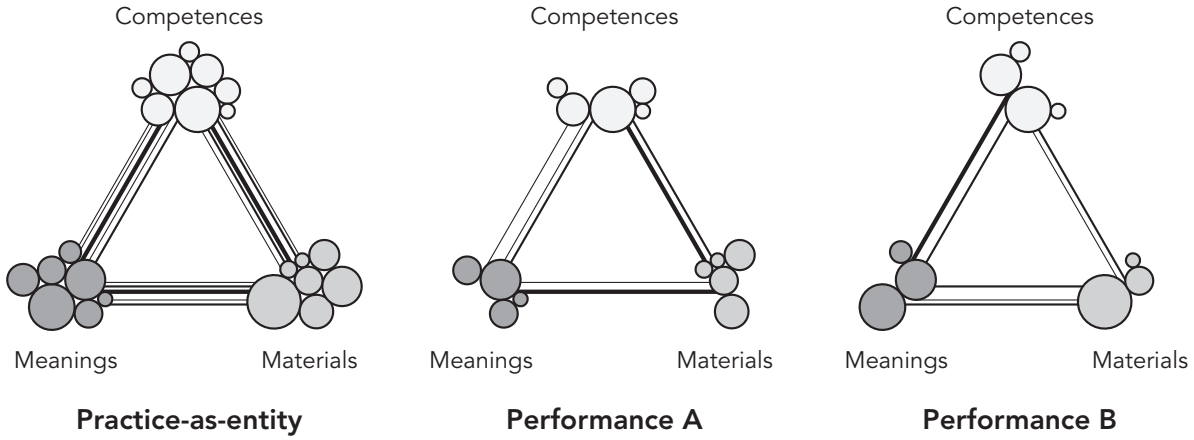


Figure 3.1. *The practice-as-entity is the sum of a variety of performances, each of which integrates a different set of elements and links (adapted from Kuijer, 2014, p. 53).*

3.2 PRACTICE-ORIENTED DESIGN

According to practice theory, consumption of resources rarely occurs for its own sake, but 'within and for the sake of practices' (Warde, 2005). A practice theory perspective enables the targeting of consumption levels by questioning what is taken for granted and by introducing sufficiency goals (Pettersen, 2016). According to Kuijer (2014), the central question of a practice-oriented design process is 'what could be less resource intensive reconfigurations that work?' (p. 95).

Pantzar & Shove (2010) define innovation in practice as the making and breaking of links; that is, new combinations of elements. Although practices are carried out by individuals in specific situations, innovations within practices are always a collective achievement and a continuous process (Pantzar & Shove, 2010). In practice-oriented

design, users or practitioners largely become active participants in the design process. Thus, this approach shares similarities with the concept of co-creation (Scott et al., 2012).

Kuijer (2014) has proposed a practice-oriented design approach, divided into two models: one that takes practices as a unit of *analysis* and one that takes them as a unit of *design*. When a target practice has been selected as a unit of analysis, Kuijer (2014) suggests that the first step (as a basis for determining a target level) is to gain an overview of the resource consumption levels connected to the target practice, including current averages, extreme values, and past consumption levels. This is important because, if no target level is defined, or if it is set too close to the current average level, it is unlikely that anything more than incremental reductions will be achieved (Kuijer, 2014). The following steps include tracking the historic development of the practice, exploring similar practices, analysing the target practice by mapping configurations of elements in relation to resource use and, finally, identifying opportunities and directions for change. The second model – taking practices as a unit of design – moves from identified opportunities for change to reconfigurations that work through the iterative process of: suggesting and triggering, facilitating performances, and combining, refining and evaluating (Kuijer, 2014).

Based on previous research from Pantzar & Shove (2010), Shove et al. (2012) and Pettersen (2013), regarding how to foster change in less resource-intensive directions, Pettersen (2015) suggests four targets for design: (1) 'the circulation and promotion of practice elements and links', (2) 'the composition and performance of practice', (3) 'how different practices relate', and (4) 'how the careers of practice and practitioners develop over time' (p. 209-210). Pettersen (2015) states in summary that 'taking the social practice as a unit of analysis may help designers understand the dynamics of consumption, by pointing their attention to the composition, performance and development of practices in space and time' (p. 210). This, in turn, may help identify opportunities to overcome inertia and resistance to change.

As noted previously, changes in one practice may also affect others. This, in turn, may lead to load shifts in consumption, making it reasonable to zoom out and address changes on the household level rather than just changes of individual practices (Pettersen, 2016). When introducing interventions aimed at changing practices, it is important that an assessment of their effects is conducted over a long period (Pettersen, 2016).

Vitvaror

Vilka vitvaror har ni i ert kök? Ringa in de ni har och skriv ned ifall ni har någon annan apparat som inte finns med bland symbolerna.

kombinerad kyl och frys
ELLER
separat kylskåp
separat frys
diskmaskin
disk

kombinerad ugn och spis
ELLER
separat ugn
separat spis
mikrovågsugn

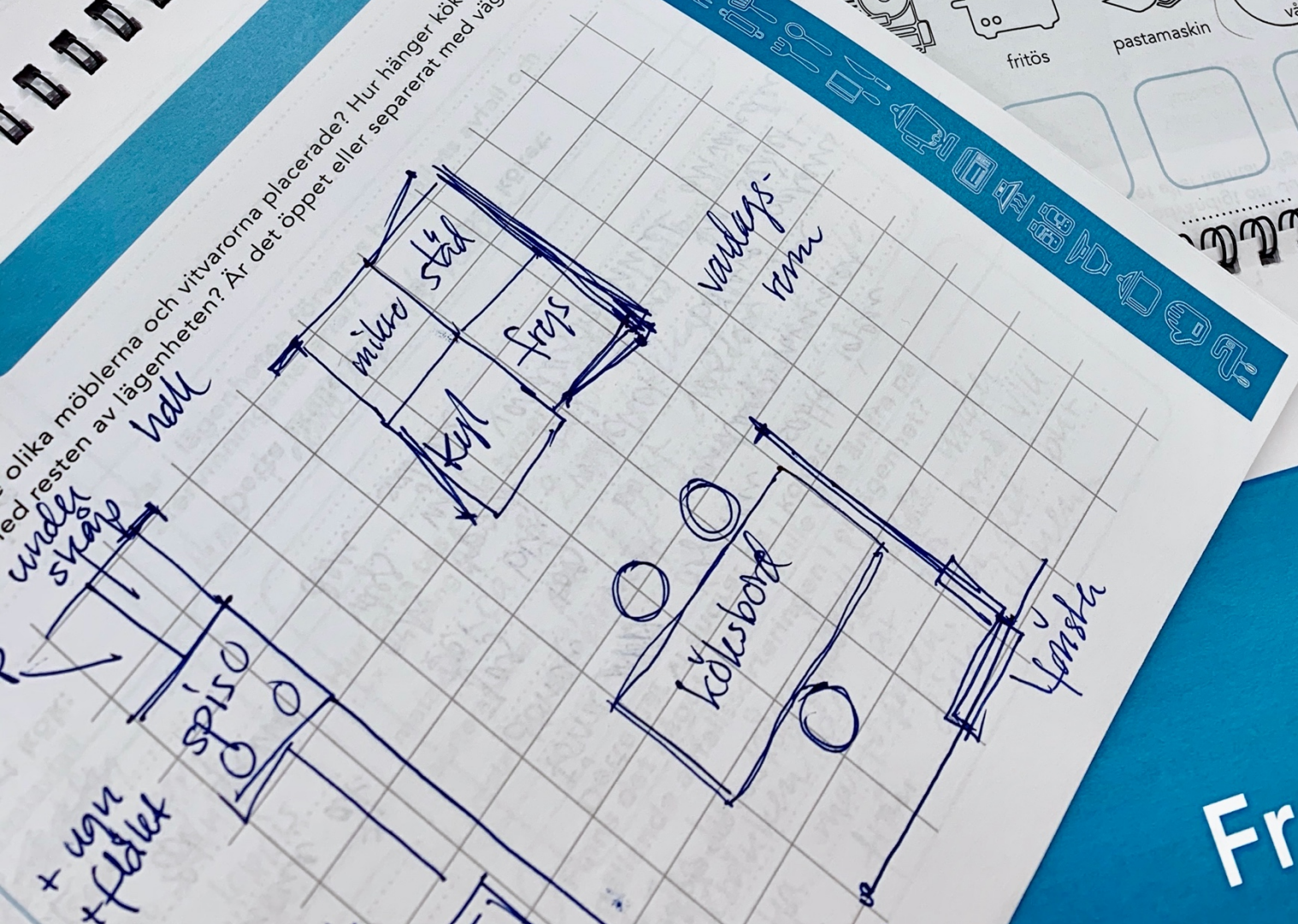
Köksapparater

Vilka köksapparater har ni i ert kök? Ringa in de ni har och skriv ned ifall ni har någon annan apparat som inte finns med bland symbolerna.

vattenkokare
elvisp
stavmixer
glasmaskin
mixer
smörgåsgrill
våffeljärn
brödmaskin
popcorn-maskin
fritös
pastamaskin
våg

Vårt kök

olika möblerna och vitvarorna placerade? Hur hänger köket ihop
ed resten av lägenheten? Är det öppet eller separerat med väggar?



Dag 1

datum

När användes köket? t.ex. 07:30 - 08:10	Vem använde köket? t.ex. Person 1, 2...	Vad gjorde du? t.ex. laga mat, diska, laga se... äta, spela, sov...
8:30 - 9:00	PERSON 1	ÄTA
—	—	FYLLER I DENNA BROSCHYR
		LÄGAR OCH ÄTER LUNCH SEN
MORGON		
		KVÄLL

4 RESEARCH APPROACH & METHODS

This chapter starts with a brief introduction of my personal background and a description of how my research is positioned, relative to other theoretical perspectives. The succeeding section outlines the design of the research studies included in this thesis. The chapter ends with a discussion of the research approach and methods.

4.1 PERSONAL BACKGROUND & THEORETICAL PERSPECTIVE

The main motivations behind my decision to enrol in the Industrial Design Engineering programme at Chalmers University of Technology were curiosity about product development and a wish to use creativity professionally. With a strong emphasis on the people who use products to fulfil needs or achieve goals in various contexts, this programme caught my interest and, through various projects, challenged me to design solutions which might contribute to better working environments and more sustainable everyday lives. These studies provided a deeper understanding of the environmental problems faced by people and which are fuelled, to varying degrees, by product development. Determined to be part of the solution rather than the problem, I profiled my education towards design for sustainability. This involved taking several courses within the Industrial Ecology Master's programme. Ultimately, I aspired to somehow contribute to a healthier planet. That determined my choice of doing a PhD in design for a circular economy and sustainable energy systems.

'Sustainability' is a term so widely used today and with different meanings connected to it, that I find it important to describe my personal viewpoint on sustainability. A widely cited definition of sustainable development was introduced in the 'Brundtland Report', entitled 'Our Common Future' from the World Commission on Environment and Development (1987): 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (p. 41). Although I find this definition to be a relevant and useful aspiration overall, it also suggests that the value of nature

lies mainly in the value it can provide to humans. My standpoint is that nature also has value in itself. Along the spectrum of opposing perspectives, with *anthropocentrism* on one side (in which nature only has instrumental value) and *ecocentrism* on the other (in which whole ecosystems are considered to have moral standing) (Hedenus, Persson, & Sprei, 2018), I therefore find my standpoint closer to *ecocentrism*. Another pair of opposing perspectives on sustainability concerns the extent to which natural capital may be replaced by goods and services produced by humans (Hedenus et al., 2018). In this regard, my standpoint is one of *low substitutability*. This holds that natural capital should be protected and kept as intact as possible.

The following is a description of the philosophical assumptions that influence my research approach. Burrell & Morgan (1979) describe four strands of debate regarding the nature of social science. First, assumptions of an *ontological nature* concerns whether reality is of an objective nature and external to the individual *(realism),* or the product of individual consciousness *(nominalism)*. My position is somewhere in between; I believe social reality to be neither completely external to the individual nor completely the product of one's mind. Second, assumptions of an *epistemological* nature concern how knowledge may be generated and communicated. In this debate, my standpoint is closer to the *anti-positivist* side, meaning that the social world is best understood from the inside perspective of individuals. The third debate concerns assumptions about *human nature*. At one extreme, human beings and their actions are completely determined by the context in which they exist *(determinism)*. At the other extreme, humans are completely autonomous and free-willed *(voluntarism)*. On this spectrum, my position lies closer to the voluntarist perspective. Finally, in the *methodological* debate, I mainly follow an *ideographic* approach, which stresses the importance of obtaining first-hand knowledge of the subject under investigation and understanding that subject's characteristics and background. However, my research also contains elements of a *nomothetic* approach; through the use of surveys to collect quantitative data, for example.

4.2 RESEARCH DESIGN

The research in this thesis is positioned within the discipline of design research and builds on empirical data from two field studies, both of which explore opportunities for more sustainable resource use at home. The ambition has been to generate knowledge of value to the research community as well as in design practice.

Design research includes studies of people, processes and products (Cross, 2006) and may be divided into the three following categories: *research on design, research for design* and *research through design* (Forlizzi, Stolterman, & Zimmerman, 2009). The research approach of the included studies falls mainly into the category of research for design which, according to Forlizzi et al. (2009), involves 'design implications arising from the investigation of people and contexts […] and the analysis of designed artefacts' (p. 2892).

An overview of the two research studies appears in Table 4.1, followed by detailed descriptions of their execution in Sections 4.2.1 and 4.2.2.

Table 4.1. Overview of studies included in the thesis.

Study	RQ	Aim	Type	Methods	Output
Study A	1 & 2	Explore households' resource use in the kitchen and typical motivations behind kitchen renovations Identify design strategies which may enable circular consumption in and around domestic kitchens, concerning products and resource flows in the kitchen	Field study	20 semi-structured interviews, 26 participants Focus group, 6 participants Kitchen diary, 10 participants	Paper A
Study B	3 (& 1)	Explore perceptions of thermal comfort and acceptance of demand-side management in rental apartment space heating from a household perspective	Field study	Initial survey, 93 participants Diary study, 48 participants Closing survey, 72 participants	Paper B

4.2.1 Study A: exploring kitchen resource use and potential for circular consumption

Study A aimed to understand how kitchens are used and transformed in a variety of different households and dwellings. Through interviews and focus groups, complemented by a kitchen diary or short survey, this study investigated how the daily use of resources in the kitchen is influenced by its design. Furthermore, the study explored reasons behind kitchen renovations and identified design strategies which could contribute to more circular patterns of consumption within the kitchen and of the products that make up the kitchen itself.

As a start, participants in Study A were recruited from one housing association in Gothenburg. This housing association was selected partly because of its connection to the CIK research project (through both the housing company and the kitchen producer delivering the original kitchen furniture) and partly because of interest expressed in the research. A kitchen diary was sent out in November 2018 to all households in the housing association. In this diary, the occupants were asked to answer simple questions about their households and kitchens, and to log all activities taking place in their kitchen for one week. Apart from collecting information about daily kitchen use, the purpose of the diary was to trigger the households' thoughts about the kitchen before they were invited to the next part of the study, a focus group. This was held in a common room belonging to the housing association. Participants were invited via the housing association's newsletter as well as via

posters in all entrances of the two buildings. In total, ten households completed the kitchen diary and six individuals participated in the focus group.

Prior to the focus group, a protocol was prepared with a set of questions under the topics of: (1) everyday kitchen activities, (2) resource use in the kitchen, (3) desired or implemented changes in the kitchen, and (4) thoughts about future kitchens. The focus group was semi-structured in nature, leaving space for discussions and follow-up questions. Three researchers organised the focus group. One moderated the session while the other two provided support by adding clarifying questions and taking notes and pictures during the session. The focus group took two and-a-half hours in total, with a break in the middle for light food and snacks. The language used in the focus group was Swedish and audio of the whole session was recorded, with permission from the participants.

To recruit more participants, additional channels were used to reach out to households under different tenures. An advertisement was posted on social media and in the newsletter of a housing company, while participants were simultaneously recruited via personal contacts and snowballing. Households who had recently renovated their kitchens were targeted but this was not a criterion for inclusion. In total, these recruitment methods generated 20 additional households, who were interviewed in their homes or via telephone/Skype. In some cases, the registered participant's partner joined the interview, which resulted in a total of 26 interview participants. They represented a variety of household constellations and tenures, from single households in rental apartments to families living in detached houses.

The interviews had a similar setup to the focus group, including the same topics as described above and starting with a few questions regarding general thoughts on the kitchen. The interviews were semi-structured, which gave freedom to adjust the order of the questions and add questions depending on which aspects of each specific case were found to be of interest. The interviews lasted between 30 and 90 minutes. All interviews were held in Swedish and audio was recorded with the participants' permission.

The focus group session and interviews were transcribed and imported to NVivo 12, where the content was thematically coded. Inspired by the approach suggested by Gioia, Corley, & Hamilton (2013), the analysis was carried out in stages: The first-order analysis stayed close to terms used by the informants in the labelling of codes, while less emphasis was placed on categorising them. The second-order analysis then focused on searching for emerging concepts and themes, which in turn were divided into aggregate dimensions. Two researchers shared the work of coding the transcribed material and discussing the findings. The coding was reviewed and partly iterated to avoid missing out on interesting information in the data. A few illustrative quotes were selected and translated into English.

4.2.2 Study B: exploring thermal comfort and perceptions of demand-side management

Study B investigated the thermal perceptions of households living in multi-residential buildings in Malmö, during a two-week trial conducted in November and December 2019. The aim was to develop a better understanding of thermal comfort at home and the acceptance of centrally controlled load shifting in space heating.

The study consisted of three phases: (1) registration and initial survey, (2) a two-week trial, in which the participants used a diary tool to report on their temperature perception, while load shifts were applied in selected buildings, and (3) closing survey aimed at comparing opinions (after the trial) on thermal comfort and energy use at home with results from the initial survey.

All participants were divided into four groups: (A) residents of buildings with power control who received notifications of planned load shifts, (B) residents of buildings with power control but no notifications, (C) residents of buildings with neither power control nor notifications, and (AC) residents of buildings without power control but with false notifications about planned load shifts.

Participants were recruited from 84 buildings, owned by the municipal housing company and connected to a Customer Energy and System Optimisation (CESO) system managed by the local energy provider. The CESO system uses the natural thermal inertia of the buildings to enable load shifting during short periods, to reduce peak generation in the district heating system. Demand-side management during the trial followed a predetermined control scheme including several load shifts of between 0.5 and 3 hours. Indoor temperatures were allowed to change by ±0.5°C.

Information flyers were distributed to residents' post boxes and posters were placed in the building entrances a couple of weeks before the trial. The printed material encouraged residents to sign up for the study via a web link and promised cinema tickets to those participants who completed the study. In total, 93 residents from 33 buildings registered and completed the initial survey, 48 of them participated in the following diary study during the trial, and 72 responded to the closing survey.

During the trial, participants could report on their perception of the indoor temperature at any time of the day using either a digital (web-based) diary tool or a paper diary. Both options included the same set of questions, to make the results from both data collection tools comparable. The digital diary enabled participants to report on their temperature perception, either as it was happening or in the form of a daily summary at the end of the day. Every evening of the trial period at 8 pm, a reminder to make a daily summary was sent out to all participants who had not yet reported on their temperature perception that day in the digital diary. Figures 4.1 and 4.2 illustrate the two diary tools.

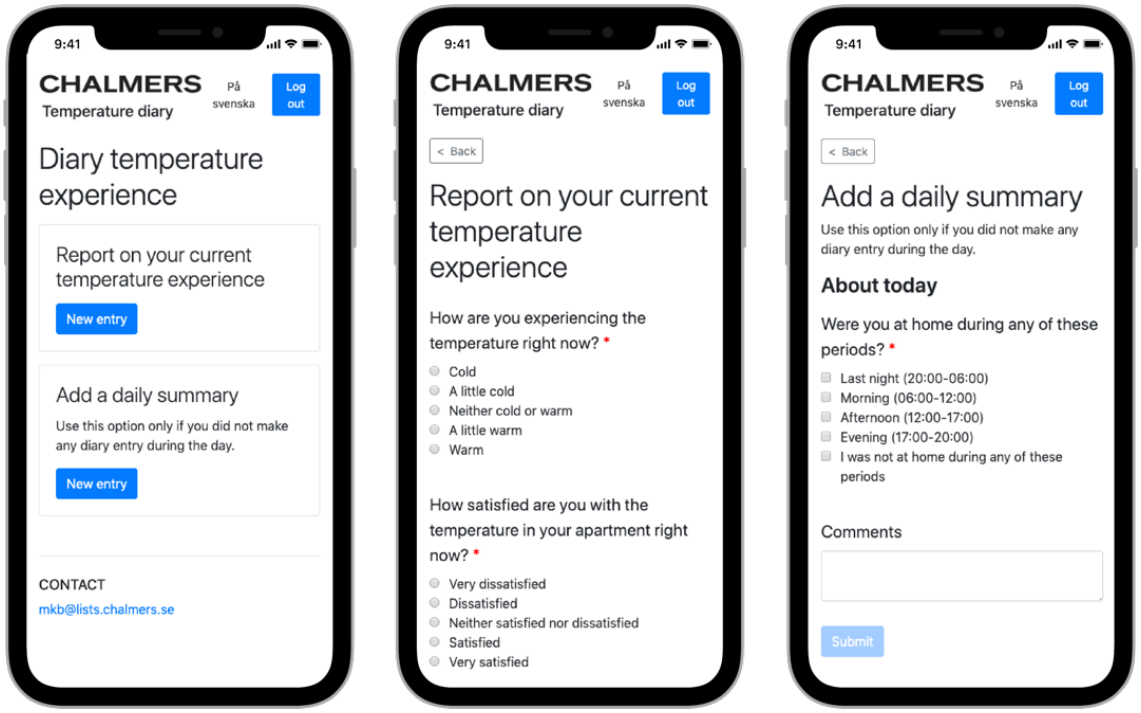


Figure 4.1. *Digital diary for reporting on current temperature perception or submitting a daily summary.*

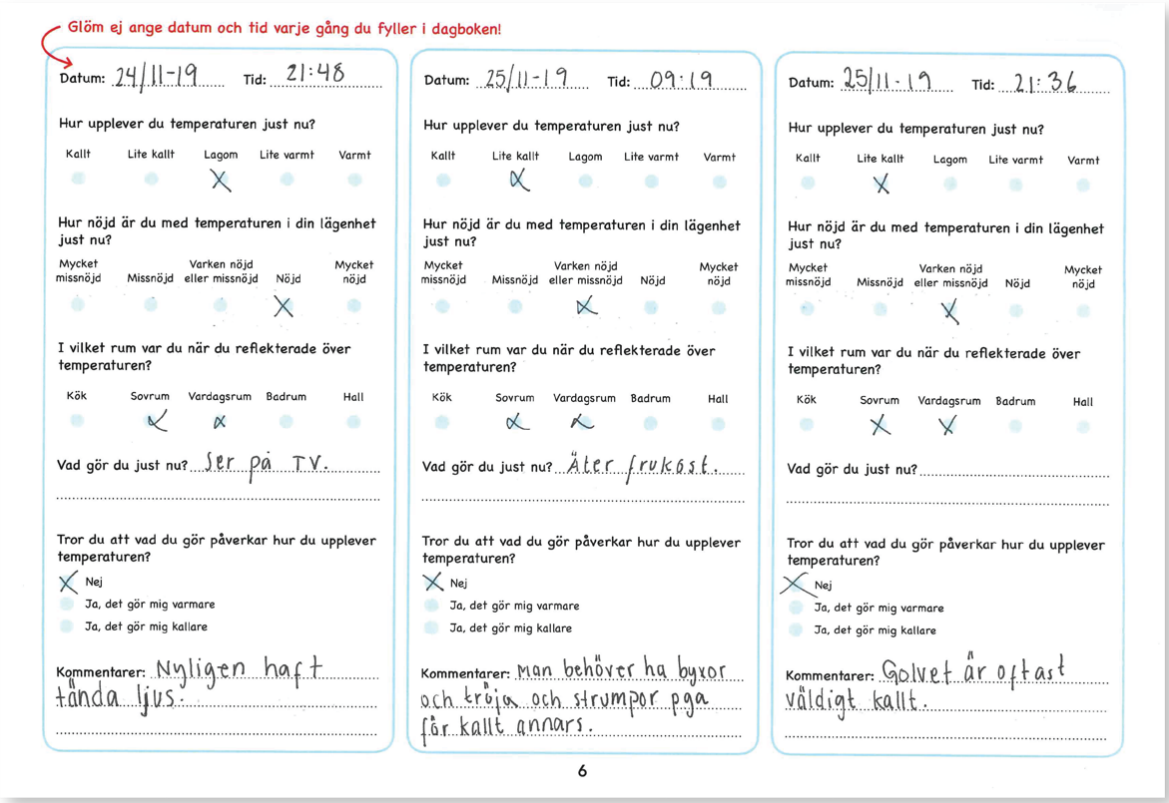


Figure 4.2. *Paper diary for reporting temperature perception.*

The diary study resulted in a total of 803 diary entries. Data from the diaries and surveys were analysed (alongside data on indoor temperatures and outdoor weather conditions) in Microsoft Excel and IBM SPSS Statistics using Wilcoxon signed-rank tests, Mann-Whitney U tests, correlation analysis and regression analysis. Qualitative data from the surveys and diary entries in the form of comments were thematically categorised and summarised to complement the quantitative data. A few illustrative comments were picked out and translated to English, if originally written in Swedish.

4.3 REFLECTIONS ON RESEARCH APPROACH & METHODS

Studies A and B share similarities and differences in their research approach and methods. The following sections will discuss the research design, sampling, data collection, analysis, validity, and generalisation of the two studies.

4.3.1 Research design

Study A may be described as a case study, with each household interviewed about kitchen use and renovation practices representing one case. This research design enabled collection of detailed descriptions about the processes, motivations, complexities and so on connected to the focus area for the selected cases. However, case studies are limited in that findings are difficult to generalise (Flick, 2018). Since Study A collected opinions and descriptions about the pre and post-renovation states of the households' kitchens, it maintains some features of both snapshot studies and retrospective studies (as described by Flick, 2018).

Study B may be referred to as a combination of a snapshot study and a longitudinal study, as described by Flick (2018). This is because it analysed temperature perception and satisfaction over two weeks, comparing the results before and after an intervention (load shifting) was introduced. The diary tools applied during the trial allowed instant snapshots of how the participants currently perceived their indoor temperature, while the two surveys distributed before and after the trial enabled comparison over time, albeit over a short period. A longer perspective might have contributed more visible differences and more reliable results.

Triangulation

Triangulation means that the issue under study is approached from different perspectives, which helps strengthen the quality of research (Flick, 2018). In both studies A and B, several types of triangulation were applied. First, they combined at least two different methods of collecting data, which may be referred to as *methodological triangulation* (Denzin, 1989, as cited in Flick, 2018). According to Eisenhardt (1989), multiple data collection methods allow deeper understanding, plus identification of relationships and prevention of false conclusions. Ideally, both qualitative and quantitative methods should be combined (Eisenhardt, 1989).

However, the different methods must be used in a way that adds something new to the data collection rather than just 'more of the same' (Flick, 2018, pp. 195).

Although Study B was mainly quantitative; it also involved some qualitative data collection in the form of open comments that provided deeper insights into participants' experiences and opinions regarding their indoor climate at home. Study A was a predominantly qualitative study but might have benefitted from additional quantitative data on kitchen use and renovation practices from a larger sample, to allow better generalisability.

Furthermore, both studies A and B used *data triangulation*, which involves investigating phenomena at different times and places and involving different people (Denzin, 1989, as cited in Flick, 2018). Study A also included *investigator triangulation*, meaning that several researchers took part in the data collection and analysis to compare findings and avoid biases.

4.3.2 Sampling

Study A involved step-by-step sampling. Initially, the plan was to recruit several housing associations in different areas of Gothenburg connected to the housing company and the kitchen producer involved in the CIK research project. As it was, few cases met these criteria and interest in participating was low. Thus, the research team began using other ways of reaching out to households; social media and newsletter ads, personal contacts, and snowball sampling, seeking interesting cases to cover a range of different renovation strategies and household configurations. As in grounded theory, the sample size was determined by the point at which saturation was reached, rather than trying to achieve demographic representation (Flick, 2018).

In Study B, the sampling was focused more on gathering breadth than depth. It aimed to recruit a large number of residents of varying demographics living in rental apartments connected to the heating control system managed by the local energy provider. However, the recruitment process was limited because the researchers were not allowed to contact the residents personally and the residents could only be reached via printed material. This generated a low response rate, which might have been improved upon, had it been possible to contact the residents more directly (by email, for example).

4.3.3 Data collection

The main method of data collection in Study A was semi-structured interviews. This method aims to collect rich, detailed information through open-ended questions, with the questions and their order adapted to the flow of each interview (Rubin & Rubin, 2012, as cited in Flick, 2018). Study A also included a focus group; a group discussion around an issue in which attention focuses on group interaction. According to Flick (2018), a principal advantage of focus groups is that they encourage dynamics in discussions, which adds to the knowledge generation in the data collection. However, focus groups are less suitable for in-depth analysis of

individual experiences. The two methods therefore complemented each other well. Additionally, some of the individual household interviews were conducted as group interviews with two household members. This allowed interviewees to build further on each other's thoughts and ideas and to express agreement or disagreement. This gave deeper insights into how kitchen use and renovations were perceived within the household.

Surveys were used in both studies; in Study A, only for collecting demographic data about the participants and in Study B as one of the main data collection methods. Finally, both studies used diaries, which enabled the collection of data at the particular moments of interest, for instance when the participants of Study A used the kitchen and when participants of Study B thought about their indoor temperature. In Study A, the diary also aimed to trigger reflections on the kitchen before the participants took part in the focus group. An interesting methodological finding in Study B was the revelation that, on average, participants who used the paper diary option instead of the digital diary tool, contributed more diary entries per person during the trial.

4.3.4 Analysis

The procedure for analysing the qualitative data in Study A, which mainly followed the 'Gioia methodology' (Gioia et al., 2013), ensured that categories were not created too early and with overly general labels. This also made it easy to find specific statements later on in the created tree of themes. The two researchers coding the data divided the work instead of coding everything twice. However, due to their regular discussions, adjustments to the coding structure, and partly iterating the process, they were able to gain a good overview of the data and agree on the structure. That said, it was not possible to report intercoder agreement rates. However, as per Gioia et al. (2013), this calculation was not considered a necessary step, because 'data structuring procedures themselves lend the requisite rigor to the analyses' (p. 22).

In Study B, the statistical analyses carried out mostly combined data from several data collection methods. In other words, diary entries in the digital diary and paper diary, plus daily summary entries in the digital diary. Although the number of diary entries per person varied, the analysis was based on the total number of entries and not the number of participants. This may have skewed the results. The analysis of the survey responses, however, gave equal representation to all participants as they all contributed one answer to each question. Even so, in many cases, the number of participants was too low to present any significant differences in responses from the different participant groups.

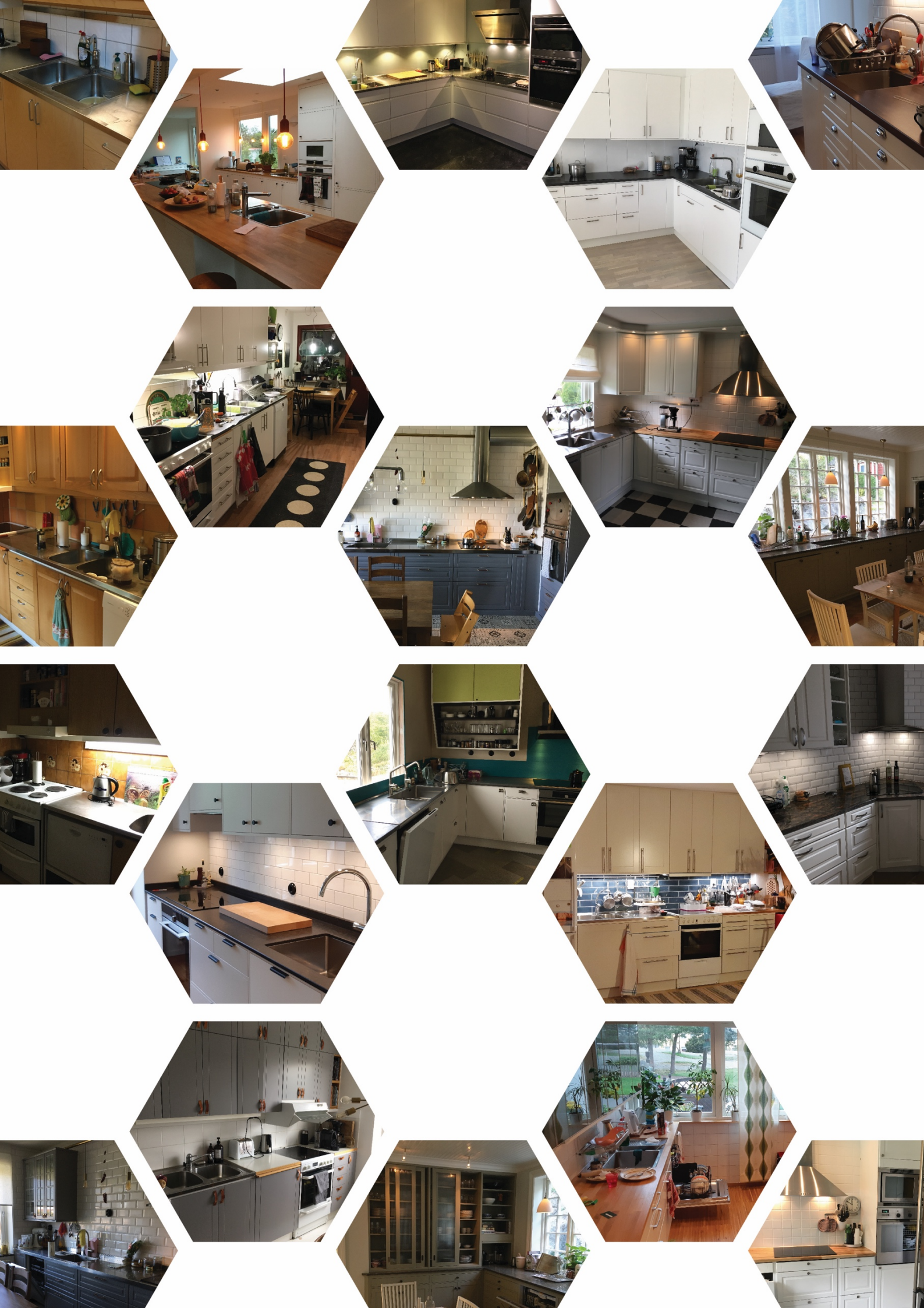
4.3.5 Validity & generalisation

Validity is one measure of research quality that questions whether the researchers 'in fact see what they think they see' (Flick, 2018, p. 543). Three different types of errors

may impact the validity: a type 1 error involves inaccurately defining relationships or seeing relationships where there are none; a type 2 error means rejecting relationships when they are actually correct, and a type 3 error means asking the wrong questions (Kirk & Miller, 1986, as cited in Flick, 2018). These types of errors have been avoided (at least partly) through different forms of triangulation, as previously described in Section 4.3.1. In Study A, the type 3 error was, as far as possible, avoided by adjusting the interview questions to the situation and asking additional questions where needed. This was not possible in Study B, in which questions in the survey and diary were predetermined. However, by letting several researchers in the project review the questions beforehand, it was ensured that the questions mirrored the research focus and were easy to understand.

Generalisation relates to whether research findings are valid independently of, and outside, the specific context of the study (Flick, 2018). A distinction is made between *internal generalisability* and *external generalisability*, where 'Internal generalisability refers to the generalisability of a conclusion *within* the case, setting, or group studied, to persons, events, times, and settings that were not directly observed, interviewed, or otherwise represented in the data collected' (Maxwell, 2012, as cited by Flick, 2018, p. 555). 'External generalisability, in contrast, refers to its generalisability *beyond* that case, setting, or group, to other persons, times, and settings' (Maxwell, 2012, as cited in Flick, 2018, p. 555). According to Flick (2018), generalisability depends largely on the sampling approach.

In Study A, the sampling procedure focused on including a diversity of cases in terms of household configurations, dwelling types, and renovation strategies. The cases were then contrasted with one another in the analysis. This contributed to an improvement in both internal and external generalisability, although the external generalisability remains low due to the limited sample size. Study B aimed at achieving better generalisation opportunities through quantitative data collection in a larger sample. However, the sample size turned out much smaller than anticipated and was scattered, with few participants spread across a relatively high number of buildings. This contributed to both low external and internal generalisability. Had the same number of residents participated and all been living in just one or two buildings, the study could have achieved greater internal generalisability within the case (the selected building(s)), although the external generalisability would have remained low.



Collage of participant kitchens from Study A.
Photographs by Sofie Hagejärd and Anita Ollár.

5 STUDY A: CIRCULARITY IN THE KITCHEN

This chapter presents the findings of Study A, which focused on identifying opportunities for improved circularity in domestic kitchens, in terms of both the daily use of resources and kitchen changes and renewal.

5.1 DAILY KITCHEN PRACTICES & RESOURCE USE

This section centres on daily kitchen use and presents the participating households' perceptions of resource use in connection with their kitchen practices. Initially, the focus group participants discussed how they felt unaware of how much energy and water that they were using in the kitchen and that there was a lack of incentive to reduce their consumption. It was also apparent that energy savings were generally of low priority in daily kitchen practices, as illustrated by the following quote:

> *No, it's not like it's my highest priority when I'm cooking to save energy – it is that I'm hungry [laughing]. Then I want energy! […] It's not like I'm thinking while I use the kitchen that 'now I should time it so that I turn on the oven at exactly the right minute to make it fit', I don't. (1-4)*

The next quote illustrates how rinsing vegetables was done in different ways by the same person, either at home or in the family's summer cottage due to the different materials and meanings associated with those contexts. At home, water was pretty much readily available all the time, whilst the summer cottage had no running water or electricity. This contributed to a raised awareness of water use at the cottage that did not extend to the home context.

> *The sick thing is that we have that mindset there, but here when you're home, it's just like you forget it. Why wouldn't we be able to pour water into a bowl and rinse all the vegetables in it like we do there? But somehow it's not in that environment so you don't really think like that (I-2)*

Two other participants also talked about other contexts where the availability of water was more limited, such as when staying on a boat or in a caravan. Unlike the

previous quote, these participants believed that the raised awareness of water use in these contexts actually did extend to the home context as well. One interviewee mentioned that she simply did not know how to further reduce her water use in the kitchen.

Avoiding food waste seemed to be given high priority by most participants. At the same time, this was seen as a complex task that was sometimes difficult to fulfil. Fruit and vegetables were given particular mention as examples of food that sometimes spoil before being used. This problem was given several explanations: lack of space in the fridge resulting in vegetables being stored too tightly, the temperature in the fridge being too low, lack of time to cook, or simply forgetting about it. When renovating their kitchen, one household solved the temperature problem by incorporating an extra fridge specifically for vegetables which they set at a higher temperature. Two focus group participants discussed a feature which they missed from previous dwellings: a naturally cooled pantry in the kitchen with a valve that lets in fresh air from the outside and located against a north-facing wall. They explained that this provided a suitable environment for storing root crops, fruit and vegetables. To prevent food waste, several households had adopted the strategy of going shopping more often and buying smaller amounts of food.

Sometimes other types of groceries also ended up as waste. Regarding the storage space in cabinets, one interviewee explained that:

> *You don't see what you have at home so you buy a lot of food you already have. I think that is not very sustainable. In the end, you have four packages of the same thing at home just because they always end up at the back (I-5)*

The different levels of priority given to avoiding food waste versus saving energy and water seemed to originate in various elements of kitchen-related practices.

First, the action of throwing away food was expressed as more serious than wasting energy and water. The prevention of food waste also seemed to be perceived as more straightforward than saving energy and water. In other words, *competences* differed, in terms of both know-how regarding how to minimise resource waste as well as in social norms regarding what is appropriate.

Second, the *meanings* differed in that wasting food seemed to generate stronger negative emotions than wasting energy and water. One interviewee explained: *"I sometimes have a bad conscience about things being thrown away"* (I-20). Another thought that *"throwing away food is completely insane"* (I-18).

Third, *materials* in the kitchen also played a role in the prevention of energy, water and food wastage. Food waste needs to be taken care of by separating it from other categories of waste and either composting it yourself or having it collected, while the amounts of energy and water used in the kitchen are generally much less visible. Something that was mentioned as a contributing factor to using more water than necessary was the slow change from warm to cold and cold to warm water. One interviewee gave an example of an appliance feature intended to improve energy efficiency but which, instead, gave the opposite effect – a fridge door that was very difficult to open if you had already opened it shortly before. This resulted in the

fridge door sometimes being left open to avoid the inconvenience of not being able to open it again. Furthermore, one interviewee who did not have a dishwasher in her kitchen stated this as a drawback since she believed she used more water and energy by hand-washing the dishes.

In discussions about cooking, one interviewee mentioned that vegetarian cooking demands more workspace because *"it's a lot of chopping"* (I-3). Regarding packaging waste, a general opinion among the participants was that the space dedicated to sorting kitchen waste is insufficient. For many participants, waste-sorting had spread to rooms other than the kitchen, often the hallway and sometimes the laundry room or basement. However, as one interviewee stated, *"most of the waste occurs in the kitchen, so it's reasonable to have it close"* (I-19). Another interview opined:

> *Many times, the reason to why we are very poor at recycling is because we don't have a natural place to put [the waste]. After all, we have filled up what we have there […] Since recycling has grown faster over time than the sink [cabinet], I think we should soon go up one module [in size] as standard (I-3)*

5.2 KITCHEN RENEWAL & CIRCULARITY

This section presents the interviewed households' motivations for, and approaches to, renovating their kitchens. An overview of the households' completed changes in the kitchen is shown in Table 5.1. The section then discusses barriers to kitchen circularity from the households' point of view.

5.2.1 Motivations behind kitchen renovations

The identified motivations for kitchen renovations in this study can be summarised into four categories: (1) functional demands and changing needs, (2) aesthetic demands and changing trends, (3) obsolescence due to wear, and (4) linkage to another home renovation.

For several of the interviewed households, renovation was seen as essential to being able to enjoy using the kitchen, functionally and aesthetically. In the first category, functional demands and changing needs, an example given by one household was that their old kitchen did not support the new needs that emerged as their family grew. They felt they needed a more open layout so as to keep an eye on the children whilst being in the kitchen. Several households found their previous kitchens to be too small or they disliked the layout. Among the households living in rented apartments, a common wish was to have more storage space as well as workspace, although they had limited opportunities to renovate their apartments. Another reason (given by two interviewees) was putting drawers instead of old cabinets with inaccessible shelves. One household saw the lack of a dishwasher as one of the main motivations for renovating the kitchen. Another household wanted a kitchen that was easier to clean.

Table 5.1. *Overview of renovations made in the residences of interviewed households.*

Case	Replaced appliances	Replaced cabinets	Replaced cabinet fronts	Replaced countertop	Replaced flooring	Painted/wallpapered/tiled walls	Added/replaced ceiling	Expanded the kitchen [1]	Removed cabinet	Moved cabinet	Removed wall [2]	Added wall [2]	Other changes
I-1	X	X	X	X	X	X		X	X	X			
I-2	X			X	X	X			X				X
I-3	X	X	X	X	X	X	X	X			X		
I-4	X	X	X	X	X	X		X	X				
I-5	X		X			X			X				X
I-6													
I-7	X	X	X	X	X	X		X	X	X	X		X
I-8	X	X	X	X	X	X		X	X	X			
I-9	X	X	X	X	X	X	X	X	X	X	X	X	
I-10	X	X	X	X	X	X	X	X	X	X	X		
I-11													X
I-12	X												
I-13	X	X	X	X	X	X	X	X	X				
I-14	X	X	X	X	X	X	X	X	X	X	X		
I-15													
I-16													
I-17													
I-18													
I-19	X		X	X	X	X							
I-20	X	X	X	X		X		X					

[1] added cabinet(s) or kitchen island, [2] between the kitchen and another room.

Aesthetic demands and changing trends were found to be common reasons for renovating the kitchen. Often, the old kitchen design was seen as outdated. Furthermore, carrying out an aesthetic upgrade of the kitchen was stated as a good investment for the apartment. One household which was planning to do a kitchen renovation did so because of a perceived lack of light in the kitchen, which they wanted to change.

Several households explained that their previous kitchens were so worn out that a renovation had been necessary. Finally, one household explained that their kitchen renovation was partly a consequence of another renovation, in which they had replaced the floor joists. Thus, they took the opportunity to completely transform the kitchen at the same time.

5.2.2 Kitchen renovation approaches

As shown in Table 5.1, the extent to which the interviewed households had renovated their kitchens varied greatly. Those who replaced parts of the kitchen instead of doing a complete renovation did so because of environmental objectives, economic reasons, an existing kitchen being in a relatively good shape but dated, or a combination of those aspects. One of the interviewees explained that another reason for only partly renovating the kitchen was that they did not plan to stay in the same house for more than 5-10 years. Otherwise they would have considered doing a full renovation instead. Another interviewee who did a complete renovation explained that from the beginning, she had planned to keep the cabinet frames from her old kitchen. However, since she disliked the layout, she was concerned this would not be completely satisfactory.

Of the households that had renovated their kitchens, all had replaced at least some of the old appliances. Several households explained that their existing appliances had either been broken, dysfunctional, outdated, or simply did not fit in the new kitchen, in terms of style or dimensions. During the renovation process, it was also common to add additional appliances such as a dishwasher, wine cooler, or extra fridge and to get rid of smaller appliances that were no longer needed. For instance, four interviewees mentioned no longer needing a kettle since they had installed an induction hob that heats water efficiently. One household deliberately chose free-standing appliances for the kitchen because of the likelihood of having to replace appliances before replacing kitchen furniture. The interviewee explained, *"it's probably the appliances that will break, the rest will last longer. The fronts, okay, but they are still of decent quality and can probably be repainted at some point before the kitchen needs to be replaced"* (I-14).

The households selected materials and designs for their new kitchens based on specific needs, style preferences, quality, budget, ease of cleaning, convenience, environmental considerations, and the available product range. Examples of environmental considerations during the renovation process by a few households included: choosing a timeless design that would last many years and allow easy replacement of parts; buying energy-efficient appliances; using locally produced appliances, second-hand cabinets, cabinets made of solid wood or biocomposite.

To summarise, the specific performances of kitchen renovation as a practice varied greatly in terms of materials, competences and meanings. This study has attempted to give better insight into which elements might be present in kitchen renovations, and how these are connected.

5.2.3 Barriers and opportunities for improved kitchen circularity

Several participants expressed frustration regarding the poor quality of both kitchen furniture and appliances. Some examples of issues mentioned that contribute to kitchen furniture not ageing well included vulnerability to water, paint that easily wears off, surfaces prone to wear, stain, or shift colour, and cleaning difficulties. A few households had negative experiences with new appliances that broke only a few years after being installed.

In addition to poor quality and difficulty repairing kitchen appliances and furniture, it was also discussed how many kitchens get replaced. This might be due to functional aspects that did not meet the household's current needs or aesthetic qualities that did not live up to their demands. Several participants reflected on how renovating the kitchen has become a way of expressing one's identity and status and that, "*we are so extremely influenced by what other people do"* (I-2). At the same time, kitchen design has become very trend-sensitive. Also mentioned was the fact that it is not sufficiently expensive or difficult to tear out an entire kitchen and buy a new one: *"As long as people have money and there are fairly cheap kitchens to buy, then they will replace them just because it is not the same white colour as desired"* (I-20).

The participants discussed a variety of opportunities for increasing the circularity of kitchens. These can be summarised as: (1) improved technical and functional quality, (2) timeless design, (3) acknowledging emotional values, (4) allowing aesthetical upgrades, (5) allowing functional upgrades and repair, (6) systemic changes and new business models, and (7) increased awareness of environmental impacts connected to kitchen renewal. The first three categories were often described as being dependent on each other, as highlighted in the following two quotes:

> *It's important to do something so good and so timeless that you understand that this is a treasure, it's an inheritance (…) But that requires a completely different authenticity in materials and an ability to withstand both wear from the eye and the hand (I-11)*

> *In my experience, doing something that has some kind of emotional value is often overlooked. If we do something and we strive for it to be beautiful, functional, made of good materials and so on, then I think there's a desire to care for it differently (…) So I think we should try to get people to appreciate how things can age and how they can do so beautifully (I-4)*

Categories 4 and 5 were discussed as strategies to ensure that needs and preferences are met over time. Allowing aesthetic upgrades of the kitchen was described as one way to enable personalisation of the kitchen without doing a complete renovation. Some participants liked the idea of having durable, high-quality cabinet frames that last many years with fronts that can easily be replaced or repainted: *"If you have the frames in good quality, then it's relatively easy to do a face-lift on a kitchen"* (I-13). However, it was also mentioned that allowing aesthetic upgrades is not solely a matter of advantages; it might risk making kitchen interiors even more trend-sensitive than they already are.

When new needs arise in the kitchen (for instance when the family grows or the residence changes owner), a functional upgrade may be preferred. Functional upgrades set the bar for modular design even higher, as it may be necessary to move cabinets or change cabinet interiors. To better support both functional and aesthetic upgrades, some participants thought that there should be an even higher level of standardisation and collaboration between different kitchen producers.

Some participants also discussed the need for changes on a systemic level, for instance through a more secure secondary market for kitchen furniture and appliances. Finally, several participants also discussed the need for a change of mindset and increased awareness of the environmental impact connected to kitchen renovations. One interviewee reflected: *"You develop something that should be replaced quickly and people think it's trendy to replace it and keep up with the latest kitchen trends, so I think it's a big societal issue that needs to be discussed"* (I-8).

5.3 SUMMARY

This study highlighted opportunities to design kitchens to better support households in their daily kitchen practices whilst encouraging minimal waste of resources in the kitchen. Regarding kitchen renewal, it was found that specific choices were sometimes motivated by sustainability considerations. These included choosing a lower level of renovation and choosing sustainable materials or energy-efficient appliances. However, sustainability considerations were not found to be the main motivation behind any renovation. Due to a lack of opportunity to make minor upgrades to the kitchen (either functionally or aesthetically), many households chose to completely renovate their kitchens, replacing (almost) everything.

Opinions on kitchen circularity did not seem to differ much based on what type of dwelling the participants occupied. The main difference between the households was the extent to which they could make changes to their dwellings; a higher level of opportunity to make changes was evident among those who owned their kitchens. Households living in rented apartments often had to adapt to the configuration of their existing kitchen, instead of adjusting the kitchen to match their needs.

6 STUDY B: DEMAND-SIDE MANAGEMENT & THERMAL COMFORT

This chapter presents the findings of Study B. This investigated households' thermal perceptions and acceptance concerning centrally controlled load shifting in space heating demand.

6.1 ATTITUDES TOWARDS THERMAL ENERGY USE AT HOME

The participants of Study B were presented with a number of statements regarding thermal energy use at home. They were asked to answer according to a five-point Likert scale from *strongly disagree* (weight 1) to *strongly agree* (weight 5), or *don't know* (excluded from the analysis). These statements were repeated in both the initial survey (S1) and closing survey (S2). The response distribution in S1 is shown in Figure 6.1.

The results from the participants who completed both S1 and S2 were compared in a Wilcoxon signed-rank test. Statement 2, *"I could imagine allowing a larger temperature variation in my apartment to save energy"*, was the only statement that evidenced a statistically significantly different result, with a lower level of agreement in S2 than in S1 ($Z = -2.471$, $p = 0.013$). Generally, the trend for all statements except the first one was lower agreement in S2, although none of the other statements showed statistically significant differences in the comparison.

To summarise, the results indicate that the participants generally perceived a lack of control over the heating in their apartments. This was also confirmed by several comments, for instance: *"I would have liked to be able to regulate the heat in the radiators myself and then pay for consumption. The change between summer [and] winter is too cold"* (Man, group C). Furthermore, most participants found it important to save energy to reduce their environmental impact, while saving energy to minimise costs was generally considered less important. An important note here is that heating was included in the rent for all participants, which explains the lower agreement with statement 3. A

majority also reported that they actively tried to reduce their daily energy consumption.

An analysis of the correlation between the first two statements showed a positive relationship, with r = 0.300 and p = 0.006. This means that those who experienced having enough control over the heating in their apartments, to a greater extent could imagine allowing larger temperature variations in their apartments to save energy.

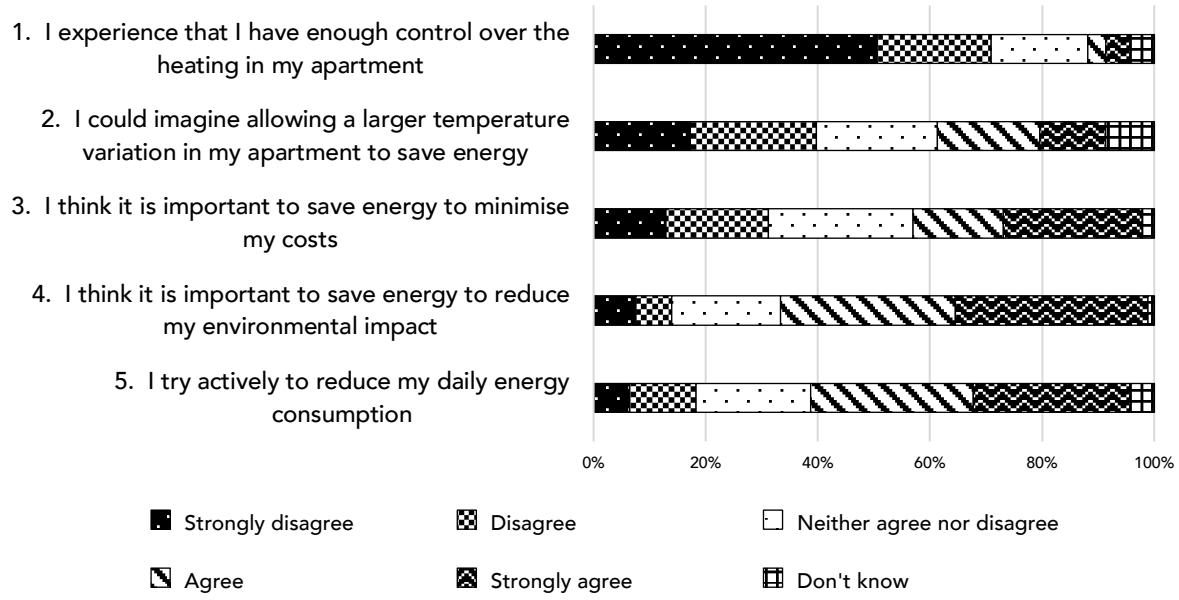


Figure 6.1. *Response distribution in S1 for statements regarding attitudes towards thermal energy use at home.*

6.2 TEMPERATURE PERCEPTION AT HOME BEFORE THE TRIAL

In S1, the participants were asked how often they felt too cold or too warm during the winter season (October to March) and the summer season (April to September). The response distributions are shown in Figure 6.2.

Comments regarding different seasons revealed that some participants perceived a major difference between the temperature in their apartments during winter and summer. A few also commented that it is usually very cold at home in the autumn, before the heating is turned on for the winter season. Furthermore, a few participants highlighted the problem of insufficient ventilation and lack of opportunities to air out their apartments. There were also complaints about inadequate insulation and the ingress of cold air when windy outside. One explained:

> *Every winter so far we have been freezing terribly at home, [with the temperature] often around 18 degrees inside. The landlord doesn't care at all. In the summers it can be up to 32 degrees indoors, because the ventilation is so lousy. In fact, the apartment is like a rainforest for several hours after you have taken a shower (Man, group A)*

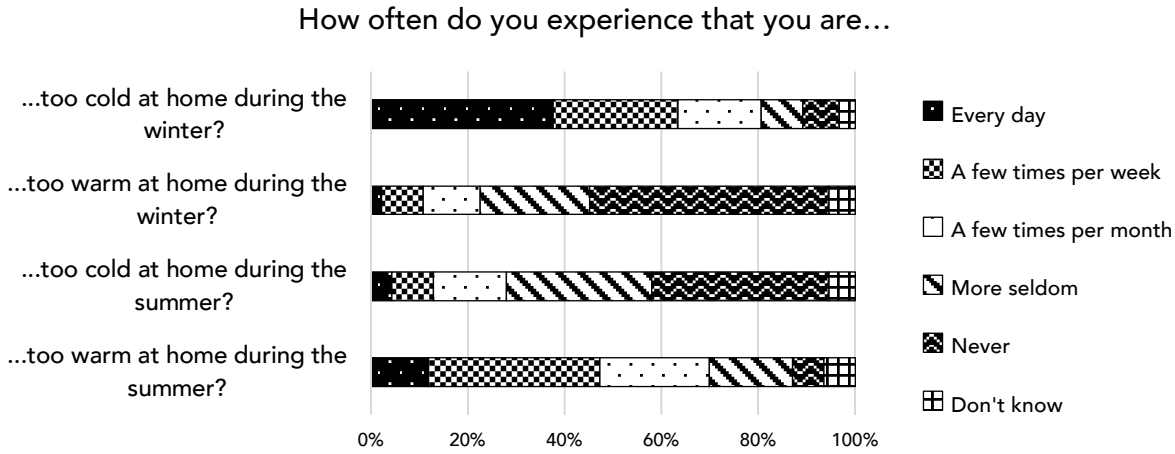


Figure 6.2. *Response distribution regarding temperature perception at home during winter and summer.*

The respondents of S1 were also asked how they generally perceived the temperature during different times of the day, divided into morning, daytime, evening, and night. The answers were given according to a Likert scale from *too cold* to *too warm*, with the additional option *don't know*. The results were analysed in a Wilcoxon signed-rank test, which indicated that the temperature was perceived as statistically significantly colder during mornings than other times of the day, with p values lower than 0.05. During mornings, 25% (n = 23) perceived the temperature as *too cold* and 42% (n = 39) as *a little too cold*.

6.3 TEMPERATURE PERCEPTION AT HOME DURING THE TRIAL

This section addresses the temperature perception and satisfaction reported in the diaries, with comparisons between participant groups and different times of the day.

6.3.1 Analysis of diary entries by group

Figure 6.3 presents the response distribution of the reported temperature perception and Figure 6.4 the reported temperature satisfaction, by group, in all diary entries. Some examples of comments connected to the diary entries were, "*Temperature in living room and kitchen are 20,4 degrees. Way too low when you are 70+ years old"* (Man, group C) and, *"When it's cloudy/rainy, the temperature in the apartment is usually good. But as soon as the sun comes out it gets very hot"* (Woman, group B). One commented:

> *Have had guests over today and the first comment you get is "God, you've got it hot!". Everyone starts peeling off their sweaters and cardigans. I myself have probably adapted to it always being warm here at home. I haven't had the radiators on since I moved in almost 17 years ago (Woman, group AC)*

A Mann–Whitney U test was used to compare the temperature perception of the groups that had load shifts during the trial (groups A and B) with the groups that were without load shifts (groups C and AC). This test indicated no statistically significant difference (U = 72195, p = 0.061). However, when comparing the groups individually, the test indicated that, statistically, group AC perceived the temperature as significantly warmer than all the other groups and group C perceived the temperature as significantly colder than group A, with p values lower than 0.05.

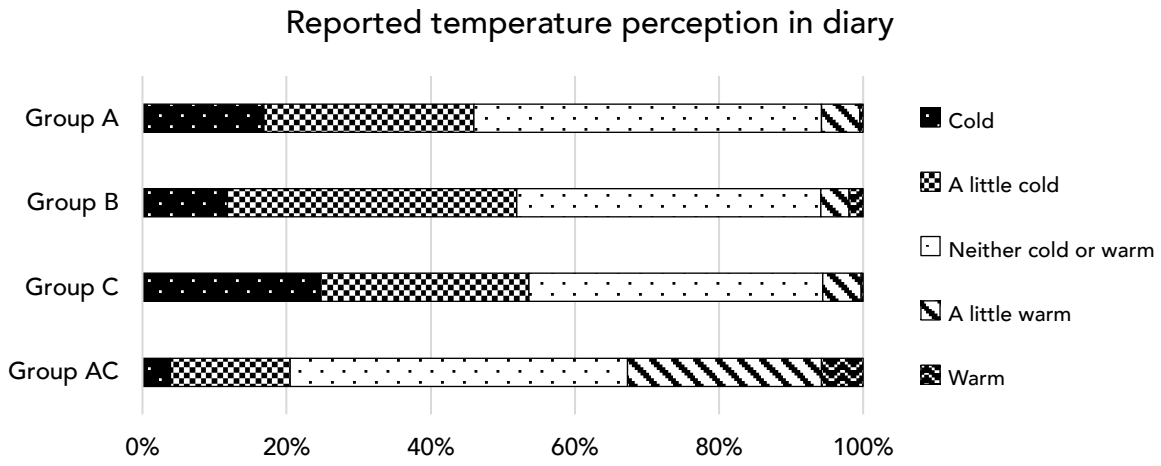


Figure 6.3. *Response distribution, by group, in diary entries on temperature perception.*

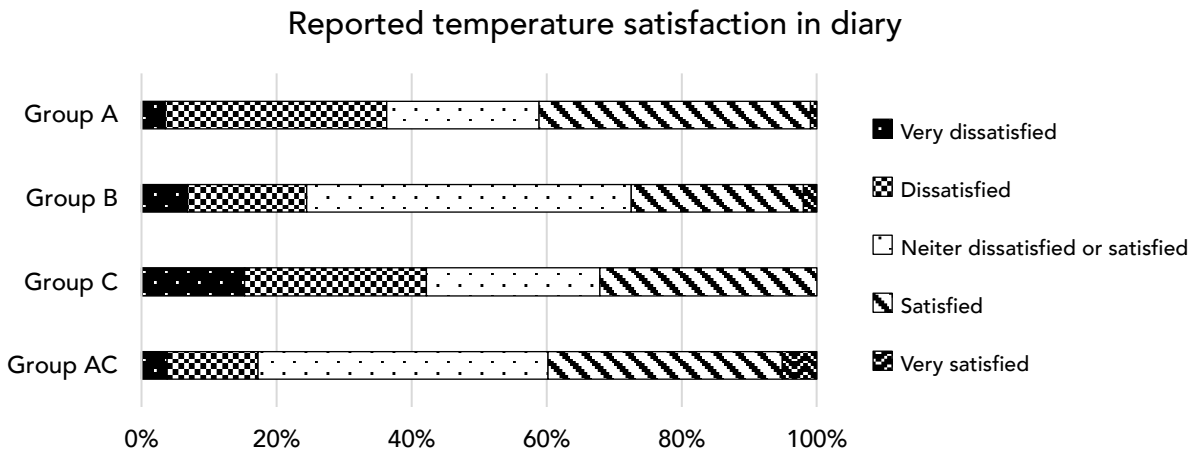


Figure 6.4. *Response distribution, by group, in diary entries on temperature satisfaction.*

Similarly, in a Mann–Whitney U test comparing the temperature satisfaction of groups A and B with groups C and AC, no statistically significant difference was found either (U = 73867.5, p = 0.271). When comparing the groups individually, the test indicated a statistically significantly higher satisfaction in group AC than in the other groups and a statistically significantly lower satisfaction in group C compared to group A.

A strong positive correlation was found between temperature perception and satisfaction in the total sample of diary entries (r = 0.632 and p = 0.000). In other

words, more participants were dissatisfied because they perceived the temperature as cold as opposed to warm. This result might have turned out differently, had the test been conducted during a warmer season of the year.

Another Mann–Whitney U test was conducted to analyse whether there was any difference in temperature perception and satisfaction between days with and without load shifts, in the two groups where this was applied (groups A and B). The outcome was no statistically significant difference in neither temperature perception or satisfaction.

An important note is that the above analyses were based on the total sample of diary entries and did not account for the low number of participants in the diary study (ranging from 6 to 23 participants per group). Due to differences in the number of diary entries per person (with a higher average number of entries from participants who used the paper diary as well as from participants who received notifications about load shifts), the results may be skewed. Furthermore, information about indoor temperature measurements could not be retrieved for the participants' specific apartments. Therefore, it was not possible to draw any conclusions about actual differences between the groups.

6.3.2 Analysis of diary entries by time of day

Figure 6.5 presents the response distribution of the reported temperature perception and Figure 6.6 the reported temperature satisfaction in all diary entries, by time of day.

A few examples of comments concerning specific times of the day were, *"Felt freezing cold in the apartment when I got up this morning"* (Woman, group C), *"Finding that that the air becomes heavy towards evening"* (Woman, group AC) and, *"Although it gets colder, I want the heating to be turned off at night"* (Woman, group C). One commented (nighttime), *"Open windows in the bedroom, closed radiators, cold outside but still it feels warm indoors (22.4 [°C] according to the thermometer)"* (Woman, group AC).

The diary entries were once again analysed using a Mann–Whitney U test, to evaluate whether there was a difference in temperature perception and satisfaction depending on the time of day. Although the results indicated that the temperature was perceived as slightly colder during mornings, no statistically significant difference in temperature perception was found when comparing the different times of day pairwise. Regarding temperature satisfaction, the Mann–Whitney U test indicated a statistically significantly higher satisfaction during the evenings than at night ($U = 17011.5$, $p = 0.035$).

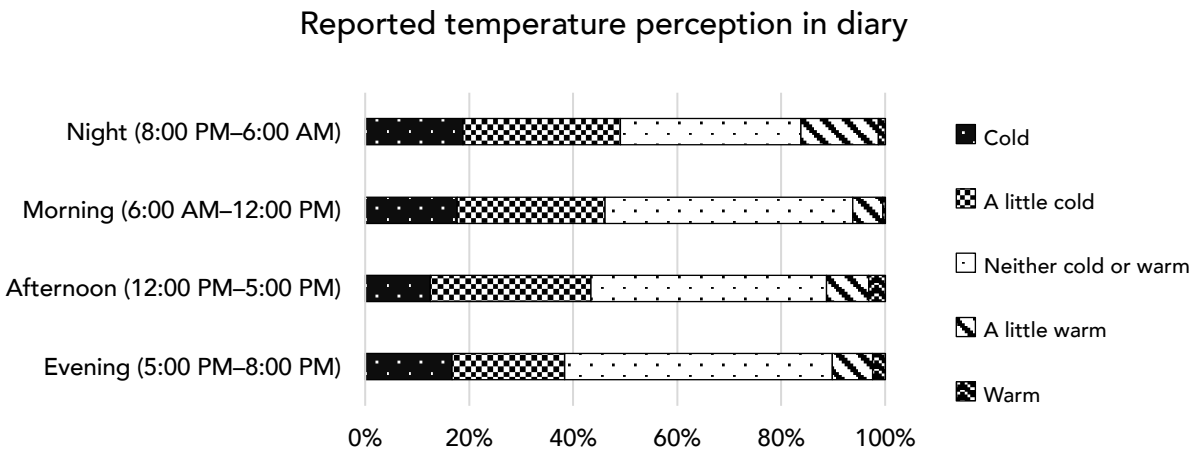


Figure 6.5. *Response distribution in diary entries, by time of day, on temperature perception.*

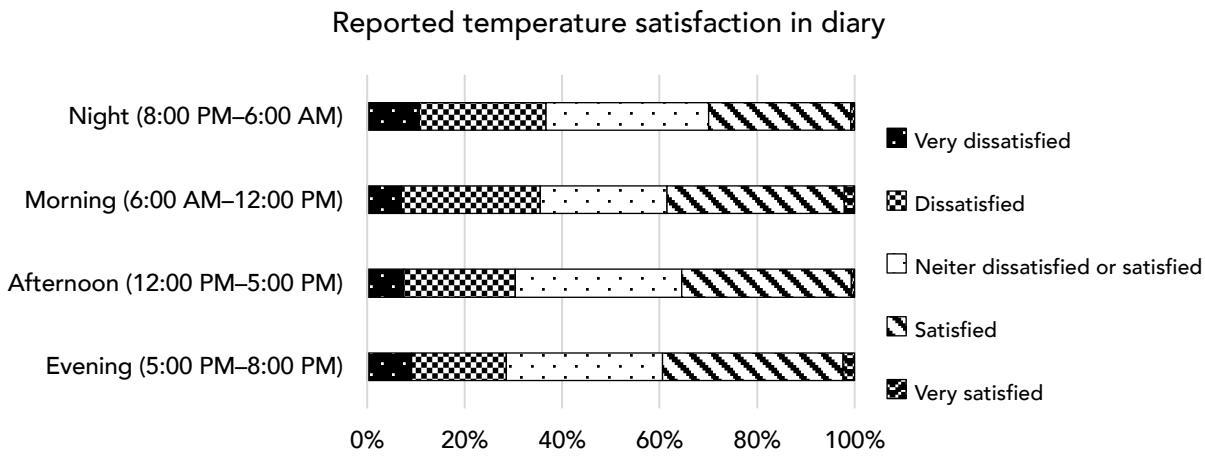


Figure 6.6. *Response distribution in diary entries, by time of day, on temperature satisfaction.*

6.4 TEMPERATURE PERCEPTION AT HOME AFTER THE TRIAL

In S2, the participants were asked a number of questions regarding their temperature perception and satisfaction during the past two weeks of the trial. First, they were asked how satisfied they had been with the temperature at home, on a scale from *very dissatisfied* to *very satisfied*. Second, they were asked whether they had perceived the temperature at home as better or worse than usual, on a scale from *much worse* to *much better*, with an option of *don't know*. Third, they were asked how often they had perceived any sudden temperature changes at home, on a scale from *never* to *every day,* with an option of *don't know*. The results were analysed in a Mann–Whitney U test, comparing the groups individually and also comparing groups A and B (groups with load shifts) with groups C and AC (groups without load shifts). None of those

comparisons showed any statistically significant differences in responses from the groups.

One question that was repeated from S1 was the one asking the participants to rate their temperature perception for morning, daytime, evening, and night; this time, referring to the past two weeks of the trial. Here, the results also indicated that, statistically, the mornings were perceived as significantly colder than daytime ($Z = -3.275$, $p = 0.001$) and night ($Z = -2.797$, $p = 0.005$) but not significantly colder than evenings. During the mornings, 16% (n = 15) perceived the temperature as *too cold* and 34% (n = 32) as *a little too cold*. Two participants commented that they could accept a lower temperature during the night as long as the mornings were warmer. One of them explained:

> *I have, during some nights, felt that you have raised or lowered the heat. Then I have taken an extra blanket or removed one. It's ok that it is colder during the night if I know that in advance. Of course, it's nice if you have it a little warmer during morning and evening (Woman, group A)*

S2 also investigated actions conducted by the participants when they had felt too warm or too cold at home during the trial. Focusing on actions that either required energy or contributed to energy wastage, 33% (n = 24) reported having opened a window when feeling too warm. When feeling cold, 35% (n = 25) reported having eaten or drunk something warm, 24% (n = 17) had taken a hot shower or bath, and 13% (n = 9) had turned on an extra heating fan.

6.5 SUMMARY

During this trial, which was conducted during early winter, more participants were dissatisfied due to finding the temperature too cold than too warm. The results indicated that, in general, mornings were perceived to be slightly colder than other times of the day. When comparing diary entries from days with and without load shifting, the analysis did not identify statistically significant differences in temperature perception or temperature satisfaction. Still, significantly fewer participants reported that they could imagine allowing more variation in indoor temperature to save energy after the trial than before. However, due to the low number of participants, the results are not sufficient enough to draw conclusions about the differences between participant groups, regarding temperature perception and satisfaction.

Another finding was that the participants generally perceived a lack of control over the heating in their apartments. Furthermore, the findings indicated varied preferences among the participants regarding indoor temperature.

7 DISCUSSION

This chapter will discuss the findings of the studies in relation to the research questions. Study A mainly addressed research questions 1 and 2, while Study B mainly focused on research question 3 and, to a lesser extent, research question 1.

7.1 RESEARCH QUESTION 1

How do households' everyday practices, lifestyles, and decisions influence the ways in which home-related resource use takes place?

7.1.1 Daily kitchen use

As frequently mentioned by participants of Study A, daily use of the kitchen may change completely due to life changes, such as when the family grows or when the children move out. Such changes may influence the availability of time to cook, what type of cooking that is done, the quantity of groceries purchased and stored in the kitchen and, consequently, the level of resources used and waste generated in the kitchen. This is in line with findings of Dubois et al. (2019), indicating that household footprints change significantly over time due to major life events.

It has previously been recognised that consumption of resources rarely occurs for its own sake, but rather for the sake of practices (cf. Warde, 2005). Similarly, the findings of Study A suggest that energy savings were seldom the main goal of everyday practices in the kitchen. Saving energy may even be a conflicting goal to the main objective of an activity, as previously suggested by Selvefors (2017). Furthermore, the priority given to avoid resource wastage varied depending on the type of resource use, with the avoidance of food waste generally getting a higher level of priority than avoiding wasting energy and water. This difference in priority level seemed to originate in competences, meanings, and materials (see Shove et al., 2012) connected to kitchen practices where food, energy or water is used.

Additionally, the performance of kitchen practices was found to depend on the context, due to different meanings and materials connected to different settings. This may result in significantly higher resource use in one context than another, even though the same practice (as an entity) is carried out.

7.1.2 Kitchen circularity & renewal

First, as found in Study A, resource use connected to kitchen renewal depends on the possibilities a household has to renovate its kitchen. This, in turn, depends on what type of dwelling the household occupies as well as its economic conditions. Ownership status of the dwelling and income level have previously been identified as having a strong connection to a household's environmental footprint (Dubois et al., 2019).

Second, the purpose of renovating the kitchen is critical to the final impact with respect to resource use. If a household's kitchen needs have changed fundamentally, a complete change of layout, or expansion of the kitchen, may be necessary to meet the new needs. If the main motivation behind the renovation is aesthetics, smaller changes and consequently fewer resources may be used to fulfil the goal of the renovation. Hand et al. (2007) identified that expansions in the kitchen space over time may be explained partly by the need to make space for more stuff. It may also be explained by the accommodation of 'particular visions and images of domestic life' (Hand et al., 2007, p. 675). In line with the findings of Hand et al., Study A may also confirm that the kitchen seems to have become the 'heart of the home'; a central place for a range of everyday practices, which to some extent motivated the renovations.

Third, the specific choices made during the renovation and the household's competences in home renovations also matter. The easiest choice may be to replace everything at once, to avoid having to deal with, say, new appliances or cabinet interiors that do not fit into existing cabinet frames. Interest and knowledge regarding more sustainable options in terms of, say, materials (locally produced, or second-hand products) also play a role.

7.1.3 Demand-side management in residential space heating

Study B identified some actions taken to improve the occupants' thermal comfort when feeling too warm or too cold at home, some of which may either require energy or lead to energy wastage. As shown in Section 6.4, some examples were opening windows or using an extra heating fan. Such actions originate in dissatisfaction with the indoor climate and will be further discussed in Section 7.3.1 below. However, the extent to which one takes action to improve thermal comfort may also depend on how much time is spent at home and personal preferences regarding indoor climate. This was found to vary between the participants, although the sample was not large enough to draw conclusions about differences in preference relative to demographic data. This was previously investigated by Hansen et al. (2019). They identified that

having a comfortable home indoor environment was valued more highly by women and older residents than other groups and related it to higher levels of energy use for space heating. Furthermore, Sovacool, Martiskainen, Osborn, Anaam, & Lipson (2020) identified how conflicts regarding space heating may arise between different members of the same household, as well as between landlords and tenants. The latter form of thermal conflict was also found in Study B, as highlighted by the participants' dissatisfied comments on how the heating was managed in their rented apartments.

7.2 RESEARCH QUESTION 2

How could the design of products and services support households in minimising their resource use at home?

7.2.1 Daily kitchen use

In Study A, it became clear that there is potential to improve kitchen storage spaces, to support both the prevention of food waste and sorting of recyclable waste. Well-planned storage spaces that allow a good overview of groceries stored at home may help prevent these being forgotten and going bad. For kitchen base cabinets, drawers were found to provide a better overview of the content than cabinets with shelves and doors. For groceries requiring cooler temperatures, it is important to provide the right temperature. For example, some vegetables and fruits stay fresh longer if stored at a slightly higher temperature than a normal fridge, but slightly lower than room temperature. By installing a 'cooler' in addition to a normal fridge (either as a naturally ventilated pantry or as a fridge set to a higher temperature), the environmental benefits could be twofold: vegetables and fruits may be kept fresh for longer and, possibly, less energy used to create a favourable climate for them. However, an obvious limitation of a naturally cooled pantry is that they are only viable in relatively cool climatic regions. Besides efficient storage spaces, the kitchen also needs to provide enough workspaces to support increased use of vegetables in cooking.

Regarding waste storage, this needs to provide enough space and good organisational capacity for different waste fractions. When kitchen space is limited, other rooms may provide alternative places for some of the waste storage. However, these should preferably be located close to the kitchen.

The findings of this study indicated that resource flows in the kitchen are somewhat obscure, especially when it comes to energy and water use. Also, households may lack the motivation and skills to act in a less resource-intensive manner. Therefore, there is an opportunity to design kitchens to allow increased visibility of water and energy use. This raises awareness of which activities are important contributors to environmental impact. Appliances might play an important role in providing households with the skills needed to use them in a resource-efficient manner. Furthermore, energy-efficient appliances which support households in their daily kitchen practices should be included in the kitchen. For

instance, dishwashers generally use less water and energy than washing the dishes by hand (Richter, 2011). However, it is also important that appliances do not disrupt workflows. For instance, a fridge door that was difficult to open shortly after it had been closed was sometimes left open to avoid this inconvenience, as explained by one participant in Study A. With a well-functioning set of appliances, the need for additional appliances may be reduced. One example mentioned was the induction hob, which may reduce the need for a kettle because it heats water just as efficiently.

7.2.2 Kitchen circularity & renewal

As shown in Section 5.2.3, opportunities for increasing the circularity of kitchens identified in Study A may be summarised into the following categories: (1) improved technical and functional quality, (2) timeless design, (3) acknowledging emotional values, (4) allowing aesthetical upgrades, (5) allowing functional upgrades and repair, (6) systemic changes and new business models, and (7) increase awareness of environmental impacts connected to kitchen renewal.

The first three categories share similarities with previously suggested circular design strategies for long product life and usage, such as design for physical and emotional durability (den Hollander et al., 2017), design for attachment and trust, and design for reliability and durability (Bocken et al., 2016). For kitchen furniture, prolonged use is positive from an environmental perspective. For appliances, there is often an optimal lifespan after which the environmental impact of continued use exceeds the embedded impact of newer and more energy-efficient products to replace them with (Bakker et al., 2014). However, with the current trend of decreasing appliance lifespans, design strategies for prolonged use are still valid. For instance, Bakker et al. (2014) determined that the optimal lifespan of a refrigerator bought in 2011 should be 20 years, although the current median lifespan for refrigerators in the Netherlands was estimated to only 14 years. Furthermore, designing for long product life and usage does not guarantee that this will be the actual outcome. As found in Study A, not all kitchens were replaced at a point when they had reached the end of their service life. Additional circular design strategies are therefore needed.

Categories 4 and 5 correspond to circular design strategies for extending product life and usage. For instance, design for maintenance and upgrading (den Hollander et al., 2017), and design for ease of maintenance and repair, design for upgradability and adaptability, design for standardisation and compatibility, and design for disassembly and reassembly (Bocken et al., 2016). To address the problem of appliances and furniture that break, design strategies are also needed for reversing obsolescence: design for recontextualising, repair, refurbishment, and remanufacture (den Hollander et al., 2017).

Both aesthetical and functional upgrades benefit from more modular designs and standardised components that are easy to replace; however, functional upgrades are slightly more demanding. If cabinets are to be moved and their interiors changed, this also requires high quality, durable frames. In improving the opportunities for

aesthetic and functional upgrades, the goal should not be to promote frequent changes just to follow new trends. Rather, there should be an alternative to more extensive renovations in which the whole kitchen is replaced. Supporting upgrades is a way of allowing needs and preferences to be met over time, so that when household compositions change, when new lifestyles are adopted, or when the dwelling changes owner or tenant, the kitchen continues to be a place to thrive whilst minimising environmental impacts.

To enable upgrades with little environmental impact, there is also a need for new business models for kitchens. Parts that are replaced but still in good shape should be recirculated while striving to minimise additional emissions and resource use from transportation and any refurbishment operations. This may require new collaborations between different stakeholders, alternative ownership models and new services relating to the kitchen. However, further investigation into these topics is beyond the scope of this research. Nevertheless, because the kitchen is a multifunctional space involving many different stakeholders and many different resource flows, it is crucial to apply a systems perspective when designing kitchens. This relates to the strategy design for systems change, as identified by Moreno et al. (2016). However, in investigating circular economy competencies for design, Sumter et al. (2020) found no indications of systems thinking being applied in practice. How to implement systems thinking in circular design therefore requires further consideration.

Finally, there is also a need to increase awareness of the environmental impacts of kitchen renewal. From a practice theory perspective, meanings such as expression of status and personal identity connected to kitchen renovations need to be toned down, while competences regarding the environmental impact of kitchen renovations need to be elevated. How such a shift might be achieved also demands further research.

Without more circular product designs and circular service offers in the kitchen, it is difficult for households to accomplish less resource-intensive ways of adapting their kitchens to their needs and preferences. Even though the household may be interested in more sustainable options, if such options are not easily available, they may in the end nevertheless decide to discard the old kitchen and replace it with a completely new one.

7.3 RESEARCH QUESTION 3

What influences households' perception and acceptance of solutions aimed at reducing the environmental impact of home-related resource use?

7.3.1 Demand-side management in residential space heating

Study B showed that the acceptance of demand-side management depends on several factors, including set indoor climate conditions, timing and magnitude of the load shifts, communication, and control. It seems that when satisfaction with the indoor climate is low, acceptance of load shifting is also likely to be low. It is therefore important to first resolve building-related problems which cause negative experiences of the indoor climate, such as poor insulation or insufficient ventilation.

In climate conditions with major outdoor temperature variations between day and night, peak demand in district heating systems often takes place at night (Kensby et al., 2015). When outdoor temperature variations are smaller, peaks in heat demand often occur during the mornings and evenings . This is due to greater demand for hot water during these periods (Kensby et al., 2015). The findings of Study B indicated that mornings were generally perceived to be slightly colder than other times of day. It may therefore be a challenge to achieve peak shavings during mornings without causing negative effects on residents' thermal comfort. To engender acceptance of load shifting in space heating, it is important to further investigate which parts of the day are often perceived as colder and then prevent significant temperature reductions during these periods. Similarly, it is equally important to avoid major temperature increases in periods that are perceived as warmer. This, in turn, may prevent heat losses from practices such as opening windows due to finding the indoor temperature too warm.

Sweetnam et al. (2019) has previously highlighted a way of avoiding raising concerns about demand shifting, by providing information to households on how the heating system operates, the benefits of their participation, and what they may do to ensure their thermal comfort is maintained. The importance of knowing beforehand when a load shift will take place was also raised by one participant in Study B. I believe that communication may play a crucial role in raising acceptance for demand-side management. Communication might also be used to raise awareness of the impact of such practices as opening windows and inform residents of periods when this should be avoided to ensure a well-functioning heating system. However, it has previously been recognised that information alone does not necessarily lead to changes in behaviour (Abrahamse, Steg, Vlek, & Rothengatter, 2005).

Another aspect which seemed central to satisfaction with the indoor climate was control. Study B showed that preferences regarding indoor temperature varied. As an example, some participants preferred a lower nighttime temperature, while others perceived the nights as too cold. More individual, apartment-level control of the

temperature was requested. However, previous research has indicated that the introduction of smart technologies which allow increased indoor temperature control may contribute to higher indoor temperature setpoints and greater requirements for thermal comfort at home (Larsen & Johra, 2019). Furthermore, the participants in the same study were sceptical about managing the feature of increased heating flexibility themselves (Larsen & Johra, 2019). Madsen & Gram-Hanssen (2017) have suggested that better opportunities for accommodating different temperature zonings in the home might help prevent heat loss from airing the bedroom at night.

I see potential in increasing individual temperature control on both apartment level and room level, whilst having load shifting controlled centrally by, say, the local energy company. However, more research is needed to find a good balance between individual control and centrally controlled load shifting in residential space heating. It is also interesting to analyse the relationship between perceived and actual control over the indoor temperature.

8 CONCLUSIONS

The research in this thesis has studied opportunities for more sustainable resource use within the home. This aim has been addressed by investigating home-related resource use concerning households' practices, lifestyles, and decisions. Furthermore, the research has explored design implications which support more sustainable resource use and analysed households' perceptions of sustainability-orientated solutions for the home.

Home-related resource use was found to be the result of a mixture of practices, preferences, choices, and contextual factors. Study A, which explored daily kitchen use and kitchen renewal, confirmed that the kitchen represents the heart of the home and is the centre for a multitude of interconnected practices. Its design plays a critical role, both in supporting sustainable resource use in everyday kitchen practices and in enabling needs and preferences to be met over time whilst minimising negative effects on the environment. Identified opportunities for increasing the circularity of kitchens were: (1) improved technical and functional quality, (2) timeless design, (3) acknowledging emotional values, (4) allowing aesthetical upgrades, (5) allowing functional upgrades and repair, (6) systemic changes and new business models, and (7) increasing awareness of environmental impacts connected to kitchen renewal. These categories share similarities with previously suggested circular design strategies (cf. Bocken et al., 2016; den Hollander et al., 2017; Moreno et al., 2016). They are relevant to companies which design and develop goods for the home in general but specifically targeted at kitchen producers and appliance producers. Ideally, several strategies should be combined, as they have potential to reinforce each other.

Study B, which explored the perception and acceptance of demand-side management in residential space heating, found thermal comfort to be a delicate matter, subject to diverse preferences and influenced by building properties such as insulation and ventilation. Consequently, the acceptance of demand-side management depends on a range of factors such as set indoor climate conditions, timing and magnitude of the load shifts, communication, and control. Regarding indoor climate conditions, it is important to maintain a good overall temperature according to regulations and taking into account vulnerable groups. This also

includes preventing the negative impacts of deficiencies in insulation and ventilation. Without a satisfying status quo for the indoor climate, acceptance of load shifting is likely to be low. The timing and magnitude of load shifting need adjusting, both to achieve a good match with the energy supply but also to prevent major temperature deviations during periods that are perceived as particularly cold or warm. The findings also suggest that communication may be an important tool in preparing households for upcoming load shifts. However, the format and frequency of such communication need to be carefully considered. Finally, the findings of Study B also suggest that a better balance needs to be struck between individual and central control of the indoor temperature.

The combined findings of the research studies indicate that:

- among other stakeholders, households seem to play an important role in enabling a transition towards more circular homes, with regards to slowing, closing, and narrowing resource loops (see Bocken et al., 2016), as well as allowing renewable energy sources to be used at home. However, households alone cannot be responsible for reducing their environmental footprints. To enable more sustainable resource usage at home, households need to be supported by circular designs and circular service offerings, plus energy systems which provide an increased share of renewable energy sources while ensuring households' satisfaction with their homes.

- dissatisfaction with the home environment may lead to additional resource consumption, as illustrated by kitchen renovations in Study A and various energy-reliant practices to improve one's thermal comfort in Study B. Enabling flexibility to adapt the home environment to household's needs in less resource-intensive ways seems an important factor in reducing households' environmental footprints.

The findings of this thesis contribute to an improved understanding of resource use and sustainability-orientated solutions from a household perspective. Such knowledge is crucial to supporting more sustainable resource use in households' everyday lives and bringing about transitions towards more circular homes. The insights presented and proposed design opportunities are relevant, not only to the research community but also to design practitioners. Hopefully, this will inspire new ways of designing products and services which contribute to a less resource-intensive and more pleasurable home life.

Another contribution of this thesis is its methodological approaches to gathering this knowledge. By using mixed methods, the research collected qualitative and quantitative data momentarily, retrospectively, and longitudinally. The combination of methods has helped ensure the quality of the research and may further be used as inspiration for the design of future studies.

8.1 FUTURE WORK

There is still much to be explored around home-related resource use and design solutions to support households in more sustainable ways of using resources. First of all, continued work is needed to develop, test and evaluate more circular kitchen designs accompanied by circular business models and services. This research needs to be conducted with a wide range of different households and dwelling types in mind, as there will surely not be one solution that fits all. Further insight studies with households are needed to collect qualitative inputs regarding their visions for future kitchens and home life generally, how they perceive various circular solutions for the home, and their experiences of testing out circular kitchen products and services.

How to combine different circular strategies so that they strengthen each other is a key question. Evaluations of the environmental impact of different alternatives need to be conducted from a holistic perspective, to ensure that environmental footprints actually are reduced. Furthermore, there is a need to investigate the roles that different stakeholders may take in order to contribute to the transition towards more circular kitchens. Opportunities for expanding circular solutions for the kitchen to other spaces and functions should also be considered.

To explore new ways of reducing resource waste in kitchen-related practices, practice-oriented design approaches should be tested out in collaboration with households. Such research may address questions such as: (1) how to increase competences regarding the environmental impact of daily kitchen practices and kitchen renovations, (2) how materials in the kitchen may support reductions in resource use, and (3) how to form new meanings around kitchen renovations which focus less on status and expressions of identity.

Regarding demand-side management in residential space heating, there is potential to apply the methodology of Study B to a larger-scale study. That would offer better opportunities to generalise results and analyse relationships between reported temperature perception in connection to load shifts and demographic data of the participants. Improvements in the research design would include the development of a more representative heat power control schedule to achieve peak shavings; having a greater number of shifts would allow better opportunities to analyse the residents' temperature perceptions during them. Indoor temperature measurements should be collected for each participating apartment, to be able to compare their reported temperature perception with the actual temperature in their apartments. Furthermore, the study should include a higher degree of qualitative data collection. This would allow a deeper understanding of how load shifting is perceived by the participants.

Future research within the area of demand-side management should more closely examine the role of communication in promoting acceptance. As discussed previously, it may be beneficial if households are informed of upcoming load shifts and their environmental benefits. However, the best way to manage such communication needs to be further explored. Future research should also address opportunities to improve perceived and actual control of indoor temperature on an

apartment level and room level, in combination with centrally controlled load shifting. In this context, special attention should be paid to ensuring thermal comfort at home for vulnerable groups.

Finally, more research is needed regarding how indoor temperature is perceived at different times of the day, when and how different heat-related practices are performed at home, and how they relate to individual preferences regarding indoor temperature conditions. As such preferences vary among residents, there is also room for more research into how to meet differing preferences within the same household.

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