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DOI (link to publication from Publisher):
10.54337/aau443225866

Publication date:
2021

Document Version
Publisher's PDF, also known as Version of record

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DISSERTATION SUBMITTED 2021

AALBORG UNIVERSITY
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Dissertation submitted 2021

Dissertation submitted: 31.03.2021

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ISSN (online): 2446-1636
ISBN (online): 978-87-7210-919-0

Published by:
Aalborg University Press
Kroghstræde 3
DK – 9220 Aalborg Ø
Phone: +45 99407140
aauf@forlag.aau.dk
forlag.aau.dk

Printed in Denmark by Rosendahls, 2021

CV

Simon Peter Aslak Kondrup Larsen has a background in Geography and Urban Planning studies and hold a master's degree (Cand.scient.) from Aalborg University. He finished his master's thesis in 2017, in which he explored urban regeneration and development project in an inner-city neighborhood in Seoul, South Korea. Simon has throughout his studies and as a PhD-student drawn on qualitative methods, and has developed competencies for making qualitative interviews and case studies in multiple settings. Before becoming a PhD-student, Simon worked with health promotion across European cities in the WHO facilitated network, the Healthy Cities Network.

Simon is part of the 'Sustainable Cities and Everyday Practice research group'(SCEP) at the Department of the Built Environment, Aalborg University. The research group consists of 15 members and research themes include studies in residential energy consumption and everyday practices, as well as sustainable development of cities and residential areas.

Simon's PhD is concerned with smart home technologies for management of heating, reflected in an everyday perspective. His dissertation investigates how heating practices reconfigure when smart home technologies for enabling heat demand flexibility are integrated in the domestic sphere. The PhD forms part of the interHUB project, funded by Aalborg University. The project is interdisciplinary and aims at investigating the role of buildings (and households) in a future low-carbon district heating system.

ENGLISH SUMMARY

Low-carbon transition scenarios imply that the district heating network will be increasingly dependent on renewable energy sources (RES) in a near future. As RES are more fluctuating in nature, enabling energy flexibility (balancing production and demand) becomes an emerging challenge. Enabling heat demand flexibility in the district heating network, include scenarios of integrating residential buildings, using them as short-term thermal storages for heat loads. Shifting the boundaries of the district heating network, using residential buildings actively, calls for a deeper understanding of the role of occupants and how they perform everyday practices.

Scenarios for shifting or shedding heat demand, foresees the use of so-called smart home technologies, which by AI capabilities and automated features will be able to conduct load-shifts of heating automatically and without direct occupant engagement. Research on similar demand side initiatives in electricity and gas grids has shown a gap between estimated and actual impact on energy demand, indicating that occupants and their way of performing everyday practices might play an important role. Little is though still known about occupants and how they perform everyday practices, and more social scientific and humanistic research is therefore needed in order to assess and shape current and future demand side management initiatives.

The aim of this dissertation is to investigate the role of occupants in relation to enabling heat demand flexibility. Industry and policy visions apply a somewhat techno-optimistic approach, assuming load-shift which are both convenient and comfortable for the occupants. However, occupant might perceive and engage with smart home technologies in unexpected ways, which might influence the potential for load shifting of heat loads.

The theoretical basis for this dissertation is inspired by theories of social practices. This entail perceiving energy consumption and the possibilities for shifting or shedding that, as the outcome of social practice performances. Practices thus becomes the core analytic unit. The basis for exploring occupants and their role in enabling a heat demand flexibility is thus relying on explorations of how heating practices reconfigure when smart home technologies enters the domestic sphere.

Based on in-depth interviews and home tours with 22 occupants in 16 different households, this dissertation has focused on understanding mundane aspects of how occupants heat their homes, how they engage with smart home technologies for load shifting and how heating is entangled in everyday life practices.

This dissertation contributes with a nuanced picture of occupants' role in scenarios for enabling a heat demand flexibility, by showing the complex ways in which heating practices are performed and how they reconfigure differently. I show that heat

consumption is a moment in certain practice-arrangement configurations, constituted and sustained by social and material elements. I show that occupants perform heating practices in many different ways, and indicate that they draw on embodied knowledge when engaging with smart home technologies for heat management.

The findings in this dissertation contributes to broadening the understanding of occupants and their role in enabling heat demand flexibility in future low-carbon scenarios. Based on the results, I argue that future initiatives towards shifting or shedding households' heat demand in flexible ways, need to consider the different practices that occupants perform and how they reconfigure with the introduction of new technology. I show how materials and technologies play an active role in shaping the performance of everyday practice and therefore also the possibilities for enabling a flexible heat consumption.

I therefore argue that occupants should not be considered as passive recipients of comfort and convenience in future demand side management initiatives, but should be included as active agents who reconfigure their heating practices along with social conventions and new technologies.

This dissertation is based on five scientific articles. Together they provide one of the first qualitative investigations of the role of occupants in low-carbon district heating scenarios. Contributions derived from this dissertation extends to both researchers and practitioners alike. I argue that research on heat demand flexibility need to better account for heating practices in building- and energy modelling work. I furthermore call for more qualitative and quantitative research on the social dimensions of the low-carbon transition in the district heating network, arguing for increased interdisciplinary research on the subject.

DANSK RESUME

Den bæredygtige omstilling indebærer at fjernvarmesystemet i stigende grad skal have vedvarende energikilder (VE) i energiproduktionen. Da vedvarende energikilder er mere fluktuerende end biobrændsel og fossilebrændstoffer, bliver det vigtigt at sikre såkaldt energifleksibilitet (opnå balance mellem produktion og efterspørgsel af energi). Visionerne for at opnå energifleksibilitet i fjernvarmesystemet indebærer brugen af bygninger som kortvarige varmelagre, for dermed at øge energifleksibiliteten. Når bygninger bliver 'aktiveret' og bliver en aktiv del af fjernvarmesystemet, kræver det samtidigt en dybere forståelse for hvordan beboerne udfører hverdagspraksisser og dermed mulighederne for at opnå energifleksibilitet.

Visionerne for at opnå energifleksibilitet indebærer brugen af såkaldte 'smart home technologier, som ved hjælp af kunstig intelligens og automatisering vil være i stand til at flytte varmeforbrug automatisk og uden direkte at involvere beboerne selv. Forskning i lignende initiativer inden for el- og gasnettet har påvist en uoverensstemmelse mellem de estimerede og de faktiske energibesparelser/potentialet for energifleksibilitet og indikereret at beboerne og måden hvorpå de udfører hverdagspraksisser spiller en vigtig rolle. Den eksisterende viden om beboerenes rolle i forhold til skabe energifleksibilitet i fjernvarmesystemet er begrænset, og der er derfor behov for mere samfundsvidenskabelig og humanistisk forskning, for på den måde at kunne evaluere og forme nuværende og fremtidige initiativer målrettet et fleksibelt varmeforbrug.

Denne ph.d.-afhandling undersøger beboernes rolle i omstillingen til et fleksibelt fjernvarmeforbrug. Politiske og erhvervsmæssige visioner for denne omstilling anlægger et 'tekno-optimistisk' perspektiv og antager at energifleksibilitet kan opnås på en, for beboerne, bekvemmelig og komfortabel måde. Beboerne kan dog opleve dette anderledes og deres interaktion med 'smart home technologier kan afvige fra visioner og antagelser, hvilket kan påvirke potentialet for af flytte varmeforbruget.

Det teoretiske grundlag for denne ph.d. -afhandling er inspireret af social praksis teori. Dette indebærer en opfattelse af energiforbrug og mulighederne for at flytte eller nedsætte dette, som resultatet af de sociale praksisser som beboerne udfører. Grundlaget for at forstå beboernes rolle i fremtidens fleksible fjernvarmesystem er dermed at undersøge beboernes varmepraksisser og hvordan de ændrer sig i takt med at nye intelligente teknologier bliver integreret i hjemmet.

Baseret på dybdegående interviews og 'home tours' med 22 beboere i 16 forskellige husstande, har denne ph.d.-afhandling fokuseret på at forstå forskellige aspekter af hvordan beboere opvarmer deres hjem, hvordan de interagere med intelligente teknologier, og hvordan opvarmning er relateret til andre hverdagspraksisser.

Denne ph.d. afhandling bidrager til at nuancere billedet af beboernes rolle i scenarier for et fleksibelt varmeforbrug, ved at vise kompleksiteten i opvarmningspraksisser og måde hvordan de udføres. Ph.d.-afhandlingen viser at varmeforbrug må ses i sammenhæng med udførelsen af sociale praksisser, som konstitueres og opretholdes af sociale og materielle elementer. Ph.d.-afhandlingen viser at beboere udfører opvarmningspraksisser på vidt forskellige måder og indikerer bl.a. at beboerne benytter sig af kropsliggjort viden når de interagere med smart home teknologier til opvarmning af deres hjem.

Resultaterne i denne ph.d.-afhandling bidrager til at øge forståelsen af beboere og deres rolle i fremtidens fleksible fjervarmesystem. På baggrund af resultaterne i denne afhandling, argumenterer jeg for at fremtidige initiativer som sigter mod at flytte eller nedbring varmeforbruget, må overveje de forskelligartede praksisser som beboerne udfører og erkende at disse praksisser ændres når der indføres ny teknologi i hjemmet. I afhandlingen viser jeg hvordan materielle objekter og teknologier spiller en aktiv rolle i at forme hvorledes hverdagspraksisser udføres og dermed også mulighederne for at skabe et fleksibelt varmeforbrug.

Jeg argumenterer for at beboere ikke skal betragtes som passive modtagere af komfort og bekvemmeligheds initiativer, men derimod bør inkluderes som aktive aktører der konstant ændrer deres opvarmningspraksis i overensstemmelse med sociale konventioner og nye teknologier.

Denne afhandling er baseret på fem videnskabelige artikler. Sammenlagt bidrager de med en af de første kvalitative undersøgelser af beboernes rolle i omstillingen til et bæredygtig fjernvarmesystem. Bidragene fra denne ph.d.-afhandling er både tiltænkt forskere samt andre der arbejder i feltet. Jeg argumenterer for at forskning i fjernvarmefleksibilitet, i højere grad må tage højde for beboernes varmepraksisser og inkludere sådanne perspektiver i bygnings- og energimodelleringer. Jeg opfordrer endvidere til øget interdisciplinær forskning i de sociale aspekter af omstillingen til et bæredygtigt fjernvarmesystem.

COLLECTION OF PAPERS

The dissertation comprises five papers:

Paper I: Larsen, S. P. A. K., Gram-Hanssen, K., & Marszal-Pomianowska, A. (2019, June). Smart home technology enabling flexible heating demand: implications of everyday life and social practices. In *eceee 2019 Summer Study on energy efficiency: Is efficient sufficient?* (pp. 865-873). ISSN: 2001-7960 (online)/1653-7025 (print). ISBN: 978-91-983878-5-8 (online)/978-91-983878-4-1 (print). European Council for an Energy Efficient Economy, ECEEE.

Paper II: Larsen, S. P., & Johra, H. (2019, October). User engagement with smart home technology for enabling building energy flexibility in a district heating system. In *IOP Conference Series: Earth and Environmental Science* (Vol. 352, No. 1, p. 012002). IOP Publishing.

Paper III: Larsen, S. P. A. K., & Gram-Hanssen, K. (2020). When Space Heating Becomes Digitalized: Investigating Competencies for Controlling Smart Home Technology in the Energy-Efficient Home. *Sustainability*, 12(15), 6031. doi: 10.3390/su12156031

Paper IV: Larsen, S.P.A.K. (2021). In control or being controlled? Investigating control of space heating in the smart home. Under review in *Energy Efficiency*.

Paper V: Marszal-Pomianowska, A., Larsen, S.P.A.K., Gram-Hanssen, K., Heiselberg, P. (2021). Thermal conditions vary in time, space, and between households. Is the assessment of building flexibility potential correct?. Submitted to *Applied Energy*

ACKNOWLEDGEMENTS

Writing this PhD dissertation has been a rewarding and challenging journey, and like every good fairy tales, I have been lucky to have good colleagues, friends and family to support me along the way. I would like to give thanks to everyone who played a role during this process.

First and foremost, I like to express my sincere gratitude to the people who so kindly invited me into their homes, allowing me to study their everyday life. I was also welcomed with open arms, a cup of coffee and a genuine interest in my research.

Second, I would like to thank my main supervisor, Professor Kristen Gram-Hanssen. Kirsten invited me onboard the interHUB-project, although I was new to the sociological field of energy consumption, but with her firm guidance, my interest and knowledge on the subject quickly grew and I became a committed PhD-student. Furthermore, I owe thanks to Kirsten for numerous discussions, feedback-sessions, commenting on papers and generally for always believing in me. Kirsten has always been committed as a PhD-supervisor and I feel lucky to have had her as my supervisor.

I would also like to give a special thanks to my co-supervisors, Associate Professor Anna Marszal-Pomianowska and postdoc Line Valdorff Madsen. Working on an interdisciplinary project, Anna has played a vital role in challenging my own perceptions and expand my understandings of heat demand flexibility. I would also thank Anna for her committed contributions to our collaborations of drafting papers. Line came on later as a co-supervisor but has been extremely helpful in reviewing my work and contributing to the final stages of my PhD submission. Furthermore, sitting next to Line at our office, she has always be keen to answer my questions or having a chat.

Furthermore, I would like to give a special thanks to senior researcher Anders Rhiger Hansen. Anders was officially appointed as my mentor when I started as a PhD-student, but we quickly developed a friendship. Anders has been essential and have had a great impact on my dissertation. Anders, despite having many other things to attend to, have always been helpful and deeply committed to the sociology of sustainable consumption. Anders has throughout the PhD process contributed with strong sociological competences and a good eye for the overall research agenda, but just as much with moral support and tons of laughs. Thanks Anders.

More over, I would like to thank fellow-PhD Lucile Sarran. Lucile reached out during the initial process of collecting the empirical data, and we quickly established a fruitful collaboration in which we shared views and conducted several interviews together. Lucile contributed to strengthening the empirical data, and inspired me with her work dedication.

I would also like to give a special thanks to my colleagues at BUILD and especially my close colleagues from the Sustainable Cities and Everyday Practices Research Group. Throughout these last three years, I have always felt welcomed and I have enjoyed our numerous meetings, lunchbreaks and discussions. I would like to give a special thanks to Toke Haunstrup Christensen, Lina Katan and Ole Michael Jensen for commenting on my PhD-plan, co-writing papers and arranging a reading group.

I would also like to thank my colleagues from the interHUB project for great discussions and company every sixth month at our seminars. It has been a pleasure working together in an interdisciplinary manner, and this has greatly shaped the narrative of my PhD dissertation.

Moreover, I would like to thank all the people at The Emerging Technologies Research Lab at Monash University for welcoming me into their work environment. Despite having to leave prior to what I planned, I enjoyed our discussions and experiencing your research approach firsthand. I would like to give a special thanks to Professor Yolande Strengers for arranging my visit and taking her time to discuss and comment on my work. Furthermore, I would like to express sincere gratitude to PhD student Rex Martin for numerous discussions and inviting me to meet his friends and family. I look forward to working together in the future.

While being a PhD, I have been very fortunate to meet and discuss with lots of people along the way. I would like to thank each and every one for providing feedback, moral support and engage in specific collaborations. These encounters has hugely inspired me and strengthened my research

Finally, I wish to thank my family and friends. A special thanks to Alissa for always making me laugh and supporting me throughout the process. I would also like to give thanks to all my friends for taking my mind off the PhD-process, reminding me about the life outside university walls. Moreover, a special thanks to my family, for providing moral support, asking curious questions and having a heart of gold.

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CHAPTER 1. INTRODUCTION

Transitioning to a low-carbon future requires that more renewable energy sources (RES) are used to produce energy services, such as heating. Contrary to fossil fuels, which historically have been used as the main energy source in heat production in Denmark (Danish Energy Agency, 2020), RESs fluctuate more, resulting in a less stable energy supply. An emerging challenge is to secure a balance between energy supply and demand, called energy flexibility.

Along with only a few other countries worldwide (Euroheat & Power, 2016), Denmark has a long tradition of collectively supplying heating, facilitated by a district heating network. This centralised form of heat provision provides 64% of all Danish households with energy for space heating and domestic hot water (Danish Energy Agency, 2020). Heating takes up the vast majority of Danish households' total energy consumption, accounting for over 80% (Danish Energy Agency, 2020). Overall, heating accounts for one-third of the total energy consumption, equal to the amount of energy used for transport, for example (Danish Energy Agency, 2020). Heating thus remains a particularly important aspect in low-carbon transitions, and the sector is investigating a (near) future of increasing levels of RESs in production, electrification of heating (Danish Government, 2020; Siemens, 2018), and increased use of digitalisation (Birk et al., 2019; Energikommissionen, 2017). Taken together, these three steps are believed to ensure a stable supply of fossil-free heating in the future.

The Danish district heating sector (consisting of more than 400 utilities) aims to become fossil-free in 2030. Therefore, this sector must implement some of these transitional measures soon (Danish District Heating Association, 2020). The sector has already initiated several initiatives targeting energy flexibility, but most have been deployed on the supply and transmission side of the heating system (Lund et al., 2014). However, to successfully fulfil its role in future low-carbon scenarios, the district heating sector must 'activate' the demand side to a higher degree. Initiatives on the demand side are envisioned to be associated with other often larger-scale initiates, such as sector coupling and low-temperature heat provision (Lund et al., 2014).

The potential of enabling heat demand flexibility by 'activating' the demand side is pushed by the potential of using the building stock as short-term thermal storage (Christensen et al., 2020; Kensby et al., 2015; Le Dreau & Heiselberg, 2016). The Danish building stock is considered energy efficient due to a high thermal mass; therefore, it is possible to maintain temperatures for hours while shifting the heat load (Jensen et al., 2020). Moving the district heating network boundaries to include buildings provides a new set of challenges for energy planners concerning how to activate the buildings (as short-term thermal storage) while considering the occupants.

The flexibility strategy aims to provide occupants with a similar heating service (allowing for different preferences concerning temperature settings) while using the building's thermal mass to enable heat demand flexibility. Therefore, how to activate buildings as thermal storage without compromising comfort or generating inconvenience for the occupants is central to the question of heat demand flexibility in current strategies.

Initiatives aimed at modulating (shifting or shedding) heat demand by activating the demand side are relatively new within the district heating network. However, experiences from other energy systems (e.g. the electricity grid) demonstrate how supplying occupants with feedback (on price or energy consumption) prompting them to shift or shed energy consumption has been central in previous initiatives (Darby, 2020). These initiatives have required manual load-shifting conducted by the occupants. However, in recent years, information and communications technology (ICT) advancements have facilitated demand-side management (DSM) initiates that rely on digital solutions, such as smart metering, digital feedback, and remote control of demand (Darby, 2020). To that end, many smart meters have been rolled out in European member states, granting utilities a better and more detailed overview of energy demand patterns (Joint Research Centre, European Commission, 2018).

A similar trend has occurred within the district heating network, where smart meters have been deployed in many Danish homes. Smart meters are the first step towards activating the demand side, as the collected data allow for in-depth knowledge on heat demand patterns. This knowledge can potentially facilitate district heating utilities to optimise grid operation and locate faults in heating installations. Furthermore, smart meter data can be used in DSM initiatives if combined with feedback to occupants (e.g. real-time tariffs and consumption visualisation) or in combination with smart home technologies, facilitating automated load control.

While a considerable amount of research on energy demand flexibility issues has been conducted concerning electricity consumption, less research has been conducted on heat demand flexibility in a district heating network. Most studies on heat demand flexibility in a district heating network have investigated either the technical potential of building materials and technologies in enabling heat demand flexibility (Le Dreau & Heiselberg, 2016) or how energy systems benefit from increased system integration (Foteinaki et al., 2020).

Only a few studies have examined how heat demand flexibility initiatives deployed in a district heating network are perceived and understood by occupants (Hagejärd et al., 2021; Sweetnam et al., 2019). Little is still known about how heating practices are reconfigured when initiatives towards enabling heat demand flexibility are integrated into the domestic sphere. This information is important because occupants and their way of performing heating practices influence the 'success' of energy demand initiatives, as experience from similar initiatives deployed in gas and electricity grids has shown. These studies have investigated various DSM initiatives, examining how occupants perceive and engage with new technology and whether initiatives result in calculated savings (Darby, 2010; Day & O'Brien, 2017; Hanmer et al., 2019; Hargreaves et al., 2013; Van Dam et al., 2010). These studies indicate a performance gap between predicted and actual energy demand and call for more research in social sciences and humanities (SSH) on the occupant role in DSM initiatives.

While SSH-based research has increased in recent years, academic disciplines, such as engineering and economics, have been dominant (Sovacool, 2014). Techno-economic research has been criticised for the perception and approach towards occupants and energy consumption. Critics have highlighted that energy consumption is habitual, socially shared, prefigured by materiality, and more than a question of changing attitudes and influencing choices (Shove, 2010). In response, social science research relying on the theories of social practices has been promoted as a conceptual framework for gaining a deeper understanding of occupants in energy consumption research (Røpke, 2009; Shove & Walker, 2014).

This PhD dissertation follows this tradition and approaches heat demand as a moment in performances of social practices. Instead of perceiving heat demand in terms of kilowatt-hours (kWh) or monetary value, heat demand is perceived in relation to the services it provides to occupants and the social practices that occupants perform in their everyday lives. Heat demand is thus 'made' (and sustained) through the performance of various practices. Understanding the occupant role in enabling heat demand flexibility is a question of understanding the practices that entail heat demand. This dissertation aims to empirically explore different performances of heating-practices and how they are reconfigured when new technologies enabling heat demand flexibility are integrated into the home. This dissertation elaborates on heat demand and the possibilities for shifting heat loads as far more complex than a question of deploying the necessary technology or information to households.

As new smart technologies for enabling heat demand flexibility are projected to play a vital role in low-carbon transitions in district heating, it remains important (but so far overlooked) to explore how heating practices reconfigure. Deploying technologies for automated load shifts of heat demand can potentially enable flexibility, depending on how heating practices are reconfigured with the introduction of this new technology. Moreover, smart technologies can potentially affect occupants' everyday lives, changing temporal rhythms, agency, and the spatiality of bundles of practices.

1.1. AIM AND RESEARCH QUESTIONS

The PhD dissertation aim is two-fold. First, it aims to contribute empirical knowledge on how occupants engage with new energy technologies and how their heating practices are reconfigured. Second, it aims to contribute to ongoing discussions on enabling heat demand flexibility in the district heating network by activating the demand side.

The overall research question is as follows:

How are heating practices reconfigured when smart home technology for heating management is integrated into households?

Four subquestions have been operationalised to guide the overall research question. The answers to these questions are sought in the collection of papers included in this dissertation:

1. What are the current visions of smart home technologies for enabling heat demand flexibility in the district heating network, and how are they embedded in technology?

2. How are embodied know-how and competencies related to and intertwined with heating practices when smart home technology is integrated into the domestic sphere?

3. How is control of heating, using smart home technology, perceived and performed by occupants ?

4. How does performance of practices influence variations in temperature conditions in time and space and between households, and what are the implications for heat demand flexibility?

1.2. OUTLINE OF THE DISSERTATION

The dissertation is structured as follows. Chapter 2 reviews various approaches to enabling heat demand flexibility, highlighting specific technologies and their narratives and technical capabilities. The chapter further reviews sociological perspectives on technologically centred approaches to enabling energy demand flexibility. Chapter 3 presents the methodological approach of this dissertation (adding to what is already included in the collection of papers). Chapter 4 outlines the theoretical framework. Chapter 5 briefly outlines the key insight from the collection of papers. Chapter 6 discusses and reflects on what can be learned from the collection results of papers, which includes the contribution this dissertation makes to the theories of social practices and academic literature on smart home technology and how to use such insight to enable heat demand flexibility.

CHAPTER 2. SITUATING SMART HOME TECHNOLOGY IN THE CONTEXT OF HEAT DEMAND FLEXIBILITY

In future low-carbon transition scenarios, smart home technologies are anticipated to play a vital role in balancing energy production and demand (Directive (EU) 2018/844; Schick & Gad, 2015; The Partnership Smart Energy Networks, 2015). The aim of using ICT in the energy system is not new, and utilities have been gathering data remotely (on both demand and production) using technologies, such as smart meters (Lund et al., 2014). Concerning heating (not just district heating), smart home technologies on the demand side mostly consist of smart meters. However, automated control of thermostats (e.g. programmable and smart thermostats) relying on basic forms of artificial intelligence (AI), such as if this then that (IFTTT), is also relatively widespread (Ford et al., 2017; Peffer et al., 2011). In heat production and transmission, ICT is also considered important for better utilisation of different sources of energy and sector coupling. Therefore, Lund et al. (2014) argue that intelligent control is a prerequisite for a fossil-free district heating network.

Sovacool and Del Rio (2020) traced smart home technologies from a historical perspective and found that the first ideas for the smart home date to the early 1900s and the introduction of electricity in the domestic sphere. Sovacool and Del Rio (2020) argued that ideas concerning the early smart home were bounded in narratives of a comfortable and convenient lifestyle enabled by new automation modes. However, the idea of smart home technologies for energy management is more recent, being introduced commercially during the 1990s and 2000s (helped by increasing internet penetration in the domestic sphere; Ford et al., 2017; Sovacool & Del Rio, 2020). Scholars have argued that the narrative of smart home technology for energy management is still bounded to ideas of comfort and convenience (Sovacool & Del Rio, 2020; Strengers, 2016; Strengers & Nicholls, 2017; Strengers et al., 2020). Strengers and Nicholls (2017) examined how current smart home technologies are marketed and promoted by the industry. They found that the advertised vision of smart home technologies still portrays home and everyday life as being more convenient with intelligent technologies but now with the additional promise of increased energy efficiency.

As an energy management tool, smart home technologies are, among others, labelled ‘smart’, referring to the technical aspect of connectedness (network connected), making it possible to connect devices, appliances, and sensors in a network and enabling some degree of automation and remote control (Gellings, 2009). The ‘smart’ aspect goes beyond what is known from ICT in television remote controls (Darby, 2018). Smart home technologies are embedded with advanced AI capabilities, making it possible to connect many different devices in a network (inside and outside of the home) and control these remotely or automatically. Another aspect worth highlighting in labelling these technologies as 'smart' is that they result from smart advertising. As previously noted, some scholars have argued that the industry promotes smart home technologies as technologies that make life more convenient, comfortable, and energy efficient (Hazas & Strengers, 2019; Strengers, 2013; Strengers & Nicholls, 2017; Strengers et al., 2019, 2020). In this dissertation, however, technologies are referred to as 'smart' depending on the technical aspect of connectedness (two-way communication). As an energy management tool, smart home technologies are often referred to as follows:

- smart home energy management systems (SHEMS),
- building automation and control systems (BACS),
- building management systems (BMS), and
- building automation systems (BAS).

The above labels refer to different technological capabilities (and control possibilities), but all include a bidirectional connectedness, allowing communication between appliances and technologies inside and outside the home.

The concept of *smart* is also applied to the energy system as a whole. The concept of smart energy systems is relatively new, emerging in 2009, and refers to a paradigm shift from single-sector to cross-sectoral and holistic thinking in the approach and understanding of energy systems (Lund et al., 2017). In a smart energy system, single-sector grids (electric, thermal, and gas) are combined using storage and conversion technologies, and coordination is ensured among the different grids and energy systems to increase synergies (Lund et al., 2017). A vital component in a smart energy system is the smart grid, which creates a platform for coordination between the different systems (Lund et al., 2017). Smart grids are also present in single-sector approaches and are a well-established part of the electricity grid. Lund et al. (2017) found that smart grids have previously been used synonymously with the concept of smart energy systems, but these are different concepts, as noted. The smart grid is only one component (ensuring coordination) in a nexus of different sectors and technologies present in smart energy systems.

In smart energy systems, residential buildings are actively included as short-term storage (for heat and electricity) and energy producers. A prerequisite for including residential buildings is that they are connected to the smart grid, and smart home technologies play an important part. In 2009, the European member states committed (under the Third Energy Package) to ensuring a large-scale implementation of smart meters in households, reaching 245 million in 2020 (European Commission, 2014). While smart meter deployment at the European level is focused on the electricity and gas grids, development in the Danish context also deploys smart meters in the district heating network. The idea of gathering a large amount of data is key. With this information, district heating utilities can facilitate DSM initiatives, such as demand response (DR), prompting occupants to shift or shed heat demand. In this way, households are envisioned as active units in the smart energy system as short-term heat storage, ensuring increased heat demand flexibility.

2.1. DEFINING SMART HOME TECHNOLOGY

Many scholars have already discussed smart home technology as a concept in the literature, most recently highlighted in reviews by Sovacool and Del Rio (2020) and Marikyan et al. (2019). Definitions of smart home technology do not differ much concerning technical capabilities but offer different perspectives on the occupants and services that the technology aims to deliver (Marikyan et al., 2019).

Reference	**Definition**
Balta-Ozkan et al. (2013)	'(…) residence[s] equipped with a high-tech network, linking sensors and domestic devices, appliances, and features that can be remotely monitored, access or controlled, and provide services that respond to the needs of [their] inhabitants'.
De Groote et al. (2017)	'A smart building is highly energy efficient and covers its very low energy demand to a large extent by on-site or district system-driven renewable energy sources. A smart building (i) stabilises and drives a faster decarbonisation of the energy system through energy storage and demand-side flexibility; (ii) empowers its users and occupants with control over the energy flows; (iii) recognises and reacts to users' and occupants' needs in terms of comfort, health, indoor air quality, safety as well as operational requirements'.
Herrero et al. (2018)	'SHTs [smart home technologies] incorporate ICTs, sensors and networking capability to automatically and/or remotely control the operation of home appliances like lights, heating and air conditioning systems. This is usually done via smartphone apps, some other kind of touchscreen panel or interface, or through digital voice assistants (e.g. Google Home and Amazon Alexa)'.
Gram-Hanssen & Darby (2018)	'One in which a communications network links sensors, appliances, controls and other devices to allow for remote monitoring and control by occupants and others, in order to provide frequent and regular services to occupants and to the electricity system'.

Table 1: Definitions of smart home technology as presented in the literature

Table 1 highlights a few of the most prominent definitions. Three of the four definitions presented below (Balta-Ozkan et al., 2013; Gram-Hanssen & Darby, 2018; Tirado Herrero et al., 2018) highlight networking capabilities. In contrast, the definition offered by De Groote et al. (2017) focuses more on services that smart home technologies offer to the energy system and the ability to accommodate occupant needs. This definition also includes a techno-optimistic perception of how smart home technologies deliver certain services (e.g. comfort, convenience, and security) to occupants. The definitions by Balta-Ozkan et al. (2013) and Gram-Hanssen and Darby (2018) are more cautious, noting that smart home technologies can deliver certain services but indicating that this is not a given. The definition by Herrero et al. (2018) does not include the aspect of services and only refers to the technical setup and how control is typically enacted.

While these smart home technology definitions differ in what they include (Marikyan et al., 2019; Sovacool & Del Rio, 2020), they share a focus on networking capabilities. This type of communication network relies on two-way communication protocols, linking appliances internally in the home to a broader network. This connectedness level allows occupants (or the technology itself) to remotely access and control appliances within the home. The definitions differ in how they perceive the occupants' role and engagement with smart home technologies, implying whether the technology can deliver services with comfort, convenience, and energy benefits in an unproblematic way or whether this is just a possible outcome. In this dissertation, smart home technologies are defined as follows:

Technologies that are two-way connected, linking internet of things (IoT) devices, smart meters, sensors, and gateways in a communication network, providing the opportunity to perform remote and automatic control of domestic appliances and energy demand.

In the definition, the potential for smart home technologies to deliver services to the occupants and the energy system is intentionally left out. By including purely technical aspects, the proposed definition of smart home technologies avoids making assumptions on how occupants engage with the technologies and the potential benefits that the technologies can deliver. Instead, smart home technologies are perceived as material objects and part of practice-arrangements.

2.2. TECHNOLOGICAL SETUP OF SMART HOMES

With a shared focus in most definitions on technical aspects, it seems important to provide a more detailed account of the technological capabilities and how they interact. In general, smart home technologies refer to many different appliances and commercialised products. They relate to different consumer segments, such as security equipment, entertainment appliances, kitchen appliances, and energy management. In the following clarification of the technological setup, smart home technologies for energy management is the focus. In the literature, five technological components are highlighted as central (Table 2).

Component	**Function**
Measurement (e.g. smart meters)	Time-based measurement of energy consumption
Sensors	Detection of data, such as temperature, occupancy, and humidity
Communication networks	Monitoring and control of the metering and sensing technology from a distance (e.g. Bluetooth, Z-wave, Zigbee, and Wi-Fi)
Internet of things devices	Appliances with integrated communication technology, such as smart thermostats
Gateways	Platforms from which occupants can monitor and control settings of multiple connected smart devices

Table 2: Five aspects of smart home technology. Derived from Paper I (Larsen et al., 2019)

The first component is measurement devices, which represent connected and digital meters that can store and send energy consumption data from the household to the energy system (Liu et al., 2016). These are referred to as smart meters and enable remote monitoring of energy demand (contrary to analogue meters).

The second component is sensing devices, which enable detection of the indoor environment (e.g. temperature, occupancy, or humidity; Liu et al., 2016). The connectedness of sensors allows for increased coordination and control by considering the current temperature setting in a home and using that information in DSM initiatives.

The third component of smart home technologies is the communication network. As previously noted and included in the definitions of smart home technologies, this network differentiates smart home technologies from other automation systems, as the network enables coordination and communication between different devices and actors (Liu et al., 2016). Appliances within the home, such as thermostats, washing machines, or heat pumps, are connected to this network (sometimes referred to as a home automation network; Lobaccaro et al., 2016). Communication networks use different communication protocols, such as Bluetooth, Z-wave, Zigbee, and Wi-Fi (Withanage et al., 2014). A technical concern with smart home technologies is the interoperability between these different communication protocols (Ford et al., 2017). In response to interoperability concerns, efforts have been made to develop gateways (the fifth component of smart home technology) that enable a ‘translation’ of different signals (from various IoT home devices).

In addition, IoT devices are the fourth technical component of smart home technology, as highlighted in the literature (Liu et al., 2016). This term refers to everyday appliances that have been equipped with networking capabilities, making it possible to remotely control or monitor them.

The last technical component is gateways, which function as the 'brain' of the smart home technology setup (Liu et al., 2016). A gateway enables different components (e.g. smart meters, sensing devices, and IoT appliances) to be connected and accessed from one platform (Lobaccaro et al., 2016). The platform is usually a computer, smartphone, or in-house display (LaMarche et al., 2012).

2.3. VISIONS OF SMART HOME TECHNOLOGY

A way to assess smart home technologies is to investigate the visions expressed by the manufacturers, utility providers, and policymakers who promote these technologies, as done by multiple scholars (Darby, 2018; Hazas & Strengers, 2019; Strengers & Nicholls, 2017; Wilson et al., 2017). As Darby (2018) highlighted, the visions promoted by these actors are often two-fold: promoting smart home technologies as a luxury good for occupants and as an energy management technology for efficient energy consumption. Others have made similar points (Strengers, 2013; Strengers & Nicholls, 2017; Wilson et al., 2017). The following section reviews the visions and assumptions of smart home technologies.

Based on a content analysis of articles in industry and consumer magazines and interviews with industry professionals, Strengers and Nicholls (2017) argued that the promoted visions of smart home technologies are based on a convenience narrative, where the technologies are portrayed as servants that 'serve' occupants in a convenient way. This vision of convenience, Strengers and Nicholls (2017) proposed, goes beyond eliminating time- and labour-intensive activities and includes a vision in which the technologies help occupants achieve a 'simpler lifestyle' and a home of pleasance. Convenience is understood as a simplification process, embedded in a user-friendly and 'one-button solution' design, generating pleasance for the occupants (Strengers & Nicholls, 2017). The industry visions of smart home technologies normatively dictate the notion of 'the good life', as Strengers (2013) argued.

In providing pleasance, automation plays an important role (Strengers, 2013). Manufacturers and designers perceive automation as a method to create very 'simple' solutions for the occupants, whose direct engagement is not needed to perform everyday tasks and load-shifting, such as adjusting the thermostat. Industry visions are embedded in the technological setup of smart home technologies. With more sophisticated AI features available today, technical solutions are increasingly embedded in AI features, allowing the technology to be self-learning and adaptive to the socio-material surroundings and conduct automated load-management of energy demand (McIlvennie et al., 2020).

In a study on how the actual design process of energy feedback solutions is conducted, Skjølsvold and Lindkvist (2015) found that prospective users of these technologies are disregarded and not involved in the design process. Instead, energy management technologies are designed based on 'ideal typical user personas' generated by the designers (Skjølsvold & Lindkvist, 2015). Although occupants are recognised in the development of future smart energy systems where residential buildings are becoming active parts (as storage units) of the energy system, the process of involvement is often ambivalent (Skjølsvold & Lindkvist, 2015). Historically, occupants have been perceived as barriers to successful implementations of smart home technologies for energy management due to a lack of knowledge and interest or simply irrational behaviour. Skjølsvold and Lindkvist argued that this representation of occupants is still present in the design process. The embedded automation features in smart home technologies for energy management are a way of bypassing the occupants', whose role is to be 'inactive', that is, they should delegate control to the technology and enjoy the pleasance of the automated features (Strengers & Nicholls, 2017).

Industry and policy visions of smart home technologies regard occupants' preferences (e.g. on comfort) as an important aspect that should be considered when implementing smart home technologies in households. Visions imply that occupants' preferences should not be compromised when delegating control to the technology, as reflected in European directives on energy efficiency (Directive (EU) 2018/844). The technological 'fix' for including occupants' preferences is a setup where occupants can personalise heating schedules, reflecting their comfort preferences (Ford et al., 2017). While acknowledging occupants as important for acceptance (and successful adoption) of smart home technology, occupants are also regarded as barriers due to certain deficits. The ambivalence, expressed in visions, is bypassed by focusing on enhancing a high level of user-friendliness and familiarity with occupants' homes while allowing for automated energy management, leaving the occupants passive in that regard. In doing so, Blue et al. (2020) argued that industry and policy visions portray occupants' preferences as rather stable (and as factors that must be met). The core concerns regarding occupant engagement become acceptance and trust, the narrative being that if people trust the technology to perform energy management efficiently and comfortably, they would be more prone to delegate control to the technology.

In visions of future heating management, thermal comfort is of specific importance for occupant engagement, as reflected in European policies (Directive (EU) 2018/844). A dominant technical conceptualisation of comfort is understanding it as a thermal phenomenon and a '(…) universally definable state of affairs' (Chappells & Shove, 2005, p. 35), which specifies the conditions under which people experience a comfortable temperature. Thermal predictions or so-called heat balance models, such as Fanger's (1970) predicted mean vote (PMW) model, are largely cited and used in terms of indoor thermal comfort in residential buildings. Fanger (1970) defined thermal comfort for office workers under different physiological conditions (metabolic rate, clothing, and environmental conditions) based on laboratory experiments. This model has since been developed and applied to building standards (Chappells & Shove, 2005; Cole et al., 2008). Chappells and Shove (2005) criticised the conceptualisation of comfort as a purely thermal phenomenon. Instead, they highlighted that comfort is not a static or fixed concept but a social phenomenon. Socio-technical accounts have instead shown how comfort has evolved historically with material and social conditions, and scholars within this tradition have argued that comfort must be considered a dynamic concept (Chappells & Shove, 2005; Gram-Hanssen, 2010; Madsen & Gram-Hanssen, 2017; Strengers, 2008; Tweed et al., 2014).

In policy visions for smart home technologies, the conceptualisation of comfort as a fixed concept is also presented. The Smart Readiness Indicator is an initiative funded by the European Union, aiming to establish an indicator that can rate the so-called smart readiness of buildings (VITO and Waide Strategic Efficiency Europe, 2021). The smart readiness of buildings is defined as 'the capability of buildings (or building units) to adapt their operation to the needs of the occupant, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility)' (VITO and Waide Strategic Efficiency Europe, 2021).

In determining the occupants' needs, comfort and convenience represent two of the eight so-called impact criteria determining the final rating (Verbeke et al., 2019; VITO and Waide Strategic Efficiency Europe, 2021). The occupants' needs, in this understanding, must be met, and they are not considered dynamic, changing with new energy technologies, as socio-technical approaches argue.

Another example is from the U.S. Department of Energy and its definition and vision for 'Grid-Interactive Efficient Buildings (GEB)' (NEEP, 2020). The GEB benefits to the occupants are described as follows: 'Homes and offices that include these connected devices can produce new levels comfort while providing building owners and operators added control and flexibility through room-level heating and cooling capabilities, tunable lighting, smart devices and appliances, and automated building management' (NEEP, 2020, pp. 8–9).

The above description depicts a vision of automation as a method of meeting and evolving the occupants' comfort preferences. Policy visions for implementing smart home technologies do not target or modulate notions of comfort. Instead, they incorporate a notion of thermal comfort as an aspect that the technology should not compromise, taking it as a given that it must be met or increased. This technocentric approach to enabling a more flexible energy demand has been criticised in the literature (Blue et al., 2020). Blue et al. (2020) argued that technocentric conceptualisations of energy demand flexibility and operationalisation and materialisation of such (in DSM solutions) risk a contradictory effect on what they aim to fix. Blue et al. (2020) stated that by deploying technologies that do not question the current levels of energy demand and how demand developed, the technocentric approach might legitimise and strengthen inflexible energy-intensive practices, disabling the needed energy demand flexibility.

To summarise, the visions of smart home technologies, as reflected by the industry and policy, promote these technologies as beneficial to both occupants and the energy system. The vision implies that smart home technologies can deliver energy benefits using automation (e.g. using buildings as heat storage) comfortably and conveniently. The visions imply that occupants experience increased comfort and convenience while receiving energy benefits (lower costs).

At the core of these visions are embedded features of automation, which imply that occupants do not have to engage directly. Instead, automation enables a simplification of domestic tasks. Certain assumptions about occupants underly these visions. They are considered passive agents with stable notions of comfort and convenience. Furthermore, deficits that occupants may have concerning competencies or material surroundings (and how occupants engage with these) are assumed to be bypassed by increased use of automation, limiting occupant engagement. In the visions of smart home technologies, the role of occupants is perceived in relation to maintaining the existing comfort and convenience levels; thus, occupants are excluded from engaging in load-shifting activities.

2.4. STRATEGIES FOR ENABLING HEAT DEMAND FLEXIBILITY WITH SMART HOME TECHNOLOGY

The terms DSM and, specifically, DR refer to initiatives that aim to modulate (shifting or shedding) energy demand. Several DSM and DR initiatives have been initiated throughout the years, primarily in the electricity system (Gelazanskas & Gamage, 2014), but contrary to expectations, many of these initiatives have had a lower effect on energy demand than anticipated (Darby, 2006). A similar critique has been raised by Buchanan et al. (2015), arguing that DR feedback initiatives only have a limited effect on reducing energy demand. While early (and to some degree current) DR initiatives have relied on more ‘hand-held’ and analogue strategies, such as providing occupants with information on their energy consumption (and how to shift or shed it) in leaflets, smart home technologies have become a more prominent part of DR programmes (Karlin et al., 2014; Strbac, 2008). With the influx of smart home technologies, DR initiatives have developed and moved in a new direction, allowing for new modes of control (remotely and automatically) and, thus, potentially new ways to modulate demand. The strategy for future DR initiatives is that energy demand can be managed more efficiently using automated features and is therefore not dependent on occupants to shift the load manually (Strengers, 2013). Instead, industry and policy visions apply the automatic control of energy demand in real time so that the DR strategy becomes a more accurate reflection of energy production at any given time (Strengers, 2013).

The DR initiatives deployed in district heating have previously concerned return-temperature and energy savings (Andersen et al., 2019). With the influx of intermittent energy sources, utilities have become more interested in developing DR initiatives to enable heat demand flexibility. Peak demand in the district heating network occurs during the morning (5 to 9 a.m.) and again (a smaller peak) in the late afternoon (5 to 8 p.m.). Figure 1 illustrates a potential load-shifting strategy in the district heating network.

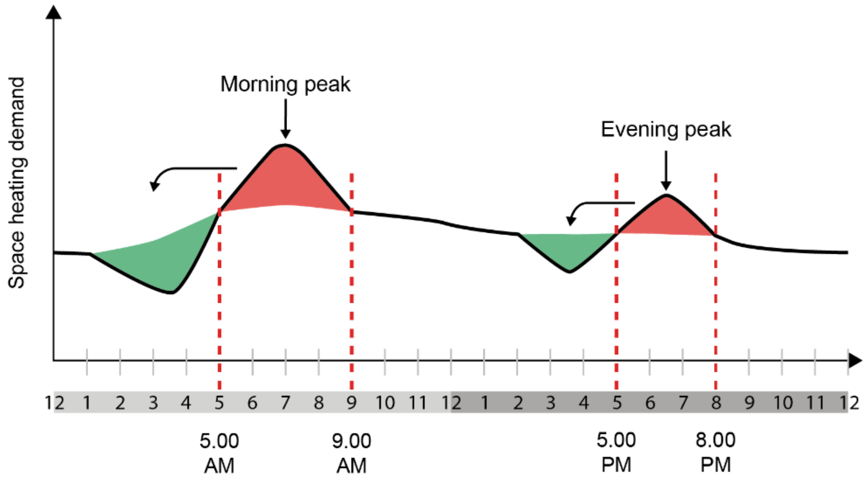

Figure 1: Illustration of load-shifting of heating. Derived from Paper III (Larsen & Gram-Hanssen., 2020).

As mentioned, the district heating network provides households with energy for both space heating and domestic hot water. In current strategies to enable heat demand flexibility in the district heating network, the focus is on shifting the base load (i.e. the demand for space heating). The idea is to take advantage of the building stock and thermal mass of residential buildings (Le Dreau & Heiselberg, 2016). Due to the high energy efficiency of the Danish building stock, residential buildings are predicted to remain at a comfortable indoor temperature for several hours, despite shutting off the heat for a period or lowering the network flux temperature (Jensen et al., 2020). This strategy is referred to as preheating and involves heating the building in 'valley' periods and shutting off heating in peak periods (Le Dreau & Heiselberg, 2016).

2.5. A CRITIQUE OF SMART HOME TECHNOLOGY FOR MODULATING ENERGY DEMAND

While smart home technologies are used in DR initiatives, a critique of these and their effects has also emerged (Darby, 2018). Critics have argued that the energy savings and demand flexibility that smart home technologies aim to deliver have not been realised in real-life settings. Critics have called for more empirical research on the actual use and entanglement of smart home technologies in real-life settings (Darby, 2018). While some studies have found that smart home technologies can potentially enable energy demand flexibility, as demonstrated by Christensen et al. (2020) in studying load-shifting in the district heating network, other studies have found that the potential energy savings are small and often short-lived (Hargreaves et al., 2018). Some scholars have even argued that smart home technologies can potentially increase domestic energy demand because they constitute and legitimise a 'new normal' (Blue et al., 2020; Nyborg & Røpke, 2011; Strengers, 2013). The technology redefines the existing boundaries between the production and demand sides of energy, creating a potential reconfiguration of the 'taken for granted' consumption pattern, as argued by Strengers (2011).

Due to the lack of evidence on energy savings and demand flexibility that smart home technologies can actually deliver, a call has been made for more SSH research on how occupants perform energy-intensive practices in the home (Darby, 2018). Within SSH, the critique has been that DR initiatives are too technocentric and neglect how energy demand is constructed in socio-material reconfigurations.

Based on a review of energy-related SSH research in Europe, Ingeborgrud et al. (2020) argued for a shift in how SSH researchers approach energy-related issues. Ingeborgrud et al. (2020) found that, although previous research perspectives focused on individualistic perspectives (inspired by psychology and economy), recent perspectives lean towards sociological understandings by highlighting how energy demand is the outcome of socio-material configuration. The latter sociological perspective was, among others, called for by Wilhite et al. (2000). Based on a critique of individualistic approaches, Wilhite et al. argued that energy-related SSH should focus more on the nature of energy demand, including social and cultural aspects of how energy demand is made (Wilhite et al., 2000). Similar points were later made by Shove and Walker (2014), arguing for a social practice-theoretical approach to energy-related issues.

A sociological critique of smart home technologies for energy demand management has focused on addressing contradictory visions of the role of technologies in low-carbon transitions (Hazas & Strengers, 2019; Nyborg & Røpke, 2011; Strengers, 2013; Strengers & Nicholls, 2017). From this perspective, the narrative of energy demand management technologies and the related embeddedness has been criticised for being too technocentric (Hagbert & Bradley, 2017) and not questioning the nature of demand and how it is made (Blue et al., 2020; Darby, 2018). Studies conducted on occupant use and engagement with smart home technology have shown that smart home technologies are, contrary to their narratives, very visible for occupants, disrupting everyday practices, as argued by Strengers (2013) and Hargreaves et al. (2018). A task taken up by the sociological perspective on smart home technologies has been to capture the ‘messiness’ of the smart home, identifying occupants’ relationship to the technology (Mennicken & Huang, 2012) and how they are entangled in everyday life (Davidoff et al., 2006; Nicholls & Strengers, 2015). Studies highlight how occupants may experience as loss of control, as technologies for increased automation of everyday practices are integrated into the home (Darby, 2020; Mennicken & Huang, 2012; Takayama et al., 2012). Other studies highlight that smart home technologies may have an array of social impacts, including manipulation and control of other household member (Nicholls et al., 2020). Summing up, the critique of smart home technologies for modulating energy demand is twofold, highlighting that energy savings may not be realised due to technocentric optimism and furthermore that smart home technologies may affect everyday practices in unforeseen ways.

CHAPTER 3. METHODOLOGY

This chapter focuses on outlining the methods used in collecting and analysing the empirical data used in this dissertation. The chapter is organised as follows. Section 3.1 considers the philosophy of science and how to approach heating practices ontologically. Section 3.2 concerns the use of qualitative data in research, including methodological considerations compared to other alternative approaches to data, also touching on the specific qualitative approaches used in this dissertation. These approaches include working with case studies (Section 3.2.1), conducting semi-structured interviews (Section 3.2.2) and home tours (Section 3.2.3), and the final condensing and coding of data (Section 3.2.4). Within each section, the collected data (and how they were collected and analysed) are presented, but only in a way that has not already been included in the collection of papers, avoiding unnecessary repetition. Instead, the specific methodological approaches are elaborated on, and the focus is on providing additional information to increase reliability and transparency. The last section (Section 3.3) presents some of the methodological limitations of the chosen qualitative method.

3.1. FLAT ONTOLOGY AND THEORIES OF SOCIAL PRACTICES

In this dissertation, ontology is understood as the fundamental assumptions about any phenomenon in social theory. Before developing methodological approaches to researching any aspect of social life, it remains important to establish fundamental ontological ideas and how they relate to the chosen theoretical framework.

The research conducted in this dissertation relies on theories of social practices. While theories of social practices represent a multitude of different theories and not a combined or grand theory (e.g. it differs in accounts of how practices organize and the role of materiality; Schatzki, 2010; Shove et al., 2012), many refer to a flat ontology, for example Schatzki (2016). Some prominent scholars within the theories of social practices have referred to social practices as the core analytic unit of social order (Reckwitz, 2002a; Schatzki, 1996). Practices and how they are organized and bundled remain central to understandings of any phenomenon, social or material. The 'flatness' of this ontology implies that the practices and how they are organised represent the only level or dimension of social order. Schatzki wrote the following:

> The site of the social is a mass of linked practices and arrangements that is spread out across the globe and constantly changing through time. All social phenomena are slices or aspects of this mass. Social phenomena differ in the practices and arrangements that compose them and in the density, continuity, and spatial-temporal spread and shape of their constituent. (2016, p. 32)

The flat ontology differs from other ontological accounts in social theory, which are more hierarchical, distinguishing between an individual and structural dimension of social life. The assumption in the flat ontology implies that people (and their behaviour) and structures (and institutions) are slices of practice arrangements, and social order cannot be understood as the sum of individual behaviour (or action) or social structures.

The ontological flatness of theories of social practices also implies that any methodological approach to the examination of a social phenomenon must investigate practices, how they are organised, and the relations between them. Although this does not prescribe any specific methods, the analytical unit of practices is clear. A flat ontology also implies a specific epistemological approach, considering social practices as the analytical unit for gaining insight into any phenomenon. In the context of this dissertation, considering the role of occupants in modulating heat demand flexibility heating demand, the practices that occupants perform become central, which implies examining how heating practices are organised and the relation between heating and other practices that unfold inside and outside the home. Understanding the performance of heating practices further contributes to understanding how practices are constituted as collective entities, indicating how they are sustained and reproduced.

3.2. USING QUALITATIVE DATA TO EXAMINE HEATING PRACTICES

For this dissertation to study heating practices in smart homes, qualitative methods were preferred as the main methodological approach. Qualitative methods were chosen for three reasons, listed below:

- The research questions explore heating practices in-depth to understand how they are performed and reconfigured.
- The research questions study heating practices in an everyday life setting, including how practices are bundled and performed spatiotemporally.
- As smart home technology for space heating management is still considered a ‘niche’ technology (low penetration rate in households), there is a lack of sufficient cases.

By choosing qualitative methods, this dissertation aims to generate insight into how heating practices are organised and bundled. To that end, it was important to study the performance of practices from an everyday life perspective, as close as possible to how occupants perform them in a routinised manner. The objective was to study occupants in their ‘natural’ surroundings, focusing on increasing the ecological (real-life settings) and internal (validity within the premises of the study) validity rather than the external validity (Generalizability). However, the results presented in the dissertation aim to inspire future quantitative research for broader generalisability. In one of the papers (Paper V) included in this dissertation, method triangulation was conducted. The aim was to empirically explore the spatiotemporal variation of heating consumption by combining numerical energy data from apartments with qualitative interviews.

3.2.1. THE CASE STUDY

In this dissertation, the overall research strategy included case studies. Selecting the proper sample of cases was key in the initial research process. Paper I in the collection of papers, presented and detailed how cases were selected and on which grounds. In the following paragraphs, the argument for working with case studies is unfolded.

The choice of using case studies is rooted in the research question and how to approach it. Yin (2003), a highly cited scholar on the use of case studies, argued that using case studies in a research design is most appropriate for research questions that include (1) why and how questions, (2) are set in real-life settings that are difficult to manipulate, (3) cover contextual conditions, and (4) have unclear boundaries.

Yin (1994) stated that the strength of the case study is to gain in-depth insight into so-called black-box questions (why and how), typically within a case set in contextual and real-life settings, thus enhancing the ecological validity of the study subject. In this dissertation, the choice of using the case study enabled a detailed examination of the occupants' 'doings and sayings', exploring how and why they performed heating and how heating practices are reconfigured along with the integration of new technology in the home. The choice of the case study allowed an exact examination of how practice-arrangements are organised and reconfigured, contributing knowledge on how heat demand is 'made' and can be modulated.

The case study resonates with this study of heating practices because it allows a holistic research approach to a phenomenon that entails many different aspects entangled with each other, where boundaries of the study object are unclear. This point is also concerning heating practices, where demarcating the practice is an empirical task that must be explored during the interviews and home tours. As a researcher, I had some established assumptions about how occupants conduct heating, including the rhythm, organisation, and relation to other practices; however, the actual interviews and home tours proved me wrong in many cases. The case study proved useful to demarcate heating practices empirically and increased the internal validity.

The applicability of using case studies in research has been criticised concerning its validity and reliability. Flyvbjerg (2006) sought to address these critics and summarised the five misunderstandings of case-study research: problems with context-dependent knowledge, generalisability problems, usefulness for other purposes than generating hypotheses, biases in verification, and problems making general propositions. First, Flyvbjerg argued that context-dependent knowledge is just as valuable as context-independent knowledge, as every social phenomenon is context-dependent and not defined by universal rules. Second, Flyvbjerg suggested that case studies could be useful for generalising depending on the case-selection process. Third, following the second misunderstanding, Flyvbjerg argued that case studies could be used to generate and test hypotheses, depending on the case selection (e.g. falsification). Fourth, Flyvbjerg proposed that the verification bias (i.e. case studies tend to confirm preconceived notions) is not true, as this is an epistemological condition and not exclusive to the case study. In contrast, Flyvbjerg (2006) proposed that the case study has an advantage due to its contextual nature of being close to real-life settings. The fifth and last critique Flyvbjerg addressed is that it is difficult to summarise case study results; however, he indicated that it is not the choice of methods that complicates summarising but the complexity of everyday life, which case studies can capture. Overall, in addressing the critiques of the case study, Flyvbjerg commented on a general idealisation of context-independent knowledge as the 'gold standard' for research. In revising these five misunderstandings, Flyvbjerg revealed the validity and reliability of the case study while highlighting the advantages of doing so.

When using a case study for research, determining which cases to work with (sampling selection) and how long they should be studied (sampling time) and choosing the appropriate methods for collecting the data (e.g. interviews and observation) are important. There are different ways to determine the sampling selection. The main difference is between single-case studies and multiple-case studies – both have advantages and limitations. While the single-case study limits the generalisability (external validity) of the study, it gains the advantage of being more in-depth and the possibility to study the case over time (increasing internal and ecological validity). In this dissertation, a multiple-case study was chosen. The reason for choosing multiple cases was to explore the differences between the cases (heating installations and household variables vary) and compare how diverse households with different material arrangements (technological setups) reconfigure their heating practices.

Another aspect when considering the sample selection is to decide which cases to choose. When working with a qualitative case study, the sampling should not be compared to that of quantitative sampling (where the aim is to increase generalisability and representation). Instead, the selection of cases aims to use a sample on a theoretical or contextual basis, aiming for high information levels to be gathered. As detailed in Paper I, the selection of cases in this dissertation followed several contextual requirements, as follows:

- located in a district heating system,
- located in Denmark,
- used advanced smart home technologies for heat management,
- set in real-world settings (contrary to living-lab experiments).

Four cases were chosen for in-depth interviews and home tours. A detailed description of these cases is in the collection of papers (Papers I to III) and is summarised below.

The four cases are all located in the Greater Copenhagen area (figure 2). Three of the cases are located within the same inner-city neighbourhood of Copenhagen (Figure 3), while one case is located in the metropolitan area (Figure 4). Each case represents a specific residential complex and differs in terms of building type and number of units. The cases located in the inner-city neighbourhood of Copenhagen are part of a newly developed waterfront area, consisting of both residential apartments and businesses. The area is considered a middle-to-high-income neighbourhood, which is reflected in the prices for buying and renting apartments. The area is frequently visited by people from other parts of the city who commute for work or to visit for leisure activities.

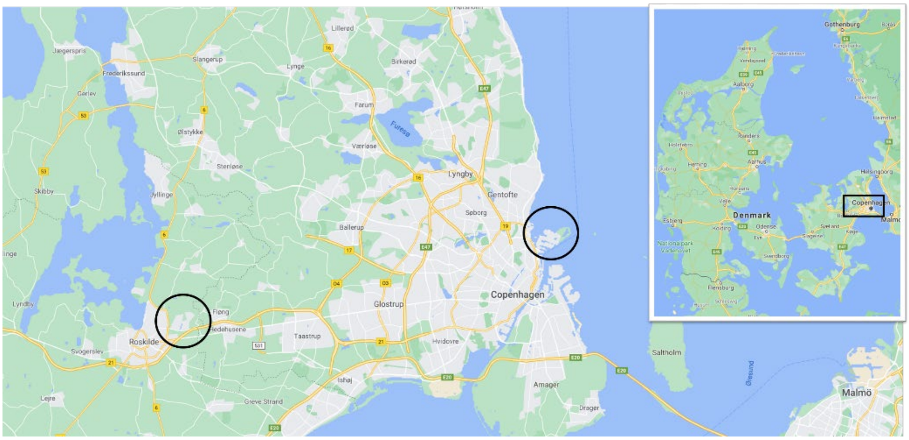

Figure 2: Map of the Greater Copenhagen Region. Google, n.d. (www.google.dk/maps).

In contrast, the metropolitan area case is within a larger residential area developed in the early 2000s. The area is close to a nearby local university, a small town centre, and a railway station where trains depart to Copenhagen every 30 min. The area is considered a middle-income neighbourhood. With ongoing housing developments in the area, it attracts many newcomers. Residents and university students primarily frequent the area.

Figure 3: Overview of Nordhavn. Note: Nordhavn with the United Nations building (Photograph by Lars Plougmann, 2016), Flickr (https://www.flickr.com/photos/criminalintent/29848366980). CC BY-SA 2.0.

Figure 4: Trekroner. Nochnajazima (Photograph by Aleksandra Birjukova, 2007), Flickr (https://www.flickr.com/photos/somretin/403438746). CC BY-SA 2.0.

Another consideration of the case study is deciding on the sampling time (i.e. how long the cases should be examined). A long sampling time is important if the research questions investigate change over time in the chosen case. If aiming to do so, multiple data collection points are needed. In this dissertation, data were only collected at one point due to a mixture of practical and theoretical bounded considerations. First, due to the lack of sufficient cases in real-life settings, the priority was locating cases where smart home technology for heat management was already installed and in use by occupants. The priority, which is also reflected in the research questions, was understanding and studying heating practices in contextual settings where smart home technologies were actually used.

Another possibility is studying changes in heating practices over time, recruiting and interviewing households, integrating smart home technologies into their homes, and conducting another round of interviews. This approach could have produced interesting findings on short-term change but would also have involved a technological risk. Initial start-up problems are anticipated with emerging technologies. By recruiting households that have had their equipment over a longer period, this dissertation adds knowledge concerning how smart home technologies are used in real-life settings.

The aim of the dissertation was not to observe changes in the performance of heating practices over time. Instead, the aim was to understand how heating practices are reconfigured with new modes of managing heat in residential homes and the effects on enabling heat demand flexibility. As part of an interdisciplinary research project, this dissertation strived to promote contributions beyond social science and contribute to the technical understanding of how to enable heat demand flexibility. This contribution has been made through extensive collaboration and method triangulation, with the aim that future research will build on the contributions in this dissertation and evaluate (over time) how smart home technologies influence both heat demand flexibility and everyday practices.

The final aspect to consider when designing a case study is the choice of methods for data collection. Similar to the other considerations, this must be guided by the research question and the practical possibilities (resources, accessibility, etc.). This dissertation combined two qualitative methods: interviews and home tours (detailed below). Both methods enrich the study of how occupant perform heating practices.

3.2.2. CONDUCTING SEMI-STRUCTURED INTERVIEWS

The (qualitative) interview may appear to be a conversation between the researcher and interviewee, but contrary to most conversations, it has a structure (determined by the researcher). The qualitative interview takes the form of a more formal conversation, where power dynamics are at play, which is an important aspect to consider when assessing the data validity, as discussed by Kvale and Brinkman

(2009). The interview is a trade-off between increasing the reliability and transparency (making it very structured) and increasing the internal validity (making the structure looser, allowing for contextual settings). Most qualitative research interviews are semi-structured, allowing the interview to follow certain themes (and associated research questions) and enabling sudden structural changes, such as follow-up questions.

The research interview can be described as a site of knowledge construction (Kvale & Brinkmann, 2009). The practical interview performance (as a social practice) is a specific important epistemological challenge, drawing back to the philosophy of science and how the researcher perceives knowledge creation. Whether researchers perceive the interview data as reliable and valid accounts of the interviewees' 'sayings and doings' or as a site of contested knowledge construction depends on the researcher's epistemological approach. In this dissertation, the aim of collecting interview data was to explore the informants' life worlds through their own words and actions. The interviews follow a phenomenological line. While theories of social practices do not recognise ontological individualist accounts, the epistemological approach appears similar: the performance of practice is a way of uncovering insight into practice arrangements.

The interview is a way of understanding how practices are performed, by letting the informants describe and demonstrate their actions. As a method of data collection of people's practices, the interview is also a site of knowledge construction, and the interview must still maintain an open-ended structure so that the constructed data reflect people's practices and not what is guided by the interview and researcher. One method of maintaining this structure is following various stages – before, during, and after the interview (Kvale & Brinkmann, 2009). This method involves making appropriate preparations (thematising and designing an interview guide), conducting the interview accounting for specific rules (theoretically and as a craft), and creating a post-analysis where the effort is dedicated to critically assessing the validity and reliability of the study (transcribing, coding, and reporting).

The data collection begins before informants are interviewed. Setting up the necessary criteria for recruiting informants is a crucial first step linked to the sample validity, which involves developing a recruitment strategy at an early stage, detailing how to identify and convince people to participate in the study. In this dissertation, the four cases provided the spatial boundaries for recruiting informants. Due to the defined geographical area of the case studies, recruitment had a narrow focus from the beginning. An important criterion for recruiting informants is to enrol occupants with different sociodemographic backgrounds and household compositions. These criteria were set up to capture as many different heating-practice performances as possible, rooted in the rationale that practice performance differs in relation to these parameters (Warde, 2005).

The first step in recruiting is determining the number of informants to include and, thus, to consider how many data are needed to examine the research questions. Theoretical and practical concerns should guide this consideration. The question of sample size is a balance between ensuring enough informants to provide insight into how heating practices are performed differently and avoiding 'drowning in data' or limiting the interview depth.

In this dissertation, the sample size was 16 households comprising 44 occupants in total (An overview can be found in Paper III). During the interviews, 22 household members were present. This sample allows an in-depth understanding of how heating practices are performed while avoiding the risk of being overwhelmed with data. While the sample size has allowed for detail and depth, it lacks external validity, and the generated data may not be generalisable across a larger population. This (de)selection of the sample size is rooted in the research question, where the focus is on developing knowledge of practice arrangements and how they are reconfigured. The results presented in the collection of papers and this dissertation do not claim to show variance across a broad population based on 16 household interviews. Instead, the dissertation results show how the performance of heating practices is reconfigured when smart home technologies are integrated into households. These results provide insight into the socio-material dynamics. This dissertation aims to contribute to the hypothesis development and the nuance of how heating practices are reconfigured in socio-material configurations when living with smart home technology.

Recruitment was conducted using a targeted campaign within the four cases. Flyers and email were used to directly contact the informants of interest (i.e. considering the recruitment criteria). Access to the informants and their contact details was obtained through so-called gatekeepers, such as board members or administrative personnel, in some cases. This method allowed for a general overview of the basic information of the occupants and enabled the sample to be derived accordingly. The appendix presents the flyer used for recruitment.

Prior to conducting the interviews, an interview guide was constructed. As stated, this document acted as a thematised interview structure, steering the interview in the direction of the research questions. Due to being semi-structured, the interview guide only provided guidance in terms of specific questions, and each interview took a slightly different route in terms of questions. The interview guide is attached in the appendix and covers five overall themes: presentation and background of the informants, everyday life routines and practices, home tours focused on 'doings', smart home technologies for heating control, and general technology experience. Each theme consists of several questions, all open-ended. When designing the questions, it was important to gain insight into what the informants took for granted or considered normal. The interview guide aimed to collect data about what people do regularly and what seems to be everyday routines, which they may perform unconsciously or with little thought.

The interviews were conducted in the informants' own homes with a duration of 1.5 to 2 hours. Prior to the interviews, the interview guide was tailored to fit the specific context in which the informants were situated, relating to the material circumstances (i.e. building type and heating installations). Each interview started with a presentation and the aim of the research project, including obtaining informed consent from the informants. Most interviews were conducted with one interviewer present, but two interviewers were present in six interviews. In these instances, one acted as the main interviewer while the other acted as a secondary interviewer. The secondary interviewer's role was to ensure that the interview guide was followed and ask follow-up questions.

While the interviews primarily consisted of the informants explaining how they perform heating in their home and engage with smart home technology to do so, an important aspect during data collection was to allow informants to demonstrate how they performed such practices. This demonstration was done through a home tour, which is described in the next section.

3.2.3. HOME TOURS

Contrary to conspicuous consumption, energy consumption is sometimes perceived as 'invisible' and intangible to people in their everyday lives (Shove & Walker, 2014). People do not necessarily reflect on their energy consumption related to performing a practice, such as heating their homes. In examining practices of inconspicuous consumption, ethnographic methods of visualisation or observation are valuable.

People's 'sayings' (expressing norms, rules, and rationales) can be captured when talking to people through a standalone interview, as argued by Hitchings (2012). Hitchings pointed out that, by talking to people (interviews), people can reflect on the practices they perform. Like every method, the interview also has weaknesses and limitations. As the interview purely relies on oral accounts of practices and how they are performed, this methodological approach relies on descriptions and recalls of how practices were performed. The spoken-word interviews lack a way to capture the 'doing' of a practice, which is unconsciously performed many times in everyday life. This lack is especially true regarding inconspicuous consumption, such as energy consumption. Another limitation of the spoken-word interview is that it ignores material aspects (and agency) of practices. Pure oral accounts of how practices are performed delegate too much agency to humans, whereas the practice-theoretical approach emphasises that practice arrangements should be the object of the study.

Conducting home tours (also referred to as household tours) is a way to solve this issue and capture the material aspects of practice performance. This methodology uses 'show and tell', where informants act as 'tour guides', showing the researcher around the home, demonstrating how practices are performed spatially and which (and how) materials are used. Besides promoting the material aspect of practice performance, the home tour also simulates (and stimulates) routinised activities that are often conducted unconsciously, prompting the informants to show skills (knowledge) that are otherwise 'invisible' and reflect and recall meanings concerning why a certain practice is performed. Home tours have been used elsewhere in studies on energy consumption and entanglement of technology, often combined with visual ethnographic methods (Hargreaves et al., 2018; Strengers, 2010).

3.2.4. CONDENSING AND ANALYSING QUALITATIVE DATA

Kvale and Brinkmann (2009) argued that an important step when using interviews as a data collection method is the post-analysis to understand the vast amount of collected data. Qualitative interviews provide a large volume of diverse data, which can be difficult to analyse in a structured way. The pure complexity of condensing hundreds of pages of interview transcripts into a meaningful analytical framework can be overwhelming. Therefore, the researcher must decide on an analytical strategy early on in the process, depending on the research questions. Given the explorative and inductive nature of examining and understanding occupants' heating practices, this dissertation is somewhat inductive in design, asking open-ended questions about routinised activities in everyday life. The thematic backdrop of the interview guide was inspired and rooted in the theory, thus following certain themes shown to be of interest (routines, flexibility, entanglement with technology, and comfort).

The overall approach is abductive in design, which is also reflected in condensing and analysing the collected data. The abductive approach is somewhat pragmatic, combining the openness of the inductive design while focusing on certain themes and ideas. Kvale and Brinkmann (2009) proposed that an abductive approach is appropriate when working with dynamic, unclear, or unpredictable phenomena. Whereas the inductive strategy assumes stable or similar entities from which the research can draw general knowledge, the deductive approach sets out to test the hypothesis based on existing (and established) knowledge. Thus, the abductive approach is better at clarifying unclear phenomena that cannot be directly deducted or inducted.

When analysing the data, different analytical and practical measures can be put into play to condense the vast data into a meaningful framework. In this dissertation, the initial data coding was conducted using the software tool NVivo. This tool allows the labelling and organisation of data, condensing the meaning of the data. The analytical strategy focused on coding the whole dataset multiple times, following an abductive approach. The abductive coding process starts with an analytical induction where the data coding initially focuses on unfolding and 'letting it speak'. This process implies being very loyal to the data content, simply letting labels/codes express the actual content. The analytical induction process aimed to find similarities across the collected data to develop or generate new concepts, frameworks, or ideas. In contrast, the deductive analytical approach translated data coding based on concepts, frameworks, or ideas established prior to the actual coding. This approach focused on the organisation of practices and their relation to other practices, taking in concepts from the literature on the theories of practices. The abductive approach resulted in a coding process that transformed from an open coding list to a closed coding list.

Following this analytical strategy enabled meaning condensation, which is especially valuable when investigating occupants' everyday practices. The approach purpose was to systematically condense data typically expressed in ordinary or layperson language while remaining 'true' to the data and not quantifying them. In this way, meaning condensation serves to analyse complex and unclear material by expressing its natural meaning units or themes (open-ended coding), grouping themes into more interpretationally or theoretically bounded closed-ended codes. The final coding list (consisting of the closed codes and a description of each) is presented in the appendix.

3.3. LIMITATIONS

The following section concerns the limitations of the chosen methodological design, including assessing the data validity and reliability. While each methodological approach produced advantages and drawbacks, practicalities also played a crucial role. One limitation of this study is related to the study cases. When examining the heat demand flexibility potential, an important difference is related to building typologies. Older buildings with a poor thermal envelope are of specific importance because their heat demand is higher than newer and more energy-efficient buildings. In this dissertation, all cases represent relatively newly constructed buildings, which are highly insulated and airtight and are made of relatively light buildings materials (i.e. they have a smaller thermal mass than older buildings; Wittchen et al., 2016, 2020).

The results presented in this dissertation therefore represent how heating practices are performed out in newer buildings, rather than older buildings (typically constructed before 1998; Wittchen et al., 2016). Older buildings represent both potential and challenges regarding heat demand flexibility due to a higher thermal mass and poor insulation but as the research questions concern emerging technologies and how to critically assess their role in future low-carbon transitions, the choice of study cases was deliberate, targeting informants who live in smart homes, which is mostly embedded in newer buildings. As smart home technologies for management of heating are becoming more widely assessable (and cheap), it is anticipated to be embedded in older buildings as well. The lack of cases that represent older buildings in this sample thus has to be considered a limitation of the study. Furthermore, the presented results do not assess the multitude of heating practices on a scale but instead offer insight into how heating practices are reconfigured with smart home technology.

A second limitation is related to the recruitment of informants. An important (and ever-present) question in qualitative research is whether the sample represents the population. Assessing the validity and reliability of the study also implies discussing what another sample could have shown. This limitation relates to the broader population of a study case (e.g. one household over another) and those represented within the household. Concerning the broader population, the recruitment of informants was based on a series of criteria, which included variance concerning sociodemographic variables and household composition.

While the final sample varies in terms of age, gender, and household size, less variance was found in the socioeconomic variables. Informants were generally well educated, held middle- to high-level jobs, and presumably had high incomes (not included as an interview question). The only exception was interviews conducted in the youth housing case, where occupants differed from the rest of the sample in terms of income and occupation. The sample lacked representation of a broader spectrum of the population (such as social housing, detached housing in rural areas, etc.), which is a limitation.

The other limitation relates to the sample and its representation within households. While the recruitment of informants aimed to gather as many household members as possible during the interview, the actual sample consisted of one to two household members, in which males were over-represented. Missing representation from other household members can be problematic because it produces distorted results. The missing representation of household members (e.g. partners or children) who also take part in or may be the main performers of heating practices results in only capturing the practices of those present during the interview. This lack of representation of other household members must be considered a limitation concerning the study validity (internally and ecologically).

CHAPTER 4. SOCIOLOGICAL PERSPECTIVES ON ENERGY CONSUMPTION

This chapter outlines how energy consumption has been approached from a sociological perspective, starting with a general introduction to the sociology of consumption. The reason for including a short introduction to sociological consumption studies, which have been treated in far greater detail elsewhere by Trentmann (2012) and Warde (2015; 2017), is to establish an argument regarding why this dissertation focuses on the mundane aspects of consumption. Following Section 4.1 on ordinary consumption, the practice turn within the sociology of consumption is introduced in Section 4.2. In this dissertation, a specific focus is placed on the role of knowledge and materiality in heating practices. Sections 4.3 and 4.4 are dedicated to further elaborating how these concepts have been treated within theories of social practices. Section 4.5 concentrates on heating and comfort.

4.1. ORDINARY CONSUMPTION

Within social science, consumption has been approached in the context of various disciplines, such as economy, psychology, anthropology, geography, and sociology. Each discipline has directly or indirectly touched on consumption in some way in theoretical and empirical work. Within sociology, studies of consumption were indirectly conducted in the late nineteenth century by classical sociologists, such as Simmel and Weber, and were more directly conducted during the 1930s, where mass-industrial production led to an increased interest in consumption (Warde, 2015). Warde identified three different phases within the sociology of consumption (Warde, 2017). Early and mid-twentieth century sociological accounts of consumption were inspired by economy and considered consumption to be subordinate to the production of goods (Warde, 2014, 2017). Cultural and symbolic aspects of consumption were largely neglected, and the production and distribution of goods were perceived as the main determinants for consumption patterns. The sociological interest in consumption was directed by establishing a critique of unequal distribution of goods, but the rationale was still bounded by economic principles (Warde, 2014, 2017).

The second phase of the sociology of consumption emerged in the late 1970s and early 1980s as part of a broader cultural turn within social and humanistic sciences (Santoro, 2011). The cultural turn reflected a shift in how consumption was approached and analysed. Contrary to previous accounts, consumption in the cultural turn was perceived as symbolic, transforming the individual from a passive to an active agent in explanations of consumption (Warde, 2015). Consumption was understood through individual desires and as a way to express symbolic lifestyle values (Warde, 2014, 2017). The individual was perceived as the primary agent driving consumption.

Leading to the third phase within the sociology of consumption was a critique of the cultural turn. Critics of the cultural turn highlighted that cultural approaches tended to overlook habitual and mundane forms of consumption consumed without much reflection (Warde, 2014, 2017), which includes inconspicuous and ordinary forms of consumption, as argued by Gronow and Warde (2001). According to the critics, cultural consumption studies favoured empirical studies of fashion, cars, and music and paid less attention to studies of energy consumption. According to Warde (2017), another critique of the cultural turn was related to the priority of pure cultural explanations and, thus, the rejection of structural explanations.

Since the millennium, a third phase in the sociology of consumption, called the practice turn, has gained increasing focus (Warde, 2014). The practice turn implies a special interest in examining ordinary and inconspicuous forms of consumption by investigating practices in which consumption is entangled. The practice turn also reinstated the material world (e.g. infrastructure), while maintaining a focus on meanings and symbolic beliefs. In the practice turn, consumption is perceived as a moment in practices (Warde, 2005), meaning that appropriation (i.e. the use of goods) becomes central for understanding consumption. However, aspects of appreciation and acquisition are still included (Warde, 2005, 2014). The practice turn is often related to the theories of social practices, as put forward by Schatzki (2002). In the following section, special attention is paid to the theories of social practices, which have been used as a theoretical framework in this dissertation.

4.2. THEORIES OF SOCIAL PRACTICES

Theories of social practices (also referred to as social practice theory) partly draw on the grand theories of Pierre Bourdieu (1977, 1990) and Anthony Giddens (1979, 1984). The errand is to move beyond the actor–structure dualism, which the grand theories by Bourdieu and Giddens both attempt. Seeking to move away from dualism, Bourdieu (1990) argued that the will and actions of individuals are structured (but not determined) by the surrounding structures. Agents are capable of having their own will and reflective mind. However, through empirical studies, Bourdieu demonstrated that individuals seem to follow certain rules without reflection. For that, Bourdieu developed the concept of *habitus*, which describes the nexus in which individuals navigate and orientate. Bourdieu (1977) stated the following:

> The habitus, the durably installed generative principle of regulated improvisations, produces practices which tend to reproduce the regularities immanent in the objective conditions of the production of their generative principle, while adjusting to the demands inscribed as objective potentialities

> in the situation, as defined by the cognitive and motivating structures making up the habitus. (p.78)

Habitus produces practices that, through enactment, reproduce and evolve the field and habitus. Important differences exist between Bourdieu's concept of habitus and the theories of social practices. Warde (2005) criticised Bourdieu for too much emphasis on predisposed dispositions (structuring how practices are performed) and too little emphasis on the dynamic organisation of social practices.

Theodore Schatzki (1996) and Andreas Reckwitz (2002a) have unfolded the theories of social practices since the start of the twenty-first century. According to Reckwitz (2002a), social order is constituted by 'collective cognitive and symbolic structures, in a 'shared knowledge' which enables a socially shared way of ascribing meaning to the world' (p. 246). Social order should be viewed as dynamic relations between actors through which practices produce and reproduce social order. To Reckwitz, practices are the smallest unit of social analysis if one aims to understand social order. In other words, social practices are the place of the social (Reckwitz, 2002a). Nevertheless, what are practices? Schatzki (2012) defined social practices as 'the sayings and doings' situated in a specific space and time: 'A practice, on my understanding, is an open-ended, spatially-temporally dispersed nexus of doings and sayings' (p. 14).

Schatzki (1996) made an important distinction between practices as entities and practices as performances. On one hand, practices are comprised and sustained by rules, purposes, beliefs (teleoaffective structures), and practical understandings, which form a nexus in which 'doings and sayings' are coupled together and coordinated. This nexus is what Schatzki (1996) referred to as practices as entities. On the other hand, practices as performances represent the set of activities that individuals (carriers of practices) enact, reproducing practices as entities (Schatzki, 1996).

Reckwitz (2002a) contributed to this understanding by distinguishing between *praxis* and *praktik*. Praktik is described as routinised behaviour, consisting of bodily activities, knowledge, and know-how, whereas praxis is socially shared and can be compared to the concept of practices as entities (Reckwitz, 2002a). Praxis refers to 'the rules of the game' through which individuals are oriented.

Practices are conceptualised as organised activities constituted and sustained in a nexus where individuals orientate, but also enacted in everyday life. What organises these activities is less clear, and scholars do not agree on this. Schatzki (1996) highlighted practical understandings, rules, and teleoaffective structures as what constitutes practices as entities (produced and reproduced through enactment), whereas other scholars, such as Warde (2005), Shove et al. (2012), and Reckwitz (2002a), applied a similar understanding but referred to this linkage using other terms, such as components or elements. For a comprehensive overview, see Gram-Hanssen (2011).

As outlined in Section 4.1, the practice turn also implies a renewed empirical focus of routinised and mundane consumption, rather than what can be labelled symbolic and visible (conspicuous consumption). The practice turn and much of the empirical research relying on such an approach aim to understand and deconstruct normality. That implies examining consumption patterns that are taken for granted and tracing their development and entanglement in social practices.

Warde (2005) argued that almost every practice includes consumption, as practices entail 'appropriation and appreciation' (p. 137). Thus, consumption is a moment in most practices, according to Warde. Understanding and examining consumption and how it develops must start with understanding these practices (Warde, 2005). In other words, it is necessary to understand '"why do people do what they do?", and "how do they do those things in the way they do?"' (Warde, 2005, p. 140).

In the next two sections, a special focus is devoted to the role of knowledge and materiality in practices. As detailed above, these two are highlighted as elements or components linking a practice together. While meanings or teleoaffective structures also represent an element in the constitution of practice, for example, concerning comfort norms, this dissertation focuses on the roles of knowledge and materiality in heating practices. This priority does not imply that meanings (symbolic beliefs, norms, and desires) are not important in the (re)configuration of practices, and this element is also included throughout the collection of papers. Focusing on materiality and knowledge is due to an interest in the visions of smart home technology for enabling heat demand flexibility. Smart home technologies are first and foremost material objects integrated into homes, but they also include new forms of agency implying a change in the knowledge needed for conducting home heating. Thus, it remains interesting to investigate how the introduction of new technologies reconfigures heating practices and, specifically, how or whether the knowledge used for conducting heating changes.

4.3. THEORIES OF SOCIAL PRACTICES AND KNOWLEDGE

In his account of theories of practices, Schatzki (2002) referred to knowledge as practical understandings, representing a form of habitus or skilled capacity that guides people's enactment of organised activities. Warde (2005) offered a similar conceptualisation, labelling it as understandings, defined as 'knowing how to do something, a capacity which presupposes a shared and collective practice involving performance in appropriate contexts and mastery of common understandings, which are the grounds for a particular act being recognizable as explaining' (p. 135). Both conceptualisations of knowledge in theories of social practices represent knowing how to perform in a certain manner. Knowledge is more than an explicit form of knowledge; it is also a bodily manner of 'doing', as argued by Wallenborn and Wilhite (2014).

Gram-Hanssen (2011) provided a helpful conceptualisation of how to perceive and differentiate between embodied know-how and habits, and institutionalised knowledge and explicit rules. This conceptualisation specifies how knowledge and its role in practice formation should be understood as formalised rules and as something that is embodied and less conscious, drawn upon by individuals. Another account of how knowledge is related to bodily enactments in practices was presented by Wallenborn and Wilhite (2014), who argued for collapsing both body and mind in reference to knowledge. The authors proposed that knowledge about energy consumption is mediated into the body through a process of mediated (personal and cultural) experiences.

As outlined in the paragraph above, knowledge is treated and given a special place in theories of social practices. It represents one of the elements in linking a practice; that is, it plays an active part in how practices are performed and constituted as an entity. Reckwitz (2002a) noted that knowledge should not be perceived as inherent within the individual agent but instead as belonging to the practice itself. Given the rationale in theories of social practices, individuals are merely carriers of certain practices (and of knowledge). How people perform everyday practices, such as home heating, is configured by spatially temporal practice entities (Reckwitz, 2002a). People are the active performers of these practices, but elements, such as knowledge, 'belongs to the practices', to which people can be recruited (performing in a certain way), and they can defect from such practices, as argued by Shove et al. (2012).

Policy interventions aimed at modulating household energy consumption have also had a specific interest in knowledge and how to use knowledge to the benefit of the intervention. In Denmark, households can obtain guidance and energy audits at home, and information campaigns have educated people on how to operate heating most efficiently (e.g. how to ensure a low return temperature). As outlined in Chapter 2, the effect of energy interventions has been questioned in the literature, but that does not necessarily imply that knowledge cannot be targeted and changed. The question may be more about how the role of knowledge is understood and used in policy interventions. Taking a practice-theoretical approach by considering knowledge to be part of the elements that constitute practices lays out a framework for understanding policy interventions and why explicit knowledge (e.g. energy feedback) does not translate into changing people's practices.

As people act as carriers of practices, the knowledge they apply is formed by spatio-temporal configurations of practices (i.e. it might be disconnected from current material circumstances or societal norms). People might have very different ways of performing heating practices, applying different kinds of knowledge (prefigured by their material surroundings). They carry certain practice configurations along in life, meaning that the way they perform heating practices is dependent on previous experiences and exposure. Therefore, their practice performances are produced in a spatial-temporal manner and constantly reproduced.

The critique of policy interventions targeting energy consumption and how to modulate it, as in the case of heating in this dissertation, is that policy interventions primarily concerns institutionalised forms of knowledge and not embodied forms, as Lutzenhiser argued (2014). A similar argument was made by Strengers (2013), stating that the widespread perception among sector professionals and policymakers resulted in DSM initiatives that rely on providing feedback or other forms of institutionalised knowledge to the occupants, neglecting the more embodied know-how already in place. The result of this one-sided focus might be that people create workarounds or interfere in other ways with their technologies, making the intervention less successful and short-lived, as detailed in Chapter 2. Instead of targeting embodied forms of knowledge (and how to activate such), new technological advancements aim to bypass occupants (and what is perceived as a lack of knowledge) by applying increasing levels of automation. In an article examining user imaginaries among technology developers for smart grid projects, Skjølsvold and Lindkvist (2015) proposed that people and their involvement in smart grid projects are often abolished due to concerns about occupants lacking knowledge for engaging more actively.

4.4. THEORIES OF SOCIAL PRACTICES AND MATERIALITY

As detailed in much of the literature on theories of social practices, materiality plays an important part in producing and reproducing what people do and say and thus how they consume energy. However, what is materiality, and how should we understand its role in shaping everyday energy consuming practices? These questions are the focus of this section.

Materiality (sometimes also referred to as matter) often refers to objects. However, to distinguish materiality from other entities, some scholars within the theories of social practice literature have attempted to clarify what characterises materiality. Schatzki (2010) suggested that materiality must be understood as physical-chemical compositions, such as humans (bodies), artefacts, organisms, or nature. Schatzki (2010) also proposed that materiality must be understood in relation to social life:

> Society is not just inevitably and ubiquitously linked to materiality and nature: the latter is a dimension of the former. More precisely, almost all social phenomena have a material dimension comprising the arrangements of material entities in which these phenomena partly consist, the physical-chemical composition of these entities, and captures or moments of the matter-energy and biological flows that pass through these arrangements. This material dimension is causally interdependent with the human practices that also compose social phenomena. It, in addition, prefigures and mutually

> constitutes these practices and is intelligible to the humans involved by virtue of their practices. (p. 141)

According to Schatzki, materiality is part of the arrangements where practices unfold, but, contrary to Shove et al. (2012), he did not consider materiality to be an element. Instead, Schatzki (2010) underlined how materiality is related to the configurations of social order. According to Schatzki, the understanding of materiality and its connection to practices is more diverse than just as a support for social life.

Schatzki (2010) developed four characteristics for the relations between materiality and practices: causality, prefiguration, constitution, and intelligibility. Causality refers to causal effects between materiality and practices (e.g. practices involved in rearranging materiality) and among materialities (i.e. not involving practices). Prefiguration refers to how materiality prefigures certain practices, making them easier or more difficult to perform. Concerning constitution, Schatzki referred to two ways in which materiality constitutes a practice: either being essential or constituting practices through space and time. Lastly, Schatzki referred to intelligibility in that the materiality that comprises certain practices is intelligible to the individuals who enact them. In Schatzki's understanding, materiality locates practices in time and space. They damage, create reactions, are used, and set up.

Reckwitz (2002b) also devoted a paper to the status of materiality. Reckwitz (2002b) traced the status of materiality from classical sociology (sociology of knowledge), which conceptualised materiality as social structures, to the cultural turn, which perceived materiality as objects of knowledge (or symbolic objects), to Latour's symmetric anthropology and theories of social practice, which is situated between perceiving materiality as neither a social structure nor symbolic objects. Latour argued that material status is in terms of the 'artefacts' that are active components in social practices (the same level of agency as humans; Reckwitz, 2002b). In this way, Latour adopted a flat ontology, giving equal agency to both material and social aspects, as 'artefacts' are exposed to human interpretation, while they are used and handled within their own materiality. In this way, artefact entanglement in social practice goes beyond human interpretation, extending and including how they are 'handled', constituting certain practice performances (Reckwitz, 2002b).

While not being completely comparable, Latour's symmetric anthropology and the theories of social practices, as outlined by Schatzki in the paragraphs above, have some similarities. While both theoretical strains highlight the importance of how materiality is more than symbolic or pure social structure (identifying them as important elements), theories of social practices adopt an asymmetric rather than symmetric relationship (Reckwitz, 2002b). As developed in the theories of social practices, materiality is only important within social practices when people perform these practices. In this way, people as agents are given a higher status, as they are carriers of practices, whereas materiality is not.

Shove et al. (2012) proposed that materiality is explicitly defined as an element in practices. Shove et al. suggested that materials are what constitute practices (with meanings and competencies). Shove et al. stated that most reconfiguration of practices involves materiality, and most change in practices can be contributed to the material. Simultaneously, materiality is a mobile entity that can be shared by practices and shifted from one to another.

Shove (2017) developed an understanding of materiality by adding a relational layer (as did Rinkinen et al., 2015), arguing for the importance of differentiating the different roles that materiality has concerning practices. Shove defined material relations as resources, infrastructure, and devices. Materials have an infrastructural relation to practices when they appear in the background or off the scene. These are still very tangible objects, but people do not engage directly with them (Shove, 2017). Typical examples are pipes, power grids, or data. Materials as devices related to practices are defined by Shove (2017) as materiality directly used in the performance of practices, meaning that they are very visible (contrary to infrastructure) and are actively used by people. Perceiving materiality as devices involves examining how materiality as devices is included in shaping the practice itself (e.g. some devices define who can use them; Shove, 2017). The last material relation that Shove developed is referring to materiality that is used up. Shove labelled it a resource relation. This relational form is specifically related to how materiality changes when being consumed. This last conceptualisation also highlights that materiality has a physical-chemical composition while also constituting practices.

Another important point that Shove (2017) made was that material relations are combined and sequenced. While infrastructure acts in the background, it connects to visible aspects, and Shove argued that infrastructure acts as the mobilisation of things in action. Similarly, Shove stated that material relations are dynamic and in flux (i.e. they can shift status). While heating is tied to material relations as devices, in the future, it might become more of an infrastructure and less of a device relation that characterises it. Following Shove's conceptualisation, the smart grid acts as a material infrastructure that mobilises smart home technologies in people's homes.

4.5. HEATING AND COMFORT

Heat has typically been perceived in physical terms, as noted by Oppermann and Walker (2019). From this perspective, heat is understood as energetic flows that are vital for being. Oppermann and Walker (2019) argued that heat should be understood in a social context beyond physics. Oppermann and Walker (2019) suggested that heat should not be conceptualised as an element of practice (as done by Shove et al., 2012), but as 'energy that circulates within and between "the" elements or components of practices, enabling their very materiality to mobilise and emerge at a chemical and physical level' (p. 134).

By conceptualising heat in this manner, heat becomes materiality used within practices, while it is also an outcome of practices, flowing through practices (Oppermann & Walker, 2019). While this conceptualisation might blur the understanding of what heat is, the important item to note is that people appropriate and appreciate heat in performances of practices (while also being an outcome). From a social scientific approach, heat can also be understood in social and cultural contexts.

Empirical studies of how occupants heat their homes have shown that occupants reconfigure their heating practices with material and social configurations, such as moving away (Rinkinen & Jalas, 2017), changing material artefacts (Madsen, 2018), or processing a certain kind of knowledge (Royston, 2014). Conceptualising heat in terms of how it is appropriated and appreciated and examining practices that entail heat consumption and how they are reconfigured add another perspective to the role of heating in a low-carbon transition. This entails investigating a broader socio-technical reconfiguration regarding how heat demand is in a dynamic flux, connected in bundles to other practices, such as ventilating and cooking.

If heating and its role in low-carbon transitions are understood in purely physical and technical terms, removed from social aspects, policy interventions might misinterpret how heat demand develops. Thus, future predictions of heat demand flexibility might be inaccurate. In technical studies of heat demand flexibility, an important aspect (often characterised as a social element) is comfort (Jensen et al., 2017). As outlined in Chapter 2, comfort has often been understood as thermal comfort in the technical literature, following Fanger's (1970) heat balance model, which is an understanding of thermal comfort as stable and universally predictable. Technical science aims to predict how to deliver and maintain a stable temperature (defined in comfort standards) to occupants while enabling heat demand flexibility. In studies on heat demand flexibility, comfort (and the social aspect of heating) is often calculated or modelled based on material or psychical aspects (i.e. how effective the building mass is at absorbing heat and maintaining a certain temperature; Le Dreau & Heiselberg, 2016).

Social scientific research on comfort has pointed towards a different approach to comfort and understanding how heat demand develops. Rather than approaching comfort as a physiological concept, Shove (2003) defined comfort as a socio-technical concept. This approach underlines the social and cultural aspects of comfort, challenging the dominant paradigm within studies of comfort and related comfort norms (Shove, 2003). The critique put forward by Shove is aimed at challenging standardised comfort conventions and the state of normality. By tracking the development of how comfort (and cleanliness and convenience) has been normalised through technological developments, policy (and the legal framework), and the performance of everyday life, Shove (2003, 2008) stated that technical solutions (such as energy-efficient technologies) are not always sufficient for modulating heat and cooling demand in residential buildings.

Studies inspired by Shove and others have empirically examined differences in comfort between households, underlining the social and cultural aspects. Wilhite et al. (1996) presented differences in energy consumption between households in Norway and Japan, underlining the social and cultural differences in heating, bathing, and lighting practices. Wilhite et al. found that energy-intensive practices and the differences in their performance can be ascribed to different notions of comfort and what it means to be cosy (Wilhite et al., 1996). Gram-Hanssen (2010) demonstrated how space heating practices are performed differently between households who share similar material settings, highlighting the different social configurations of knowledge and meaning (e.g. notions of comfort), which also constitute how heating is conducted. Heating practices are constituted by social and cultural aspects while being prefigured by material settings, as revealed by Madsen (2018) and Rinkinen and Jalas (2017).

4.6. SUMMARY

Sharing similar materiality is key in the configuration of social practices. By having a uniform heat provision, which Denmark offers to some degree, a certain way of performing heating practices is also prefigured. In the Danish context, many households use the same materiality (devices) when they heat their homes, typically involving radiators and manual valves. On a similar note, the district heating network represents a material infrastructure, and many occupants have a certain understanding of and ideas about it. While sharing similar materials might result in similar way of performing heating practices, elements of meaning and knowledge have also influenced the configuration of heating practices, making it wrong to assume that Danish households have similar heating practices

The case of Denmark is still interesting due to the high penetration of district heating in households. With the new influx of smart home technologies, the materiality in heating practices in Denmark is changing. Management of heating is becoming digital, and occupants can operate their temperature settings from outside their homes using connected devices. The smart grid can be considered a material infrastructure that mobilises an array of new material devices in people's homes, which they can actively engage with in performing heating practices. According to Shove et al. (2012), the key to understanding heating practices is to explore how they are reconfigured when new materiality is used in heating practices. This understanding involves exploring the knowledge and competencies needed to control and manage smart home technology and how comfort norms change with this new materiality.

In Schatzki's terminology, the relation between materiality and practices is somewhat different, but materiality is still conceptualised in relation to the social world.

Following Schatzki, smart home technology integration can prefigure heating practices, making it easier or more difficult for occupants to conduct heating. Furthermore, it can rearrange practices and other materials inside the home, which implies that smart home technology can have a causal effect on how practices are performed (e.g. concerning teleoaffective structures of competencies). It can also have a causal influence on other materials in the home, such as underfloor heating or radiators. Smart home technology can also be perceived by how it constitutes heating practices by becoming an essential technology for heating practices and a material constituting practices through space and time.

These conceptualisations of materiality given by Schatzki (2010), Shove et al. (2012), and Shove (2017) contribute to the understanding of smart home technologies as a material object within practices. Whether it is perceived as a background of social life (Schatzki, 2010) or as part of the elements that link elements in a practice (Shove et al., 2012), it becomes clear that smart home technologies must be understood in relation to the social world. As smart home technologies enter people's homes, they become tangible objects that rearrange practices and how they are performed.

CHAPTER 5. KEY INSIGHTS FROM THE COLLECTION OF PAPERS

In the following chapter, the main insights this dissertation brings forward are presented and summarised. Five papers are included in the dissertation, each providing new aspects of the role occupants may have to transition to flexible heat demand. Together, this dissertation provides new knowledge on how heating practices are reconfigured when smart home technologies for heat management are integrated into households. All papers are based on the same sample, consisting of in-depth interviews and home tours with 22 occupants in 16 different households.

Papers I and II provide initial insight into the field of smart home technologies for heat management, including a review of the technical capabilities and embedded visions. The first two papers aim to discuss the interdisciplinary approach and make a case for why more sociological knowledge on the occupants' role is needed. Papers III and IV further detail heating practices, exploring how they are reconfigured by focusing on the role of competencies and concepts of control. The contribution from these two papers is sociological and touches on aspects of everyday life. Paper V is based on an interdisciplinary approach, bringing the understanding of heating practices and how they are reconfigured into the field of building modelling, assessing assumptions of spatiotemporal temperature variations.

5.1. KEY INSIGHTS FROM PAPER I

The first paper, *Smart Home Technology Enabling Flexible Heating Demand: Implications of Everyday Life and Social Practices*, is co-authored with Prof. Kirsten Gram-Hanssen and Associate Prof. Anna Marszal-Pomianowska. The paper provides a state-of-the-art review of smart home technology integration in Danish households for heat management in a district heating network. Based on a review of 155 cases in real-life settings, the paper develops a classification and analytical framework of the how, who, and what of smart home technology in a district heating network. The analytical framework is applied to 21 cases, reviewing them in detail regarding technical components (how), actors involved in control (who), and which part of the home is controlled (what). Based on this classification, we discuss the implications of everyday life and social practices when integrating this new technology. The paper aims to place smart home technologies for enabling heat demand flexibility into a sociological perspective of consumption and argues for an interdisciplinary approach.

We found that smart home technologies for heat management include a technical setup where user interfaces for control are combined with automated solutions, allowing occupants to interact directly with heat management while deploying automation for simplification and heat demand flexibility purposes. The technological setup indicates a techno-optimistic view, which aims to empower occupants with the notion of being in control of their home by defining heating preferences while enabling a convenient and efficient heat demand using automation.

A similar techno-optimistic view was found concerning the actors involved in heating control. The most widespread modes of control were a combination of decentralised (e.g. in-home display) and automated modes, meaning that occupants had control possibilities (e.g. overriding) while technologies were using some degree of automated control (e.g. through prediction and sensor technology). Furthermore, we found a recent shift from standalone solutions towards integrated solutions (connecting various appliances in the home), indicating that future smart home technology solutions could include various household appliances controlled from a single entry point.

We conclude with a discussion on the current state of smart home technologies for heat management and the possibility of enabling heat demand flexibility. Based on the discussion, we indicate that smart home solutions based on automation and limited occupant involvement risk pursuing stationary visions of convenience and comfort at the expense of enabling heat demand flexibility. We suggest that the current smart home technology integration in the district heating network may not achieve its potential of enabling heat demand flexibility, and more research on the reconfiguration of heating practices is necessary.

5.2. KEY INSIGHTS FROM PAPER II

The second paper, *User Engagement with Smart Home Technology for Enabling Building Energy Flexibility in a District Heating System*, is co-authored with postdoc Hicham Johra. The paper provides preliminary results from qualitative interviews in 16 Danish households and explores how occupants engage with smart home technology for heat management and the possible implications for load-shifting heat demand. The paper was presented at a conference concerning the future of low-energy buildings, and the aim of the paper was, among others, to inform and provide knowledge on the role of occupants into the technical sciences, bridging two fields of research. Understandings of heating practices is thus not treated in detail but put into a wider perspective.

Based on an overview of four cases, including the technical and social aspects, the paper provides three main observations on how occupants engage with smart home technology when performing heating practices. We found that experience with network-connected technologies, such as smartphones, seemed important for occupants' engagement with their smart home systems. Occupants with more experience with ICT devices seemed to engage more actively with smart home technology and generally expressed ease and trust in doing so. In contrast, occupants with less experience engaged less and expressed dissatisfaction and uncertainty.

Second, the interviews indicated that notions of comfort might increase with the integration of smart home technologies. Occupants appreciated the convenience of heat management enabled by smart home technologies, as it provided them with remote control of heating. The occupants expressed an increase in comfort due to these new control possibilities. The convenience of smart home technology control was primarily perceived by the occupants as a means to increase their comfort and not to enable heat demand flexibility.

Third, we found highly differentiated ways of engaging with smart home technology, often contrary to the intended design. In many instances, occupants conducted workarounds because the smart home technologies 'interfered' with other practices performed in the home. The occupants expressed concern about the potential of enabling heat demand flexibility with the technology due to the entanglement of other materialities in the home.

5.3. KEY INSIGHTS FROM PAPER III

The third paper, *When Space Heating Becomes Digitalized: Investigating Competencies for Controlling Smart Home Technology in the Energy-Efficient Home,* is co-authored with Prof. Kirsten Gram-Hanssen. Based on qualitative interviews and home tours with occupants in 16 Danish households, the paper explores the role of competencies in the performance of heating practices using smart home technology.

The paper explores how heating practices are reconfigured differently, depending on which competencies occupants carry and embody. To that end, four variations of how heating is performed are presented, displaying four ideal types of households: tech-savvy households, 'no friction' households, reluctant households, and devoted but limited households. The results indicate a relationship between occupants' experience with ICT (defined as competencies) and their engagement with smart home technology. Some occupants possessing a high level of ICT competence had greater ease engaging with smart home technology for heat management, whereas others with low ICT competence had greater difficulty. Furthermore, the results indicate that the competencies are embodied in the occupants; thus, experiences with similar technologies prefigure easier use and engagement with smart home technologies.

Importantly, the results reveal that competence alone does not constitute how heating practices are performed (e.g. high-level ICT competence does not necessarily imply engaged occupants). Instead, the results indicate that competencies are one element in the reconfiguration of practices, which must be understood in relation to the shared meanings and material objects and their part in heating-practice configurations.

The paper concludes that occupants routinely draw on embodied forms of knowledge when performing heating practices and with the integration of smart home technologies, heating practices reconfigures in different ways. A challenge for future smart home technology rollout is that it is impossible to foresee how occupants will engage with the technology and that supplying occupants with 'rational' and 'energy expert' knowledge does not necessarily lead to specific engagement modes. The paper highlights that the current scenarios for smart home technologies and their use in enabling heat demand flexibility are limited in scope, relying too much on a simplistic understanding of competencies. Future initiatives should include considerations of how occupants draw on different sets of competencies and engage with smart home technologies differently.

5.4. KEY INSIGHTS FROM PAPER IV

The fourth paper, *In Control or Being Controlled? Investigating Control of Space Heating in the Smart Home*, explores the concept of control in relation to smart home technologies. The results highlight three aspects of specific importance: practical knowledge, notions of being in control, and temporal aspects of everyday life. First, the practical knowledge needed to control heating in occupants' homes is reconfigured when smart home technology is integrated. Second, how control is performed and understood is influenced by shared meanings that occupants ascribe to their homes and everyday lives and what it means to be in control. Third, the results indicate that control is to be understood as a relational concept, influencing the temporal aspect of everyday life. Furthermore, the paper provides empirical evidence regarding how occupants perform control when feeling out of control. To maintain a meaningful performance of practices, occupants tend to conduct workarounds when feeling out of control.

A new conceptualisation of control is suggested by drawing on these insights, considering control in the context of social practices, which is broader than aspects of technology design. This conceptualisation perceives control as the outcome of social practices, facilitating a broader and multifaceted approach where knowing how to control, notions of being in control, and the embedded control features are all included. Furthermore, control is produced and reproduced in the performance of practices, reconfiguring agency and the temporality of control.

Based on the empirical findings and the new conceptualisation of control, the paper provides four implications for the design and policy of smart home technologies for enabling heat demand flexibility. The following initiatives are recommended: design for homely practices, increase familiarity with technology, increase the role of intermediaries and consider contradictory visions.

5.5. KEY INSIGHTS FROM PAPER V

The fifth paper, *Thermal conditions vary in time, space, and between households. Is the assessment of building flexibility potential correct?,* is co-authored with Associate Prof. Anna Marszal-Pomianowska, Prof. Kirsten Gram-Hanssen, and Prof. Per Heiselberg. The paper is based on a mixed-method approach, combining a quantitative dataset on heat consumption in 24 different households with a qualitative sample of interviews and home tours in 16 different households. The paper explores the concept of flexible buildings and the assumptions behind this. We empirically demonstrate that temperature settings vary in three dimensions, namely space, time, and between household units. We further provide qualitative empirical insight, showing how practice performances cause spatiotemporal variations in temperature settings. We indicate the following five aspects of social practices, which cause spatiotemporal variations: activity-based, caring, comfort, convenience, and surroundings. By highlighting these interdependent and non-exclusive aspects of practice performances, we demonstrate that heat variations in households are the outcome of certain practice configurations.

Therefore, we argue that assessments of the flexibility potential in using buildings as short-term heat storage must include perspectives on how occupants perform practices in time and space. The gap between estimated and actual heat demand flexibility is depending on more than materials and differences in building typologies. Instead, our results make a case for more accurate modelling work, including aspects on how practice performances results in certain spatiotemporal variations of temperature settings. We propose that it is problematic to use one room in an apartment as a representative for modelling. We recommend that future modelling work uses zonal differences in temperature.

Concerning temporal variations, we suggest that modelling work must acknowledge variations caused by the performance of practices. We indicate that preheating considers the performance of practices and that preheating bedrooms during the early morning might be difficult because it goes against the shared meanings of sleeping in a cold room. Nevertheless, we find that preheating bathrooms might be more suitable due to certain practice configurations.

CHAPTER 6. CONTRIBUTIONS AND IMPLICATIONS

This dissertation investigated heating practices and how they are reconfigured when smart home technologies for enabling heat demand flexibility are integrated into households. The answers to this research question were sought through qualitative interviews and home tours with occupants, adding to a pool of research on occupants and their role in low-carbon transitions. This dissertation aimed to understand the social dynamics of potential flexible heat consumption by providing empirical insight into how occupants perform social practices.

This chapter highlights the main contributions by discussing the empirical findings presented in the collection of papers. Furthermore, by working in an interdisciplinary manner, an important aim of this dissertation was to contribute to developments in decarbonising the district heating network by providing knowledge of the occupant role. In the final section, implications and recommendations are presented for policy and research on low-carbon initiatives in the district heating network.

6.1. DISCUSSION OF KEY FINDINGS

The use of smart home technologies for modulating heat demand in a district heating system is relatively new, and this dissertation contributes one of the first investigations of how occupants engage and use these technologies in relation to heat demand flexibility. Knowledge on the occupant role is called for because the potential for energy modulation using various demand-side technologies for load-shifting has shown diverse results in evaluations, implying that occupants might be crucial for more accurate energy effects (Buchanan et al., 2015; Darby, 2018). The main task of this dissertation was to provide initial insight into the social dynamics of how occupants engage with and use smart home technologies in real-life settings when using residential buildings for short-term heat storage. Based on this insight, policy implications on future decarbonisation initiates in the district heating network were derived.

The methodological approach in this dissertation sought to focus on heating practices, studying them in detail to understand what constitutes them and how they are reconfigured with new technology. In doing so, the theories of social practices provide the conceptual framework. Practices have been perceived as the core analytical unit to understand heat demand and the possibilities of shifting it. In the following section, three main aspects derived from this dissertation are placed into a wider perspective.

Some of the findings presented in this dissertation focus on the role of knowledge. This focus was applied due to an interest in examining the very different ways occupants perform heating practices, configured by both material and social aspects, which seemingly differ from industry assumptions of occupants and their engagement with the technologies (Strengers & Nicholls, 2017). The dissertation findings supplement the growing body of literature concerning how occupants engage with smart home technologies for energy management by showing the embodied knowledge that occupants draw upon when conducting heating practices using smart home technologies. How heating practices are configured and performed in very different ways is presented, resulting in various engagements with smart home technologies for heat management.

While the results seem generic in some aspects (e.g. that practices are important for shaping heat demand), these empirical insights are needed to challenge existing ways of assessing DSM and modulating heat demand. Perceptions about occupants and their role in flexible heat demand initiatives still seem dominated by a technocentric perception, in which technologies (using automation) are expected to deliver the needed load shift (Paper I). As indicated in this dissertation and argued elsewhere (Skjølsvold & Lindkvist, 2015; Strengers, 2013), occupants are perceived as passive agents in load-shifting activities, and scenarios tend to rely on automation for load-shifting. As the current technological approaches towards modulating heat demand only include occupants to a limited degree (e.g. concerning their preferences on comfort), they risk neglecting important social dynamics of heat consumption.

As the dissertation reveals, heating practices cannot be considered static. With smart home technology integration, heating practices are reconfigured, possibly leading to unintended energy effects and disruptions in everyday life. Future DSM initiatives must include occupants as active agents (along with smart home technology initiatives). Solely using automation for load-shifting does not seem to be a reliable method of enabling heat demand flexibility, as heating practices are dynamic and constantly reconfiguring.

A second focus throughout this dissertation was smart home technologies and their role as a material object in the home. In this relation, the core focus was to investigate how new materiality reconfigures existing heating practices, including perspectives on how occupants engage with the technology. This focus was central due to the technocentric approaches applied in DSM of heating, which others have also highlighted (Ingeborgrud et al., 2020; Skjølsvold & Lindkvist, 2015; Strengers, 2013). In the collection of papers, how materiality is entangled in heating practices and that occupants engage with smart home technologies in very different ways are demonstrated. Smart home technologies must be considered socio-technical entities, acting as sites for negotiations. Occupants engage with smart home technologies in ways that they find meaningful and feel competent doing, despite the embedded visions and knowledge in technology. This situation implies that, while some occupants find it meaningful to engage, others do not. While enabling heat demand flexibility is a concern to practitioners and policymakers, it might not be for occupants. Providing them with the ‘tools’ or technology for enabling load-shifting may not result in the expected energy effects. This perception of materiality does not imply a disregard for materials and technologies as opportunities for change in a transition perspective but instead argues for a broader, more holistic understanding of how technologies constitute heat demand.

A third and important perspective provided in this dissertation is that (embedded) visions of heat demand flexibility are not necessarily translated into actual performance when engaged with by occupants. As smart home technologies seem to rely on automation for enabling heat demand flexibility, the role of the occupants is merely as passive recipients of comfort and convenience. These contradictory visions of smart home technologies involve a risk of driving demand in a different direction than intended. By perceiving occupants’ preferences as static and not involving occupants directly in load-shifting activities by challenging existing comfort norms, there is a risk that occupants might use smart home technologies to increase their comfort and maintain inflexible practices. This may result in less flexible heat demand patterns because it risks strengthening the existing heat consumption patterns and associated practices.

6.2. CONTRIBUTIONS

As one of the first in-depth studies of occupants’ heating practices in a future flexible low-carbon district heating network, this dissertation aimed to contribute knowledge that can be applied in current and future DSM interventions. In the following paragraphs, the most important contributions to the research on occupants and their role in future low-carbon district heating networks are outlined.

A primary contribution was to nuance the picture of current and future initiatives that aim at enabling heat demand flexibility. The task was to investigate the role of occupants in a largely technocentric array of solutions. This dissertation reveals that the potential for heat demand flexibility is part of practice-arrangements. Similar arguments have been made both in empirical and conceptual work, but this dissertation provides one of the first empirical insights into how heating practices are configured related to low-carbon district heating and demand flexibility. The flexibility potential, being part of practice-arrangements, implies that materials (such as smart home technologies) and social dynamics (norms and knowledge) matter in unleashing heat demand flexibility in the district heating network. Therefore, future research must adapt a more holistic perception of the occupants’ role, considering dynamic practice-reconfigurations.

This dissertation contributes to an increasing pool of research aiming to empirically investigate the role of smart technologies in energy transitions. The bulk of this research has focused on how smart technologies are entangled in the performance of everyday life practices and what that implies for energy consumption (e.g. Darby, 2018; Gram-Hanssen & Darby, 2018; Hanmer et al., 2019; Hargreaves et al., 2018; Marikyan et al. 2019; Mennicken & Huang 2012; Nyborg & Røpke, 2011; Strengers, 2013). Most of this research was conducted concerning electricity consumption. This dissertation provides important empirical evidence for tendencies related to district heating and how to approach heat demand flexibility from this viewpoint.

Furthermore, the dissertation adds to the same pool of evidence investigating how smart home technologies affect everyday life and practices people perform. Control of smart home technologies should be understood as a multifaceted concept and as the outcome of social practices. Spatiotemporal aspects of heating practices are changing with smart home technology, indicating that notions of comfort and convenience might change (possibly leading to a less flexible heat demand). Furthermore, smart home technologies also influences the competencies needed for the proper performance of heating, and smart home technologies can be a place for increased negotiations in the home.

Heat consumption is a moment in the performance of social practices, and heat variance in time and space, which is urgent for enabling heat demand flexibility, is the outcome of what people do. Furthermore, this empirical work indicates why practices are performed differently, and add non-technical evidence for differences in heat demand between households. Know-how or practical knowledge is something that people draw on when they conduct heating practices. Rational or energy expert knowledge on operating energy technologies (such as smart home technologies) might not be appropriate or sufficient to make a transition. Future initiatives must consider the role of knowledge that people ‘carry’.

6.3. RECOMMENDATIONS AND IMPLICATIONS

Working with the research question that aims to investigate an interdisciplinary problem, an important aim of this dissertation was to derive implications for future policy interventions. The presented findings apply to a wider audience of practitioners and researchers alike, working together for a low-carbon heating transition. Based on the findings, four general recommendations for enabling heat demand flexibility in the district heating network are proposed.

Overall, energy flexibility issues must be perceived from a holistic perspective because heating consumption (and how demand develops and shifts) is entangled in the performance of practices. These are the ‘sayings and doings’ that occupants perform in a habitual manner and with various intentions. Policies must support the social, mental, and material aspects of occupants’ lives to strengthen the potential for demand flexibility.

6.3.1. INCREASED INTERDISCIPLINARY COLLABORATION

A recommendation based on the findings is that collaboration between different disciplines must be increased. Knowledge and specific experiences need to be shared in interdisciplinary forums to a much higher degree. While technical disciplines have gained a high degree of knowledge on heat demand flexibility, little is still known about including occupants in future low-carbon transitions in the district heating network. Bridges must be built between different disciplines and professions to gain knowledge of occupants in DSM initiatives, including working in interdisciplinary teams, where researchers and practitioners with different backgrounds and professional knowledge are represented. Moreover, SSH must be included in earlier stages in DSM initiatives, allowing for engaging with and unfolding the narrative of smart home technologies and how the narrative influences the possibilities for enabling heat demand flexibility.

Furthermore, collaboration must be supported by practitioners and researchers. There seems to be a gap between commercialised products that can potentially enable heat demand flexibility and research projects directed towards enabling heat demand flexibility. Representatives from industry and research need to increase collaboration. A broad lift of knowledge (on technologies and occupants alike) must be supported to promote such collaboration, and securing access to such knowledge is essential.

6.3.2. ENERGY DEMAND FLEXIBILITY ACROSS POLICY AREAS

Policy plays a vital role in shaping scenarios for heat demand flexibility, extending to both national and international levels by e.g. introducing the Smart Readiness Indicator in European member states. Based on the findings, heat demand flexibility does not merely concern energy policy; collaboration across policy areas must be supported and promoted. Issues of flexible heat demand are entangled in performing various everyday practices and must be a concern for other policy areas, ensuring that demand flexibility issues do not become only a question of technical energy solutions but also involve broader societal rhythms and how to shape them more flexibly. To that end, including questions of heat demand flexibility across a political and policy sphere promotes shared meanings and understanding of what needs to be done.

From a broader perspective, it is important to include questions of sustainable consumption across different policy areas. Recently, this trend has been observed in climate considerations included as a concern across various policy areas. If questions of heat demand flexibility are deemed important for a future low-carbon district heating transition, they need to be addressed in policy development across different policy areas. To that end, organisational aspects are important, and municipal and national policy must consider how to break down silo thinking.

Furthermore, it is important to work for and with the people who demand flexibility, namely, the occupants. They need to be included in policy development, ensuring a more holistic view of how heat demand flexibility is enacted in everyday life. This involvement ensures a foundation for current and future DSM initiatives. One implication of the dissertation is that change takes time. Heating practices do not change overnight; therefore, creating a common ground for flexibility concerns is important.

6.3.3. SUPPORT UNIVERSAL AND DIFFERENTIATED INITIATIVES

Based on the findings, one implication is that occupants perform heating practices very differently. Occupants possess different kinds of knowledge, have different norms and values, and live in very different buildings (also involving different climate conditions). While this seems like a generic contribution, future modelling work and policy must be better at differentiating occupants and their ways of performing heating practices. This differentiation includes developing dynamic models to handle variations of how heating practices are performed. While occupants have previously been perceived as a barrier to the potential of enabling heat demand flexibility, they must be considered a resource. Even though it seems difficult to consider the very different ways occupants act and interact with technology, this is important for future success.

In this way, initiatives should consider the challenges that each occupant faces due to certain practice configurations. Energy consumption is habitual, and occupants rely on different ways of performing heating in their everyday lives. The possibilities for shifting heat demand must acknowledge that occupants have very different starting points.

Future scenarios for low-carbon transitions of the district heating systems need to apply both universal and differentiated initiatives. While initiatives, to this date, have primarily been universal, there is a need to develop differentiated initiatives. Universal initiatives still need to be available, as they form a common ground for future generations.

6.3.4. STRUCTURAL CHANGE

Based on the results, transitions to low-carbon district heating should include structural measures, which implies creating a foundation for making sustainable (and flexible) practices easy and meaningful for occupants. A key aspect of the heat demand flexibility transition is to ensure that practices are meaningful for occupants to perform. This dissertation demonstrates that occupants do not find shifting the heat load meaningful in their everyday lives. They perceive load-shifting activities as complicated and fear that they will disrupt other, more meaningful practices they perform. The monetary value that could be gained by preheating the household may not be considered meaningful because it 'collides' with the notion of sleeping in a cold bedroom. While recent technological development relies on automation to shift the heat load and promote it as more convenient and easier, future initiatives must focus on making heat demand flexibility meaningful to occupants' everyday lives. This issue is not solely solved by increasing automation levels but should be accompanied by initiatives that target and challenge the status quo of existing heating practices.

Shaping flexible practices and recruiting occupants to this practice require additional attention. The flexible way of performing heating practices must not be costly, unhealthy, or difficult to conduct. Policies should focus more on structural change, promoting the development of shared meanings concerning the need for flexible heat demand. This change could include support for energy communities, where technologies and socially shared meaning and competencies are enhanced.

LITERATURE LIST

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APPENDICES

Appendix A. Interviewguide (Translated from Danish)

Appendix A displays the interviewguide which formed the base for conducting interviews in the 16 households. As detailed in chapter 3, the interviewguide is semi-structured, meaning that certain themes are included but questions remain open-ended and the interviewees were encouraged to speak freely and follow strains of thought. Six of the interviews were conducted in a collaboration with PhD-student, Lucile Sarran, PhD-student at Technical University of Denmark (DTU). In these instances, one acted as the primary interviewer, while the other acted as a secondary interviewer. The same interviewguide was used.

Aim:

- To develop an understanding of heating practices and how performances have changed and constitute when ‘smart’ home technologies have been integrated into the home
- To develop an understanding of which practices and activities that are associated with heating practices
- To develop an understanding of how occupants engage with and understand ‘smart’ home technologies
- To understand how heating practices are negotiated among occupants

Presentation of the project (Given to the interviewees in the start of the interview):

- PhD-student

from AAU who is interested in how technical installations in relation to heating are used and understood by occupants who have them integrated in their home

- The InterHUB project aims to understand the role of buildings and the people who live in them in future low-carbon energy systems - balancing supply and demand for heat - especially with a focus on district heating.

- Occupants are interviewed in several places in DK – together these accounts provide a picture of how occupants engage with smart home technologies

- This is an open interview, so talk completely free (feel free to pursue your thoughts). There are no right or wrong answers.

- The interview is completely confidential - data is stored securely and only handled by researchers who have a direct connection to the project. The data is anonymized

- Has the information sheet been read and understood?

- The interview is recorded electronically and will subsequently be transcribed - max. Length of 1 ½ hour.

- As a thank you, you will receive two cinema tickets

- Give a brief introduction to interview themes.

Themes	Questions	Elaboration
Presentation	Give a presentation of yourself: Including age, professional background, job, settlement patterns, etc. How does your current home differ from your previous home(s) (incl. childhood home) How was heating performed in the past and who controlled/was in charge of this? Why did you move to your current home? What was important?	Make sure to cover: Age, gender, how long the person (s) have lived at the address, where the person (s) have previously lived. Is the home rented, owned or other conditions?
After these introductory questions, I have a series of questions about heating practices and how they relate to other activities you perform in your home		
Comfort, practices, activities	Can you describe a typical/normal weekday for me? What are the biggest differences between your activities and routines on weekdays and weekends?	Morning routines, after work / study routines, evening routines

	Are there rooms in your home that you spend more time in than others? What makes you just spend more time here? (And has it changed over time?) Are there rooms in your home where you do not stay and why?	Rhythms and sequence
	How do you relax? What do you do when you need to relax? And what objects / things do it include? Where do you relax? Why there? And not elsewhere? Do you agree with other households members on what it means to relax and what it entails? What role does heating play in relation to relaxing? What do you do if the comfort is not good in a room? Adaptation strategies	Gain an understanding of comfort - Special focus on heat, indoor climate and air quality
	How often do you adjust heating in your home and does it differ for e.g. when you get ready for work / study, prepare breakfast, make dinner, have guests, relax etc. How do you use the hood / ventilation, in which situations, for which activities?	Find out which activities relate to heating practices and to comfort - get a broad understanding of how the informant organizes

	Is ventilation important in this? (how often do you ventilate? - Why do you ventilate? (Adjustment of heating, ventilation) Are there activities where you use / adjust other sources of heat (in relation with certain activities – e.g. carpets, clothes, baths, open windows, turn on lights). Cooking. How do you ensure the right temperature / indoor climate in relation to the activity you have to perform? (e.g an evening on the couch or a cold winter morning? Is your way of heating routinized? What do you do if unforeseen challenges arise (the heat shuts off, strong food smell inside, overheating.) And how does it affect the heating of your home? What role does comfort play in heating of your home? Is comfort always equally important to you, or does it differ in terms of what activities you do or perform?	activities in everyday life.
	When and how did you last adjust the heat? Did it differ from how you normally do it? Why? How does heating practices differ on weekdays and on weekends? Do you sometimes take work or school home and if so, how does it affect the heating of your home?	

<table>
<tr><td colspan="3">Now for a tour around the house. I hope you will tell me a little about the different rooms in your home and how you use and understand them. You are the guide, and say what comes to your mind. Questions are repeated for each room</td></tr>
<tr><td rowspan="3">Home tour</td><td>Can you tell me how to use this room? - What activities do you perform here?

Has it changed after XXXX technology has been installed?</td><td rowspan="3">For each room, focus on heating and comfort and ICT</td></tr>
<tr><td>How does this room make you feel?

What do you like and what do you like less?

What makes you feel that way?

Has it changed after XXXX technology has been installed?</td></tr>
<tr><td>In this room, how do you control the temperature?

Can you show me?

How do you ensure the right indoor environment here?

Favorite temperature / indoor climate - why?

Why this temperature in here? Rationales behind

Is it just you who controls the temperature in here?</td></tr>
<tr><td colspan="3">The next theme deals with the technologies you have in your home for heat management.</td></tr>
</table>

Technologies for controlling heating in the home	How long have you had XXXX technology installed in your home? How did you control / adjust the heat and ensure the right indoor environment before you had XXXX technology installed? Was it also the same people who controlled the heat?	The informant's relationship to smart technologies
	Where is XXXX technology currently set up? Has it moved? Can you show me that? Can you describe how XXXX technology works?	To develop an understanding of how the interviewees engage with the smart home technology and how this is negotiated among the residents.
	What have you used XXXX technology for? - Can you show me? (possibly simulating a morning routine or evening routine) Are you looking at the information on the screen about your indoor climate? (Relative humidity, temperature, co2) and why? Do you make changes based on this? What makes you change the settings? (E.g. outdoor temperature, guests, etc.) How do you change them? (Can you show it?) How much do they change the temperature if it is cold or too hot?)	

	What have you tried? - experiment, play, Ad-HOC, pre-programmed etc. How did you learn to use the system, did you read the manual, what information did you receive?) Do you make the most of the pre-installed features or have you configured the technology yourself?	
	How has it been to use XXXX technology? E.g. easy, difficult, frustrating? What is your overall experience of XXXX technology so far? Good and bad experiences Problems and with what frequency What kind of problems (Technical problems, lack of information, design problems / conflicts) Do you feel that you have control of the heating of your home? Or do you have too much control? Do you want a higher degree of automation?	

	Does XXXX technology live up to your expectations? What will your ideal system look like? (Control, design, reaction, etc.) Who has mainly used XXXX technology? Does everyone in the household use it? How? If not, why not? What happens if you disagree? Are there any rules (unwritten) for who may use it / can use it? - who decided that? Is XXXX technology used in the same way by everyone in the household? Has it changed who is responsible for heating? – E.g. also in relation to previous dwellings Have you experienced any changes in comfort after the XXXX technology is installed? Possibly, also in relation to previous homes Are there any of your activities that you perform differently (or do not perform at all) after the technology is installed? (e.g. take work home?) Has there been a change in where you perform activities after the XXXX technology is installed -	

	e.g. control on the way home from work?) Do you currently use the technology more or less compared to when you got it installed? – Do you still use it? Do you think the XXXX technology works properly? Have you used support? Who do you contact if the XXXX technology does not work properly? And what do you do about heating your home? What did you do the last time there was a problem? Did you try to solve it yourself?	
The next questions deal with your relationship to technology more generally? Special focus on ICT and smart technologies		
Relationship to technology	Do you have a smart phone? - If so, what do you use it for? - control or automation? Do you have a technological object that is your favorite? And why is it so? Have you previously had smart technologies in your home and what have you used them for?	Understand the interviewees relationship to technology in a retrospect - including competencies for technology

	Do you have technologies in your home that can be programmed? If so, can you make use of this? Do you have technologies in your home that "communicate" with each other?	
	What role does privacy play in your use of technology? Are you worried about sharing data or similar with others? Does data security play a role in your use of technologies? Why / why not?	
	Have you recently purchased new technology ?, If so, why? How does it connect with other technologies in your home?	
	If you have to buy a new technology, how do you decide? Are you talking to anyone else about it?	
End of interview	That was the end of the interview and thus my visit. Was there anything I did not get to ask you that you would like to add? Is there anything you would like to ask me? You have my contact information, so of course you are always welcome to get in touch. Do you think your neighbors might be interested in an interview?	

	Here are two cinema tickets as a thank you for your participation.	

Appendix B. Code list (Translated from Danish, extract from Nvivo[1])

Appendix B displays the code list which is based on the 16 interviews with occupants. Each row present one code and include a short description of what it refers to. The code list is relational and hierarchical, meaning that one code (labelled 1),can include several sub-codes (labelled 2, 3, and 4). Where codes labelled 1 refer to broader themes/concepts, sub-codes further down in the hierarchy refer to more exact references and in some instances the codes are so-called in vivo coding i.e. the code is an exact representation of a reference.

The coding process (described in chapter 3) has been conducted as an open to closed process. The codes displayed in the table below is thus the closed codes. Some reference have been coded more than ones and are therefore included in several codes.

As the interviews and home tours where conducted in Danish, the coding process was also conducted in Danish. The codes presented below has thus been translated into English in order to display the transparency to a wider audience.

Name of the code	Description of what the code refers to
Background of the informants (1)	Refers to current and previous socio-demographic circumstances of interviewees e.g. household size, age, gender
Housing history (2)	Refers to where interviewees have lived throughout their life, including building-typology, ownership status
Job and education (2)	Refers to educational background and current and previous jobs

[1] Nvivo, version 12: https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

Comfort (1)	Refers to notions of comfort, including perspectives on materiality, control, convenience
Embodied experiences of comfort (2)	Refers to personal and cultural bodily mediated experiences of comfort
Cold childhood home (3)	Refers to childhood experiences of a cold house and other materialities (floor, windows)
"It has always been like that" (3)	Refers to a notion of comfort as something which has always been in the same way
Clothes and other materiality for thermal comfort (2)	Refers to a relation between matter (material and natural – heating installations not included)and notions of comfort
External heat source is only for extra comfort (3)	Refers to objects (e.g. fluid gas stoves) which are used to increase comfort (more than thermal)
Comfort = a stable and uniform heat source (2)	Refers to a notion of comfort, where a uniform a stable heat source (e.g. underfloor heating) is preferred
Comfort = warm feet (2)	Refers to having warmth underneath the feet as particularly important for notions of comfort
Comfort must not be compromised by enabling heat demand flexibility (2)	Refers to perceptions of comfort as very important - should not be compromised because of initiatives targeting heat demand flexibility
Comfort is not problematic in relation to preheating (3)	Refers to interviewees who expressed that preheating their home would not compromise their notion of comfort

Preheating compromise comfort (3)	Refers to interviewees who express that preheating their home would compromise their notion of comfort
Control increase comfort (2)	Refers to interviewees who express that a notion of being in control also relates to a notion of increased comfort
Comfort norms are important for how control is performed (3)	Refers to notions of comfort and how control of heating is conducted (e.g. comfort is key for how heating is performed)
Convenience = Comfort (2)	Refers to interviewees who express that a 'simple' and automated control of heating, increase their notions of comfort
Different notions of comfort among household members (2)	Refers to the different notions of comfort that households members have, and how they are negotiated in relation to management of heating
Heat is in the background for comfort (2)	Refers to understandings of heat (warmth) as invisible and in the "background" of everyday life
Indoor environment (2)	Refers to indoor environment (CO2 level, air quality, humidity) and the relation to notions of comfort
Air circulation = good comfort (3)	Refers to interviewees who express that air circulation (Natural or mechanic ventilation) creates increased notions of comfort
Taking a bath or drying clothes can give a bad indoor environment (3)	Refers to interviews who express how activities which results in increased humidity, can create a decrease in their notion of comfort

Low-energy buildings increased comfort (2)	Refers to interviewees who express that living in a low-energy building has increased their comfort (broadly)
Low-energy buildings are good for heat efficiency (3)	Refers to interviewees who express delight in living in a low-energy building, as it increase their thermal comfort and result in lower energy bills
Set-points og temperature settings (2)	Refers to specific temperature settings and the relation to notions of comfort
A warm bathroom (3)	Refers to interviewees who keep a high set-point in their bathroom due to comfort considerations
Comfort = not feeling cold (3)	Refers to interviewees who express that comfort is thermal and that entails high set-points
Prefer a cold bedroom (3)	Refers to interviewees who keep low temperature settings in their bedroom due to comfort considerations
Temperature settings in the living room = t-shirt and shorts (3)	Refers to interviewees who maintains a temperature in the living area so that they are able to walk around in t-shirt and shorts
Competences (1)	Refers to skills required in performance of heating practices or being able to evaluate a performance as skilful or not
Adjustments (2)	Refers to competences in relation to adjustments of heating (thermostats, smart home display)
Adjusted more on radiators (3)	Refers to interviewees who express that they adjusted more regularly on thermostats than on a smart home display

Adjustments and airing (3)	Refers to how/if adjustments where made, when airing was conducted at the same time
Adjusts if there are guests (3)	Refers to how interviewees adjusted the heating when having/anticipating to have guests in their home
Adjusts in accordance with outdoor temperature (3)	Refers to interviewees who adjusted their heating, based on the outdoor temperature (skills for accessing were both sensory and more explicit rules)
Adjusts in relation to sun exposure (3)	Refers to how interviewees adjusted their heating in relation to sun exposure.
Calendar scheduled adjustments (3)	Refers to interviewees and their use of a scheduled heating plan
Control (3)	Refers to how interviewees perceived control of adjustments of their heating
Central control is positive (4)	Refers to interviewees who preferred to have adjustments of heating done in a central manner (outside of the home)
Do not know how control is conducted (4)	Refers to interviewees who did not know how adjustments of their heating were controlled
Consumption overview and automation = control and surveillance of other household member (4)	Refers to interviewees who performed control and surveillance of other household members and how they performed adjustments of heating.

Remote control is positive (4)	Refers to interviewees who perceived remote control of adjustments as a positive thing
Remote and moveable thermostats are positive (5)	Refers to interviewees who perceived remote and moveable thermostats as a positive thing
Too little control (4)	Refers to interviewees who perceived that they had too little control of how adjustments were conducted
Does not adjust in accordance with activities (3)	Refers to interviewees who did not make adjustments of heating in relation to which activities they performed
Does not adjust in accordance with feedback (3)	Refers to interviewees who did not make adjustments of heating in relation to feedback on energy consumption from utilities
Does not adjust underfloor heating (3)	Refers to interviewees who did not make adjustments of underfloor heating
Does not use the pause function (3)	Refers to interviewees who did not make use of the pause-function on their smart home system
Only make few adjustment - the heating installation is slow (3)	Refers to interviewees who conducted few adjustments of their heating, due to ‘slow reacting’ building materials and heating installations
High temperature in the bathroom because of slow	Refers to interviewees who kept a high temperature in their bathroom, due to slow adjustment of heating

regulation (4)	
Only makes few ad hoc adjustments (3)	Refers to interviewees who only did few adjustments on an ad-hoc basis
Puts temperature all the way down if going away for longer periods of time (3)	Refers to interviewees who adjusted their temperature all the way down if going on e.g. holiday
Does not adjust if going away for a longer period of time (4)	Refers to interviewees who did not adjust their temperature down, when going away for a longer period of time
Rarely do adjustments – "it takes care of itself" (3)	Refers to interviewees who did very few/no adjustment and expressed that the heating installation would take care of itself
"You turn off the heating on the 1st of May" (3)	Refers to a rule, expressed by interviewees, that heating is supposed to be turned off on the 1st of may
Airing and indoor environment (2)	Refers to competencies in relation to airing and indoor environment
Closing and opening doors are important (2)	Refers to skills in heating practices and the closing/opening of doors
Differences between set-point and actual temperature (2)	Refers to how interviewees perceive/evaluate a difference between the set-point and the actual temperature

Difficult to learn about the system (2)	Refers to interviewees who found it difficult to learn to use their smart home system
Drying clothes (2)	Refers to interviewees and the skills used in heating practices when drying clothes indoor
Easy to approach (2)	Refers to interviewees who found it easy to learn how to use their smart home system
Feedback is difficult to understand (2)	Refers to interviewees who found feedback from the utility difficult to understand and did not know how to act upon it
ICT competences (2)	Refers broadly to the interviewees competencies for ICT devices and how they use them in everyday life
Easier with an old oil burner (3)	Refers to interviewees who found it easier to understand and use an old oil burner (compared to a smart home system)
Initial learning process (2)	Refers to how interviewees initially approached their smart home system and how they learned how to use it
Low-energy buildings require new competences (2)	Refers to interviewees who expressed that living in a low-energy building required new competencies in relation to heating
Monitors using a notebook, not digital (2)	Refers to an interviewee who used a notebook to monitor energy consumption despite having smart metering
Taking care of technical errors (2)	Refers to how interviewees took care of (possible) technical errors
Transfer of competences (2)	Refers to how interviewees had learned competencies for heating, and how they

	transferred these to other members of the households
Who’s responsible (2)	Refers to which household members that interviewees perceived to be responsible for performing heating practices and why
Not one is responsible – ad-hoc adjustments (3)	Refers to interviewees who expressed that no one had the main responsibility for performing heating
“The man is responsible for making adjustments” (3)	Refers to interviewees who perceived that ‘a man’ (husband, father) was responsible for performing heating
Data security (1)	Refers to how interviewees perceived potential data security issues in relation to sharing of consumption data
Data should only be used by utilities (2)	Refers to interviewees who expressed that consumption data should only be shared/used by the utilities
Hacking can be problematic (2)	Refers to interviewees who expressed a concern in relation to ‘hacking’ of their consumption data
“It is important that occupants can 'disconnect' from surveillance” (2)	Refers to interviewees who expressed that occupants should have the possibility to disconnect from sharing data when they wanted to
Sharing data and surveillance is OK (2)	Refers to interviewees who were positive towards sharing data and surveillance of their consumption data

Energy consumption (1)	Refers to how interviewees perceived heat consumption and initiatives towards modulation of that
District heating utilities (2)	Refers to how interviewees perceived DH utilities and their role in heating
Economic incentives (2)	Refers to how interviewees perceived the role of economic incentives in modulation of heat demand
Environment and climate (2)	Refers to how interviewees perceived the role of environment and sustainability in modulation of heat demand
Heat demand flexibility (2)	Refers to how interviewees perceived initiatives towards enabling heat demand flexibility
Automation will help enable heat demand flexibility (3)	Refers to interviewees who expressed that increased use of automation would help them enabling heat demand flexibility
Comfort is not problematic in relation to preheating (3)	Refers to interviewees who expressed that their notion of comfort would not be compromised in relation to preheating of their home
Comfort is problematic in relation to preheating (3)	Refers to interviewees who expressed that their notion of comfort would be compromised in relation to preheating of their home
“There is a lack of incentives”(3)	Refers to interviewees who expressed that they lacked incentives for consuming heat in a more flexible manner

Perceptions of energy consumption (2)	Refers to interviewees perception of what energy consumption is
Everyday life routines (1)	Refers to the rhythm and sequence of everyday life
Activities within the home – spatial (2)	Refers to how (sequence and rhythm) the interviewees conducted activities inside of their home
"Everyday life and automation is not a fit" (2)	Refers to interviewees who expressed that automation would not 'fit well' with rhythms and sequence of everyday life activities
Everyday life is steered by job and school (2)	Refers to interviewees who expressed that their everyday life routines were structured by societal rhythms, such as job and school
Everyday life is very diverse (2)	Refers to interviewees who expressed that their everyday life was not routinized on a daily basis
Weekends and weekdays (2)	Refers to differences routines between weekends and weekdays
ICT, automation, smart home technology (1)	Refers to how the interviewees perceived and used ICT devices and their smart home system
Automated control is only OK in intervals (2)	Refers to interviewees who only would apply automated control of heating in certain intervals
Automation = loss of control (2)	Refers to interviewees who felt a loss of control, when having their smart home system integrated
Automation does not fit with everyday life (2)	Refers to interviewees who expressed that automation would not 'fit well' with rhythms and sequence of everyday life activities

Automation is a gadget and used for fun (2)	Refers to interviewees who perceived the use of automation in appliances and their smart home system as a gadget, which was only used for fun
Control from the smart phone is a very good feature (2)	Refers to interviewees who expressed that being able to control heating from their smart home was a very positive thing
Feedback (2)	Refers to how interviewees perceive and acted upon getting feedback on heat consumption from the utility
In-home-displays (IHD) (2)	Refers to how interviewees perceived and used in-home-displays
Light from IHD is disturbing (3)	Refers to interviewees who expressed that the LED light from the IHD was disturbing them
Dislikes the design (3)	Refers to interviewees who disliked the aesthetically design of the IHD
Touchscreen are a positive thing (3)	Refers to interviewees who like the touchscreen of the IHD
Increased automation is a good thing (2)	Refers to interviewees who expressed that increased automation of heating was a good thing
Integrated solutions are interesting (2)	Refers to interviewees who expressed that they were interested in connected multiple devices and segments of their home
Looks like a normal thermostat (2)	Refers to interviewees who perceived that smart thermostats looked liked analogue ones.
No engagement after automation (2)	Refers to interviewees who expressed that increased automation, resulted in less/no engagement with heating installations and adjustments of such

Consumption overview on smart phone is rarely used (2)	Refers to interviewees who expressed that they rarely/never used the smartphone for getting an overview of consumption
Schedules are a positive thing (2)	Refers to interviewees who liked being able to schedule their heating
Smart home technologies are cheap (2)	Refers to interviewees who though that smart home technologies are cheap
Smart home technologies does not function without a network (2)	Refers to interviewees who expressed a concern of losing network connection, and thus not be able to engage with their smart home system
Smart home technologies need to adapt to occupants needs (2)	Refers to interviewees who expressed that their smart home system need to adapt (automatically) to their needs
Solutions from Google and NEST are better (2)	Refers to interviewees who expressed that they liked solutions from Google and NEST, more than their current setup
The app does not work, it is bad design (2)	Refers to interviewees who expressed that the app on their smartphone for controlling heating did not work probably and this was due to bad design decisions
"With an integrated solution, everyday work well together" (2)	Refers to interviewees who liked integrated solutions and expressed that it would help them in their everyday life
Intermediaries (1)	Refers to the role of intermediaries and how the interviewees used and perceived them

Advice from district heating utilities is important (2)	Refers to interviewees who expressed that advice and information from the utility were important for how they performed heating
Intermediaries are important to control of flow temperature (2)	Refers to interviewees who expressed that the role of intermediaries was specifically important for regulation of the flow temperature
Intermediaries does not know about the technology (2)	Refers to interviewees who expressed that intermediaries did not know about the smart home technology and how it worked
"It would be nice with more personal advice" (2)	Refers to interviewees who expressed that they would like more personal advice on heat consumption (e.g. energy audits)
Spatially (1)	Refers to spatial aspect of temperature settings and how heating is performed within the home
Bathroom (2)	Refers to temperature settings in the bathroom and how heating was performed here
"Bathroom for the kids is kept cold" (3)	Refers to interviewees who kept cold temperatures in the kids bathroom
Bathroom temperature is varying because of bathing (3)	Refers to interviewees who expressed that the temperature setting in their bathroom did vary because of steam and following airing of the bathroom
High temperature - underfloor in the bathroom (3)	Refers to interviewees who kept a high temperature in the bathroom because they had underfloor heating and liked this sensorial notion of comfort

Opening the door after taking a bath (3)	Refers to interviewees who opened the door to the bathroom after taking a bath
The bathroom must be warm (3)	Refers to interviewees who expressed that their bathroom always should be warm
Bedroom (2)	Refers to temperature settings and how heating practices were performed in the bedroom
Living room (2)	Refers to temperature settings and how heating practices were performed in the living room
Other rooms (2)	Refers to temperature settings and how heating practices were performed in other rooms in their home
Guestroom is kept cold (3)	Refers to interviewees who kept low temperature in the guestroom
Technical installations (1)	Refers to how interviewees perceived and used heating installations and building materials in relation to heating practices
Building envelop (2)	Refers to how interviewees perceived the building envelop of their home and how it impacted heating of their home
Cooling (2)	Refers to interviewees who liked cooling technologies (air-con) and had an interest in getting more of these
Electrical heating (2)	Refers to how interviewees perceived electrical heating (in a retro perspective)
Flow and return temperature (2)	Refers to how interviewees understood the role of flow and return temperature

Difficult to understand flow and return temp (3)	Refers to interviewees who found it difficult to understand the role of flow and return temperature and its impact of heating
Fuel-shift (2)	Refers to how interviewees perceived fuel-shift and its role in heating
PVs (2)	Refers to how interviewees perceived PVs
Radiators (2)	Refers to how interviewees perceived radiators and its role in heating
Thermostats (2)	Refers to how interviewees perceived analogue thermostats and its role in heating
Underfloor heating (2)	Refers to how interviewees perceived underfloor heating and its role in heating
Mechanical ventilation (2)	Refers to how interviewees perceived mechanical ventilation and its role in heating

Appendix C. Information letter (1)

Appendix C display an information letter which was used for recruitment of informants in several of the cases. The information letter was drafted together with PhD-student Lucile Sarran

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STATENS BYGGEFORSKNINGSINSTITUT
AALBORG UNIVERSITET KØBENHAVN

DTU

DTU and AAU would like to hear about your experiences with your new home!

Would you help DTU and Aalborg University to create better low energy housing and understand how households can be integrated into a sustainable energy system?

Why do we want to talk to you?

Smart control of heating and ventilation provide opportunities for shifting and reducing domestic energy consumption, but at the same time, residents' comfort must not be impaired at the expense of these new technologies. Two PhD projects at DTU and Aalborg University investigate how smart technologies for controlling heating and ventilation are used and understood by occupants.

We would therefore like to hear about your experiences with living with smart technologies in your everyday life. Has your comfort been affected? What do you think about the technical installations (heating and ventilation) and how do you use the control systems in your home? Do they live up to your expectations and how can they be improved?

The practical stuff

We hope that you want to participate in an interview (maximum 1 ½ hours) conducted in your home. The themes will concern technology and control of such, but we are generally interested in your perspectives and experiences. The interview will be recorded. Your answers are only handled by people directly connected to the projects and obtained in a completely secure and anonymous form.

What's next

We hope that you are willing to participate in the research projects, and we will therefore contact you during the coming weeks, in order to arrange the further details. After the interview you will get a free sensor that can be used to evaluate and understand the indoor climate in your home.
If you have any questions or comments, don't hesitate to contact us at the phone numbers and e-mail addresses provided below. You will receive a small "thank you" gift for your participation

Best regards

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Appendix D. Information letter (2)

Appendix D display an information letter which was used for recruitment of informants in several of the cases. The information letter was by me. The information letter has been translated to English (from Danish)

STATENS BYGGEFORSKNINGSINSTITUT
AALBORG UNIVERSITET KØBENHAVN

Participate in a research project on heating and new technologies

Invitation to participate in a research project at Aalborg University: Technologies used for heating the home - behavior and practices

Dear resident of XXXXXX,

As part of my PhD project at Aalborg University, I want to investigate the use of technologies used for heating the home. The work is carried out in collaboration with [*name of social housing association]* and I hope you will consider participating.

This information letter will give you a brief introduction to the project.

What is the project about?

The project examines the use and perception of so-called smart technologies related to heating of the home. As renewable energy sources are integrated into the district heating network it becomes important to balance supply and demand for energy. ‘Smart’ technologies, with automation and new forms of control, are often highlighted as a solution to this end. This PhD project will contribute with more knowledge about how "smart" technologies are used by occupants.

Your involvement

Your participation in the research project will consist of an interview which will take place in your home (duration approx. 2 hours). The interview will be recorded. The purpose will be to investigate what you and the rest of the household do in relation to heating of the home and how technologies affect this practice. The interview will be conducted in the middle of the heating season (February).

Why is your participation important?

Your participation is important for understanding how energy is used in Danish homes and how energy consumption can be adapted to a future with a larger share of renewable energy sources. Knowledge of your practices and behavior can thus contribute to solutions that ensure both a fossil-free and sustainable future and include new technology that works for ordinary people.

What happens to your data?

The data generated in the interviews will be stored and handled in a completely anonymized and secure form. Data will be stored on Aalborg University's secure network and will only be handled by researchers with a direct connection to the project. Your data is anonymized, which means that names and other identifiable data is changed. Data will be stored for five years and then deleted completely. You can at any time request access to your own data and at your request have it deleted.

Who else is participating in the project?

The research project involves a selection of households from different places in Denmark and with different backgrounds. Common for all the participants is that they have technologies that control the heating of the home. Some of your neighbors will also be involved in the project, but will at no time be informed about your participation or data.

What is data used for?

Your data will be used in scientific articles and reports. This, of course, happens in a completely anonymized form. Scientific articles are published internationally and results based on your data will be presented at conferences.

If you have questions or are in doubt about the information in this letter

If you have any questions or comments, please contact me (contact information at the bottom of the page). It is important to me that you feel that all your questions have been answered.

If you are in doubt about your continued participation along the way

If you are in doubt along the way whether you still want to participate in the research project, you can stop at any time and your data will be deleted immediately.

Do you want to participate?
I hope you feel like participating in the research project, and I will therefore contact you in the coming week. As a thank you for your participation, you will receive a small gift.

Best regards

Simon Peter Kondrup Larsen
PhD- student
Aalborg University
E-mail: spl@sbi.aau.dk
A.C. Meyers Vænge 15, 2450 København SV
Read more: www.interhub.aau.dk

This research project is subject to section 10 of the Data Protection Act, which provides authority for Aalborg University to collect and receive personal data for research purposes.

Appendix E. Information sheet (1)

Appendix E displays an information sheet which was used for recruitment through gate-keepers e.g. social housing association. The aim of the information sheet was to inform about the project and establish collaborations prior to recruitment of occupants

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STATENS BYGGEFORSKNINGSINSTITUT
AALBORG UNIVERSITET KØBENHAVN

BY, BOLIG OG EJENDOM

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Information about the PhD-project - Danish Building Research Institute, Aalborg University

PhD Title:

"Demand flexibility in district heating grids: An exploration of heating practices when smart home technology enters everyday life"

Project period:

April 2018 – April 2021 – Part of the InterHUB project. Read more at: Interhub.aau.dk

Project partners:

Danish Building Research Institute, Aalborg University, Department of Planning, Aalborg University, Department of Civil Engineering, Aalborg University, Department of Communication and Psychology, Aalborg University

Aim and purpose:

The main aim of the PhD-project is to investigate the use and engagement with smart home technology in the Danish district heating system. Relying on renewable energy sources, smart home technologies are important in order to balance demand and supply in the sys-tem of tomorrow. User engagement and intertwinement of technologies in everyday life is though crucial to such, and this PhD-study will generate knowledge on how social practices of heating and comfort develop and constitute when smart home technology is integrated in the domestic sphere.

Research question:

How do practices of heating and comfort develop and constitute, when smart home technology is integrated in the domestic sphere?

Hypotheses:

- People consume energy in order to carry out social practices (e.g. comfort)
- Understanding social practices is important for the success of smart home technologies
- Social background and competences are important for the use of smart home technologies
- Technological innovations in energy efficiency is not enough in order to shift time-of-use (ToU) or reduce demand.

Methodology:

Data will be obtained by conducting interviews and ethnographic studies within the occupants home. Data will be recorded and subsequently transcribed, and can at any time be deleted on the request of the occupants (following the GDPR guidelines). Otherwise, data will be obtained for a 5 year period and thereafter deleted.

Participation is voluntary and occupants will be informed thoroughly before conducting the interviews.

The interviews and ethnographic studies will broadly concern the occupants routines and practices concerning space heating. This includes investigating the use and engagement with smart home technologies, but also other practices connected to space heating e.g. airing. Furthermore, focus will be on occupants' notion of comfort.

Handling and storage of data:

Data generated in this project will solely be used in an anonymized form and only for the purpose of this PhD. Storage of data (including sensitive data) will be stored in an anonymized and secure form, protecting it against access from third parties. Handling of data will only be carried out by relevant employees at Aalborg University, and only for the use of the InterHUB-project and in accordance with the information given to the occupants. Data is otherwise handled in complete compliance with the legal framework of the GDPR. Data will be used for writing scientific papers, presentations and articles. We guarantee confidentiality and anonymity.

Questions?

If you have any questions, please do not hesitate to contact Simon Peter Larsen (Email:spl@sbi.aau.dk or phone: 53 65 35 50).

Best Regards

Simon Peter Aslak Kondrup Larsen, PhD-student, Danish Building Research Institute

Appendix F. Information sheet (2)

Appendix F display an information sheet concerning data protection rules. The information sheet was handed to interviewees prior to the interviews, securing that they understood how their data was stored and handled. The information sheet has been translated to English. Some information have been removed prior to publishing due to privacy concerns.

AALBORG UNIVERSITET

Date: Title of research project: ["Demand flexibility in district heating grids: An exploration of heating practices when smart home technology enters everyday life")

According to the data protection rules, Aalborg University has a duty to provide you with a number of information in connection with your information being used for research purposes. If you have any questions, please feel free to contact the project manager.	
Datacontroller:	Aalborg University (Some information has been intentionally removed prior to publishing)
Project leader:	Simon Peter Aslak Kondrup Larsen, spl@sbi.aau.dk
Data Protection Advisor:	(Information has been removed prior to publishing)
Aim:	Your information will be used for the following purposes: The purpose of the PhD project is to investigate residents' use and interaction with smart home technology in the Danish district heating system. As renewable energy sources are integrated into the district heating system, smart home technologies will play a central role in balancing supply and demand for energy. Users and their everyday lives play a major role in this and are crucial to how the technologies work. This PhD study will generate knowledge about how social practices in relation to heating and comfort are

	developed and constituted when smart home technology is integrated in the home. You should also be aware that your information may be used for other research projects. This will be done in accordance with the relevant rules of the Data Protection Act. Your information will be used for research purposes only.
The basis (legal basis) of the law: According to the Data Protection Act, any processing of personal data must have a legal basis in the law, and this basis must be disclosed to the persons whose data is processed.	Legal basis, jf. ”Databeskyttelsesforordningens” art. 6, stk. 1, litra e, 1. led og art. 9, stk. 2, litra j, jf. art. 89, stk. 1 og 2. You can read the Data Protection Ordinance here: https://www.datatilsynet.dk/generelt-om-databeskyttelse/lovgivning/
Processing of personal information:	When your information is processed for research purposes, it cannot be used for other purposes, and therefore any recipients of your personal information will always be researchers. It can e.g. be other researchers from Aalborg University or researchers from other universities or similar both in Denmark and in other EU countries. If your information is passed on to other research purposes, this will be done in accordance with the rules of the Data Protection Act.
Transfer to countries outside the EU	Your information will not be transferred to countries outside the EU.
Categories of personal information	☐ Identification information (cpr, names, email addresses, addresses, etc.) ☐ Health conditions, including abuse of drugs, alcohol and drugs, etc.. ☐ Political beliefs

	☐ Religious belief ☐ Philosophical belief ☐ Trade union affiliation ☐ Racial or ethnic background ☐ Sexual relationships ☐ Criminal offenses ☐ Association conditions ☐ Significant social problems ☐ Other things. Describe:________________________________
Time period:	Your personal data will in principle be deleted, anonymised or archived in accordance with the Archives Act on [insert data (5 years after conducting the interview)]. It is possible that this time will change if the research project is delayed or if data from the project, including your information, is reused in a new research project in accordance with the rules of the Data Protection Act.
Rights	You can request that Aalborg University delete your information. If your information is no longer necessary to fulfill the research purpose, and deletion of your information does not mean that it will probably be impossible or seriously prevent the implementation of the research project, Aalborg University will delete your information. If you want to use your rights, you are welcome to send an email to the project manager.
Complaint	You can complain to the Danish Data Protection Agency if you believe that Aalborg University is disregarding the data protection rules in connection with the university's processing of your information for research purposes / the research project. You are

	encouraged to contact the project manager or Aalborg University's Data Protection Adviser before you complain to the Danish Data Protection Agency, as the case may be resolved or clarified.

PAPERS

Paper I: Larsen, S. P. A. K., Gram-Hanssen, K., & Marszal-Pomianowska, A. (2019, June). Smart home technology enabling flexible heating demand: implications of everyday life and social practices. In *eceee 2019 Summer Study on energy efficiency: Is efficient sufficient?* (pp. 865-873). ISSN: 2001-7960 (online)/1653-7025 (print). ISBN: 978-91-983878-5-8 (online)/978-91-983878-4-1 (print). European Council for an Energy Efficient Economy, ECEEE.

Paper II: Larsen, S. P., & Johra, H. (2019, October). User engagement with smart home technology for enabling building energy flexibility in a district heating system. In *IOP Conference Series: Earth and Environmental Science* (Vol. 352, No. 1, p. 012002). IOP Publishing.

Paper III: Larsen, S. P. A. K., & Gram-Hanssen, K. (2020). When Space Heating Becomes Digitalized: Investigating Competencies for Controlling Smart Home Technology in the Energy-Efficient Home. *Sustainability*, 12(15), 6031. doi: 10.3390/su12156031

Paper IV: Larsen, S.P.A.K. (2021). In control or being controlled? Investigating control of space heating in the smart home. Under review in *Energy Efficiency*.

Paper V: Marszal-Pomianowska, A., Larsen, S.P.A.K., Gram-Hanssen, K., Heiselberg, P. (2021). Thermal conditions vary in time, space, and between households. Is the assessment of building flexibility potential correct?. Submitted to *Applied Energy*

ISSN (online): 2446-1636
ISBN (online): 978-87-7210-919-0

AALBORG UNIVERSITY PRESS