THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

INVITING INTERACTION

explorations of the district heating interface for people

Sara Renström

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Product and Production Development
Division Design & Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Inviting Interaction – Explorations of the district heating interface for people
Sara Renström

Report no 104
ISSN 1652-9243

Published and distributed by
Department of Product and Production Development
Division Design & Human Factors
Chalmers University of Technology
SE-412 96, Gothenburg, Sweden
Telephone +46(0)31-772 1000

All photographs and illustrations by Sara Renström, unless otherwise stated.

Title: 'district heating interface for people' referes to all the channels through which people can make sense and make use of district heating – everything from advertisements, information, and energy bills, to radiators, showers, and operating devices such as taps and thermostatic radiator valves.

Printed by Chalmers Reproservice
Gothenburg, Sweden 2016

ABSTRACT

District heating provides more than half of the homes in Sweden with heating and hot water and have the potential to play an increasingly important role in the development towards fossil-free energy systems – yet it is rather unknown by the public. To understand why this is the case and to influence the situation, this research aims at exploring the district heating interface for people.

In the first part of this research, I explored the interaction space of people and district heating in two research studies: (1) a diary study focusing on the role district heating plays in everyday pursuit of thermal comfort and (2) an interview study focusing on people's ways of making sense and making use of district heating. The findings seem to suggest that district heating provides basic heating in a uniform manner, but that additional means often are used to achieve thermal comfort. The use of additional means, in combination with infrequent interaction with the heating system due to lack of (perceived) control over the heating, seems to obscure services available with district heating. Especially in apartments, people have been excluded from the district heating system in the sense that they do neither get any output (in the form of e.g. information or feedback) besides the district heating services, nor are they able to give much input (in the form of e.g. control) to the system. One reason for this is that heating costs generally are included in the rent.

In the second part of this research, I integrated the findings from the first part into three possible directions to suggest how to redesign the district heating interface for people. The first direction represents making use of district heating in more ways than what is currently available. The second direction concerns enabling residents to be informed of the status and in control over the processes in the building's central heating system as well as in the district heating system. The third direction is about designing means for thermal comfort and pleasurable thermal experiences through indirect use of district heating.

Prior to this work, attempts of raising awareness about district heating have addressed people in their role as citizens through information about the beneficial characteristics of district heating. Instead I have tried a different path. The three design directions address people in their role as residents, occupants, and users by focusing on the services offered by district heating. Findings from an exploratory field study with prototypes based on the third direction seem to suggest that district heating services can be utilised to invite people to take a more conscious role with regard to their building's heating system. Yet, for that consciousness to reach beyond the building's heating system to the district heating system, the connection between the two systems must be very clear. The district heating interface for people could in this way be redesigned to invite interaction.

Keywords: design, district heating, means for thermal comfort, residents, users

ACKNOWLEDGEMENTS

First, to the 220 persons who in different ways took part in my research studies – I could not have done this without you. Thank you so very much!

To Göteborg Energi, thank you for the privilege of working in this research project, and to my supervisor Gunnar Nilsson at Göteborg Energi, thank you for guiding me through it. Your vast knowledge and experience within this field has given me the firmest foundation.

Ulrike Rahe, my examiner and main supervisor, thank you for believing in me and for allowing me to do it in my own way. To Maria Håkansson, my current co-supervisor, thank you for the new perspectives you bring and for providing me with tools to explore those perspectives. Under your supervision, I constantly evolve. To my former co-supervisors, Alexandros Nikitas and Anders Ådahl, thank you for all your valuable insights.

Pernilla Hagbert, to collaborate with you is inspiring, enlightening, effective, and fun! Thank you for that. Thanks to all at the design bureau Boid for working with me – especially David Lamm, Katharina Merl, and Mikael Sundgren. I am so impressed by you! Thank you Fredrik Axelsson for your untiring data analysis. Anna Krook Riekkola, thank you for that final touch. To fellow researchers within my field of research: thank you for all rewarding discussions!

My warmest thanks to all previous and current colleagues at the division Design & Human Factors. To my fellow doctoral students (and juniors) Maral Babapour, Erik Ohlson, Isabel Ordoñez, Ingrid Pettersson, and Eva Simonsen – your work inspire me (and that is why I keep asking you what you are currently working on). Helena Strömberg and Anneli Selvefors, thank you for everything! (Including upcycling what I do.) Helena, you always seem to know where I am going even when I do not know. Thank you for that! It is incredibly reassuring to have you by my side. Anneli, thank you for being my everyday sounding board, my research confidante, my project advisor, my teaching partner, my travel companion, and for cheering me up. It is a pleasure to work with you!

To friends and family, now I have that elevator pitch I know you all have wanted to hear. (Thank you for trying to understand what I do anyway.) Mamma, you recently told that one of your hobbies is to constantly learn more. I might have inherited this trait from you. Pappa, thank you for being so eager to discuss what I do with me. David, thank you for caring more about who I am than what I do. To Lena, thank you for showing me all those other things that are important in life.

APPENDED PUBLICATIONS

PAPER 1

Renström, S., & Rahe, U. (2013). *Understanding Residents' Use of Heating and Hot Water – An Exploration of the Potential for Reduced Energy Consumption.* Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies, Isanbul, Turkey.

Renström planned the studies in the paper, carried them out, anlaysed the data, and wrote the paper. Rahe reviewed the paper.

PAPER 2

Renström, S., & Rahe, U. (2013). *Pleasurable Ways of Staying Warm.* Paper presented at the IASDR Conference 2013, Consilience and Innovation in Design, Tokyo, Japan.

Renström planned the studies in the paper, carried them out, anlaysed the data, and wrote the paper. Rahe reviewed the paper.

PAPER 3

Renström, S., Strömberg, H., & Rahe, U. (2016, submitted). *Design for Alternative Ways of Doing – Explorations in the Context of Thermal Comfort*.

Renström planned the study in the paper, carried it out, and anlaysed the data. Strömberg advised during the study. Renström and Strömberg wrote the paper. Rahe reviewed the paper.

ADDITIONAL PUBLICATIONS

Lidman, K. M. E., Renström, S., & Karlsson, I. C. M. (2011). *The Green User. Design for sustainable behaviour.* Paper presented at the IASDR Conference 2011, Diversity and unity, Delft, the Netherlands.

Lidman, K. M. E., Renström, S., & Karlsson, I. C. M. (2011). *I Don't Want to Drown the Frog! A Comparison of Four Design Strategies to Reduce Overdosing of Detergents.* Paper presented at the Sustainable Innovation 2011, 'Towards Sustainable Product Design', Farnham, UK.

Lockton, D., Renström, S., Bowden, F., Rahe, U., Brass, C., & Gheerawo, R. (2014). *Energy storytelling through annotating everyday life.* Paper presented at the Behave Energy Conference 2014, Oxford, UK.

Lockton, D., Renström, S., Bowden, F., Rahe, U., Brass, C., & Gheerawo, R. (2014). *Narrating energy through annotating everyday life.* Paper presented at the Royal Geographical Society 2014 Annual International Conference, London, UK.

Renström, S., Strömberg, H., & Selvefors, A. (2013). *Pathways of Sustainable Behaviours.* Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies, Isanbul, Turkey.

Selvefors, A., Strömberg, H., & Renström, S. (forthcoming). *What a designer can change: A proposal for a categorisation of artefact-related aspects.* Paper presented at the DRS2016 Future Focused Thinking, Brighton, UK.

Strömberg, H., Selvefors, A., & Renström, S. (2015). Mapping out the design opportunities: Pathways of sustainable behaviour. *International Journal of Sustainable Engineering*, 8(3), 163-172. doi:10.1080/19397038.2014.1001469

TABLE OF CONTENTS


This thing gives me:
heat
hot water
I wonder how much energy this thing uses?
Comments?
I think it is inefficient

1 INTRODUCTION

The energy sector is the single sector that produces the most carbon dioxide in the world and residential energy use constitutes one fourth of that (IEA, 2013). Thus, the current ways of supporting residents' energy-related everyday needs is a global challenge in the quest for a fossil-free energy world.

District heating is a system that moves heat from available heat sources to the users of heat, in this case residents, where it is used to heat up spaces and tap water. In Sweden, a country with a widely extended district heating grid, half of the buildings are heated with district heating (Werner, 2010). Where district heating is common it plays a significant part in a less fossil-dependent energy system by making use of locally available heat sources that no other energy supply method can utilise, for instance low temperature excess heat from industries. District heating in Sweden is an example of fast transition away from fossil fuels (Werner, 2010) and today such fuels are mainly used during rather short peaks in demand. In areas without district heating expansion has the potential to considerably decrease the use of fossil fuels (cf. Connolly et al., 2012). Despite these unique qualities of district heating, it is unknown to most people (Svensk Fjärrvärme, n.d.-b). Why is this? What are the consequences of its lack of noticeability? These are some of the questions that inspired the research in this licentiate thesis.

For most people district heating is not an energy supply method that they actively choose to be connected to – instead it came with the home they decided to live in. As a result, the fact that district heating is unknown to people does not currently necessarily influence day-to-day business for district heating companies. However, the energy landscape is changing: fossil fuels must be phased out and intermittent renewable energy sources must increase, highlighting the importance of temporality and of balancing supply and demand with energy storage and peak demand technologies (e.g. Kensby, 2015), energy grids as well as homes are becoming 'smart' (e.g. Geelen, Reinders, & Keyson, 2013), consumers of energy are becoming producers of energy – so called prosumers (e.g. Herngren & Làzaro Morales, 2013), and the energy industry is being digitalised resulting in solutions aimed at influencing people's energy use, for instance (e.g. E.ON, n.d.). There are two trends of importance with these changes. One of the trends points towards a less fossil-depending energy system, and the other trend points to emphasising the end user's active role in energy systems – more user-oriented energy systems in the sense that energy users are directly targeted and expected to act. As described above, district heating has the potential to fit well in the trend towards fossil-free energy systems. The question is how district heating can fit into a more user-oriented energy landscape if people do not even know what it is?

In Sweden, this question has been addressed in local and national attempts to make district heating more known to people, mostly in campaigns aimed at the general

public presenting general information about district heating and its beneficial characteristics. Is this the best way of becoming more known to people? Does being known suffice? Or can actual services provided by district heating companies become more people-oriented, more useful to people, and thus more appreciated?

If district heating would be both known to and appreciated by people it would strengthen district heating's position in more user-oriented energy systems – something that might become a necessity for district heating to keep and expand its role in future fossil-free energy systems. The long-term goals of this research is therefore to indirectly contribute to fossil-free energy systems by **making district heating more known as well as more useful to people**. In addition to that, a second goal is to **identify how to influence people's use of district heating**, especially during peaks in the demand. To reach these two goals, a thorough understanding of the relation between people and district heating is required.

1.1 AIM

The relation between people and district heating can be seen as an interaction space – as a collection of contact points where people and district heating can interact in different ways, for instance through thermostats, heated spaces, and energy bills. This interaction space is the district heating interface for people and it is in this space that people make sense and make use of district heating. To better understand the interaction space this licentiate thesis aims at **exploring people's perspectives on district heating** and **investigating the potentials of redesigning the district heating interface for people**.

Herein, 'people' primarily mean 'residents'. However, since they can take on several roles in the context of district heating (e.g. users, residents, citizens, see section 1.4.1), I have decided to use the term 'people' collectively for simplicity. The word 'interface' is herein used in its widest sense covering all types of interaction between people and district heating; everything from advertisements, information, and energy bills, to radiators, showers, and operating devices such as taps and thermostatic radiator valves.

1.1.1 RESEARCH QUESTIONS

District heating is used in homes for space heating and hot water – two services that are important for satisfying people's needs for thermal comfort. In previous research into district heating, thermal comfort has only been studied rather narrowly, for instance, by only investigating indoor temperature or use of thermostats (Palm & Isaksson, 2009). To avoid this, I wanted to look at thermal comfort in a wider perspective and to understand the role of district heating. The first research question was therefore: **What role does district heating play in people's everyday pursuit of thermal comfort?**

As it is not well investigated how residents relate to and use their heating systems

in everyday life and how people regulate indoor temperature (Palm & Isaksson, 2009), the second research question reads: **How do people make sense and make use of district heating in everyday life? Are there any specific factors influencing people's understanding and use and if so, which ones?**

The first part of the aim, exploring people's perception of district heating, is addressed through research question 1 and research question 2. Based on these findings the second part of the aim, to investigate the potentials of rredesigning the district heating interface for people, was addressed through research question 3: **What possibilities are there in redesigning the district heating interface for people?**

1.2 ORGANISATION OF RESEARCH WORK & THESIS

This research has been carried out in a project within a collaboration platform, including Chalmers and the energy utility Göteborg Energi, and financed by the latter. Göteborg Energi provides commodities and grid for district heating, district cooling, natural gas, and electricity. Furthermore they provide energy services to the inhabitants of Gothenburg. The company is a wholly owned subsidiary of the City of Gothenburg, and the owners of the company are thus indirectly the citizens of Gothenburg. Through research projects within Chalmers' and Göteborg Energi's collaboration platform the two organisations would like to contribute to a shared vision – a sustainable Gothenburg. During this research both collaborators have been present in the form of supervisors.

The organisation of the research work follows the two parts of the aim. In the first part, called part A, I explored people's perspectives on district heating and the findings are presented in chapter 4. In the second part, called B, I investigated the potential of redesigning the district heating interface for people. The findings from part B are presented in chapter 5 in terms of three design directions and in chapter 6 in terms of exploration of one of these design directions. The findings are discussed in chapter 7, and in chapter 8 conclusions and implications are presented. Following the introduction in chapter 1, chapter 2 presents the background for this licentiate thesis and chapter 3 explains the research approach.

1.3 LIMITATIONS

District heating is not the only option for thermal energy supply in a fossil-free energy system. If district heating would play a part in a future fossil-free energy system, as suggested above, such an energy system requires much more than further development of district heating. In addition, district heating is not a fossil-free energy system in itself (see section 2.1), but facilitates the use of low temperature heat that cannot be used elsewhere. In this licentiate work I will focus on district heating only and more specifically on the relation between people and district heating.

District cooling can be provided in more or less the same way as district heating. District cooling has not been a part of this project and will not be further addressed in this licentiate thesis. In the context of people's use of energy, the size of the heated space is also an important factor, as discussed for instance by Hagbert (2016). Yet, I will look into other aspects of energy use and space will not be investigated further in this research; the focus will be on the heating system per se.

In this licentiate project I have focused on people mainly in their role as residents, as indicated in the aim and research questions. Through the collaboration with Göteborg Energi, the perspective of an energy provider is also present. However, people and energy providers are just a few of the stakeholders within a district heating system. Building owners and managers, as well as property caretakers are examples of other stakeholders who have not been studied and whose perspectives have not been addressed in my research studies.

1.4 TERMINOLOGY

With this licentiate thesis I bridge different research areas with their own terminology. To facilitate understanding for readers from different areas, some of the terms are clarified in table 1.

Table 1. Terminology

TERM USED IN THE THESIS	EXPLANATION OF THE TERM
district heating interface for people	'Interface for people' is used as an synonym to user interface (although a different wording has been chosen to acknowledge that people are more than users) and refers to all the channels through which people can make sense and make use of district heating, everything from advertisements, information, and energy bills, to radiators, showers, and operating devices such as taps and thermostatic radiator valves
interaction space (of people and district heating)	All the tangible and intangible interactions between people and district heating, such as radiators, heated spaces, advertisements, and district heating bills
district energy	An umbrella term for district heating and district cooling
district heating company	A privately or publically owned company that own and manage district heating networks through which they provide district heating to their customers, a type of heat provider
(district heating) substation	A component connecting district heating systems to heating systems in buildings and houses, usually placed in or near the buildings

TERM USED IN THE THESIS	EXPLANATION OF THE TERM
customer installation	The energy transfer station in which thermal energy in district heating systems is transferred to a buildings' heating system, including the district heating substation but not limited to that and usually placed in or near the buildings
(a building's) (central space) heating system	Space heating is provided by a building's heating system that is connected to a district heating system, for instance
(a building's) hot water (supply) system	Domestic hot water is provided by a building's hot water supply system that is connected to a district heating system, for instance
thermal energy	Used as a synonym for heat
energy use/consumption heat use/consumption	Although energy and heat cannot actually be consumed the two words consumption and use are used synonymously to denote when energy or heat is being used for a specific purpose
(thermal) energy supply method	The method for supplying (thermal) energy, for instance district heating or ground source heat pumps
person heating	Heat directed to people's bodies (e.g. hot water bottle), in contrast to space heating that predominately heats the air in a space (e.g. radiators) (Kuijer & de Jong, 2012)
excess heat (from industrial processes and fuel refineries)	Recovered heat from industrial processes and fuel refineries that can be utilised in district heating systems
(private) (detached/semi-detached/terraced) house	A private detached, semi-detached, or terraced house where the residents own the house, usually intended for one household
rental apartment	An apartment that a resident rent from a landlord
leasehold apartment	A type of dwelling common in Sweden where each household owns their own apartment, but the apartments are a part of a leaseholder association and common areas as well as the central heating system is owned and maintained together
leaseholder association	A leaseholder association owns the apartments that its members reside in
apartment building	A building with several apartments, either rental apartments or leasehold apartments
building owners and managers	Persons or companies owning and managing all types of buildings – but in this thesis specifically owners and managers of apartment buildings, often synonymous to landlords/landladies

1.4.1 PEOPLE'S ROLES IN THE CONTEXT OF DISTRICT HEATING

In my work I have focused on the interaction space of people and district heating, although I acknowledge that people can take on several roles in the context of district heating. In table 2, I present different roles for people I have studied and I have used the word 'people' to denote all of these roles, and when applicable used the different words denoting the more specific roles, such as 'resident' or 'user'.

Table 2. Studied roles that people can take towards the district heating system

STUDIED ROLES		DESCRIPTION OF STUDIED ROLES
people	citizens	People in their role as inhabitants of a city, country, and the world and as such having a wider perspective than themselves
	residents	People in their role as someone who has a home and is in control of some aspects of that home
	occupants	People in their role as occupants of a particular space, for instance, at work, as guests in someone else's home, or in their own homes
	(end) users	People in their role as users of products or services, for instance as users of district heating, showers, or thermostats

2 BACKGROUND

In this chapter I will give the background to the research presented in this licentiate thesis based on the three research questions. The first section gives the background to district heating, how it functions on a larger scale, how it connects to a building's heating systems, and how it is used in everyday life. This background is mostly relevant for research question 2. In the second section I provide the background to the concept of thermal comfort, as this is relevant for research question 1. In the third section the background to how the topic of energy has been approached in the research field of sustainable design is provided together with a presentation of a review of existing design projects related to district heating, which is relevant for research question 3. Finally, I have provided a visual overview of the whole chapter.

2.1 DISTRICT HEATING

District heating is a system that moves thermal energy (i.e. heat), from available heat sources to the users of heat, in this case residents, where it is used both for heating and hot water. District heating is a large-scale technology with a high investment cost but low running costs, and rely on a critical heat demand (i.e. customers) in order to be financially viable. By making use of locally available heat sources such as low temperature heat that cannot be used elsewhere, thermal energy from district heating can be inexpensive compared to other energy sources, but it is associated with a high cost for distribution. In Denmark, Finland, and Sweden district heating covers around half of the net heat demand or above. District heating is common in apartment buildings and then all apartments in the building are connected. The description of district heating herein is largely based on the Fredriksen and Werner (2013) comprehensive overview on district heating.

To provide homes with heating and hot water, a district heating system must have four major components: heat supply units, a distribution network, substations, and heating systems in the buildings receiving the heat. The heat is transferred from various heat sources depending on local availability. In Sweden, waste incineration, biofuels, and excess heat from industrial processes and fuel refineries are common heat sources, see figure 1 (Svensk Fjärrvärme, n.d.-c). A distribution network carries the heat from the heat supply units to the substations. The distribution network usually consists of insulated underground pipes in which pressurised water carries the heat. In the substations, placed close to or inside the buildings, the heat in the distribution network is transferred through a heat exchanger to separate the heating system and hot water supply system in the buildings. This so-called indirect space heating and hot water supply is common in Sweden. Within the building's central heating system, the heat is once again distributed through water filled pipes, a hydronic space heating system, and usually transferred to the indoor environment via radiators or less commonly, by floor heating. The hot water is instantaneously

heated inside the heat exchanger and then distributed through separate pipes in the building.

Within the district heating system in Gothenburg, recovered excess heat from industrial processes and fuel refineries represent the largest heat source, while waste incineration is the second largest heat source, see figure 2 (Göteborg Energi, n.d.-a). In 2015, 8% of the heat in Gothenburg came from fossil energy sources.

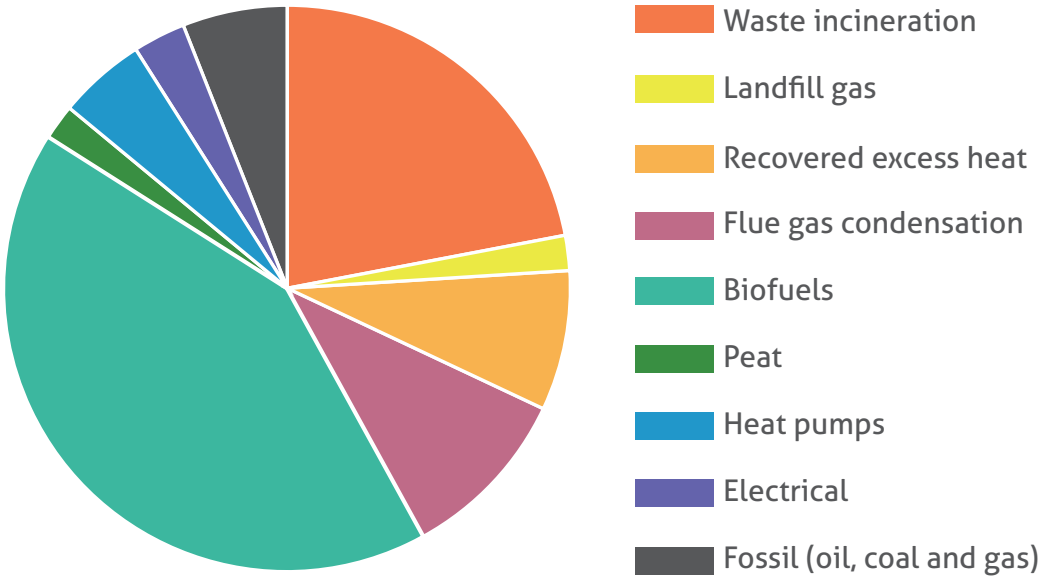


Figure 1. Heat sources utilised in district heating in Sweden 2014

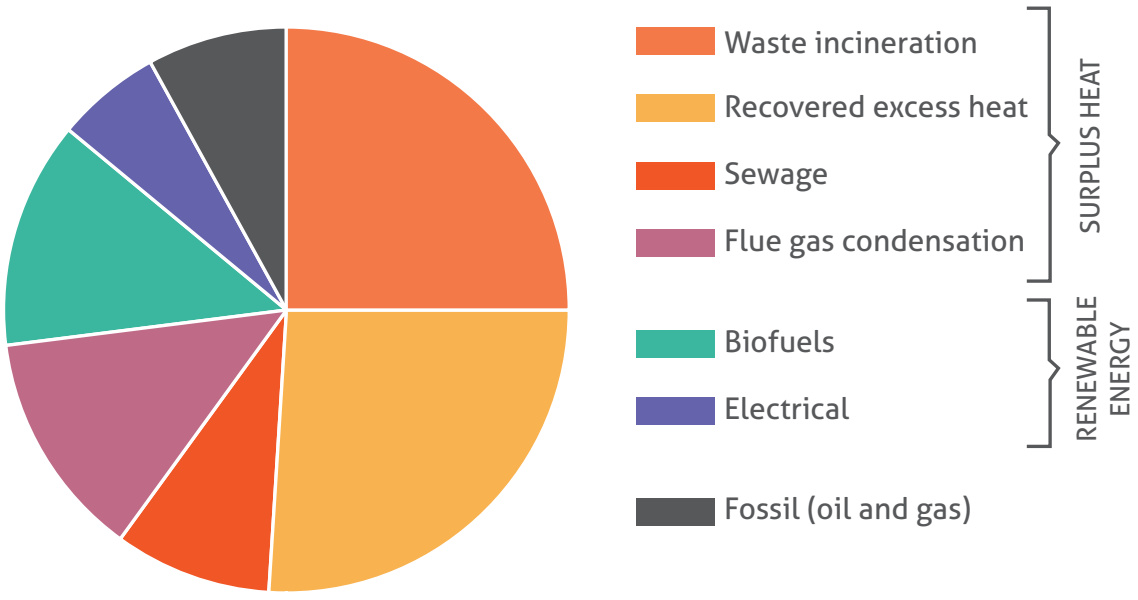


Figure 2. Heat sources utilised in district heating in Gothenburg 2015

2.1.1 DISTRICT HEATING IN HOMES

In Sweden there are three predominant types of dwellings: of all households 43% are privately owned detached, semi-detached or terraced houses, 29%

rental apartments, and 20% leasehold apartments (Statistics Sweden, 2015). In Gothenburg the rental apartments are in majority (47%), followed by leasehold apartments (26%), and private houses (20%) (Statistics Sweden, 2015). District heating provides 90% of all the apartments in Gothenburg with heating and hot water and approximately 25% of the private houses (Göteborg Energi, n.d.-b; Statistics Sweden, 2015).

The heating share of the total energy use in a home varies considerably between types of homes and activities in the home, but in general the use of district heating is higher than the use of electricity. In a typical private house, space heating stands for around 56%, hot water for 17% and electricity for 27%, based on pre-defined settings for a private house in Gothenburg connected to district heating through an online tool by the Swedish Energy Agency (Energimyndigheten, n.d.). The CO2 emissions calculated in the same tool are nevertheless higher for the electricity use.

In Sweden a standardised fee for heating and hot water is included in the rent for most leasehold and rental apartments, and the heat consumption of each apartment is usually not metred. Instead, the building owners and managers, either the housing company or the leaseholder association, pays for all district heating used collectively by all apartments in the building. The building owners and managers are thus direct customers of the district heating companies. This means that the customer and users of heating and hot water – the residents – is not the same person in residential apartments. Residents in rental apartments are not explicitly informed whether they are connected to district heating and landlords usually only come in direct contact with residents if they complain about the heating (Carlsson-Kanyama, Lindén, & Eriksson, 2004).

In leasehold apartments, residents are invited to annual meetings where they are informed about the leaseholder association's annual balance sheet, including the total cost of district heating for the entire leaseholder association, and they are generally informed about through which type of thermal energy supply method they receive their heating and hot water in most of those meetings, at least implicitly.

In private houses connected to district heating the heat consumption is metred and generally the residents pay for their heating supply themselves. The heat consumption can, in most cases, be followed in real-time at the substation inside the house and is communicated on the bill. The bills are based on last months' actual consumption and thus vary greatly over the seasons. Note however, that just because someone in the household is informed about the heat consumption via the bill, does not mean that all members in the household know that they are supplied with district heating and have an overview of their level of heat consumption.

In homes connected to district heating, the control of the heating is shared between controls in the building and controls managed by the district heating company. The district heating company controls the temperature and pressure in the distribution network at the customer's substation, both in private houses and in apartment

buildings. Then, settings at the substation, usually based on outdoor temperature, control the flow through the heat exchanger. In private houses the residents themselves control the settings on the substation, although this is a difficult task (Sernhet & Pyrko, 2006). In apartment buildings, the building owners and/or managers control these settings. The residents can only control their heat through valves on the radiators, usually thermostatic radiator valves, or through corresponding controls for floor heating. In Sweden, some building owners and managers are trying to limit residents control of the heating (Carlsson-Kanyama et al., 2004), although I have not found any confirmation of the magnitude of this share. Hence, many people in apartments perceive that they lack satisfactory control of their heating or lack of information about the extent of their control (Carlsson-Kanyama et al., 2004). An important factor for resident satisfaction is their ability control the heating systems in their building and as a result, credits are now given for allowing residents control in various building sustainability rating tools (de Dear et al., 2013).

Even though the building owners and managers in the Carlsson-Kanyama et al. (2004) study knew that the households' everyday behaviours had a significant impact on the energy consumption in total, they had not considered addressing the above issue, however, other owners and managers have. Ways of giving residents in apartments more control over their heating includes providing them with individual consumption meters and bills. Berndtsson (2003) reviewed approximately 150 projects where individual metering and billing had been launched in apartments in Sweden. He found the heat consumption was reduced by 10 to 20% and that hot water consumption was reduced by 15 to 30%. In most of the reviewed systems for individual metering and billing, the residents were also able to increase their use of heating, but fewer increased than reduced. High reductions in heat consumption were a result of residents lowering their indoor temperature from a very high level and from not letting excess heat escape through airing.

Daily variations in desired indoor temperature, such as night set-backs, are despite from being associated with energy efficiency, usually problematic for a district heating system (Fredriksen & Werner, 2013). This is due to the temporary increase in heat load needed to accelerate warming up following a set-back. Daily variations in the total heat load is also problematic, as heat supply units used at peak load often use fossil oil and gas (Kensby, 2015; Svensk Fjärrvärme, n.d.-c). Yet, buildings can also provide thermal energy storage by deliberately charging the buildings by using too high temperature indication and discharging them by using too low temperature indication. Recent pilot tests and simulations in Gothenburg have shown that if 20% of the heated floor area is used as thermal energy storage the daily heat load variation in the system would decrease by 50% (Kensby, 2015).

Homes heated with district heating have, as mentioned above, hydronic space heating systems, but this is not unique for district heating. The types of radiators, taps, and showerheads used are also not unique for district heating. Further,

radiators are in themselves anonymised when painted in neutral colours or hidden behind radiator covers (Ketola, 2001). Room thermostats also seem to be anonymous to residents as they are often unaware of them, as found in a study in England (Shipworth, Firth, Gentry, & Wright, 2010). In a home supplied with district heating, the experiences of heating and hot water supply are not necessarily different to other thermal energy supply methods. Altogether, these factors make it difficult to know if a home is connected to district heating or not. More unique parts of a heating system in a home heated with district heating, such as the substation, are often located in the basement and not always accessible to residents. In addition, residents generally prefer the heat source to be hidden, except for wood-burning stoves (Ketola, 2001).

Further, central heating systems and their components are difficult to comprehend and use (Carlsson-Kanyama et al., 2004; Combe, Harrison, Craig, & Young, 2012; Sernhet & Pyrko, 2006), and residents often have mental models for the different devices, and of the system as a whole, that differ significantly from actual functionality (Revell & Stanton, 2014; Revell & Stanton, 2016).

district heating in everyday life

District heating consumption is not directly visible in daily routines, although it is not imperceptible. It is experienced through bodily sensations, for instance, when taking a long, hot shower or when walking on heated ceramic floor tiles on a cold winter morning (cf. Berker, 2013). In everyday life, use of district heating is associated with expectations on comfort, comfort practices, routines, and levels of knowledge, and those differ between different residents (Gram-Hanssen, 2010). In an interview study with a social practice theory focus on heat practices with 30 households in private houses of a similar kind in Denmark, Gram-Hanssen (2010) found three times higher thermal energy consumption in high consumption households than in those with low consumption. Householders who associated higher indoor temperatures with a cosy and welcoming home consumed more thermal energy than householders who considered a low indoor temperature to be natural and cold bedrooms to be healthy. Hot water consumption can vary even more between households, the variation can be up to six times for similar households (Energimyndigheten, 2009).

Aune (2007) analysed domestication of the home to understand energy consumption in everyday life. She found three approaches to home creation with different implications on thermal energy use. In the approach the home as a project, the home is in the making and the homes keeps becoming more pleasing and more comfortable and, as a consequence, more energy-demanding. In the approach the home as an arena for activities, the home should be a practical place for social activities which resulted in less energy intensive lifestyles. In the third approach, the home as a haven, the home is a symbol, a feeling of home, and achieving a feeling of cosiness is important and often realised through light, heat, and hot water.

Carlsson-Kanyama and colleagues (Carlsson-Kanyama et al., 2004; Carlsson-Kanyama, Lindén, & Eriksson, 2005) investigated household energy use and attitudes towards energy use in a questionnaire study with 600 respondents in rental apartments, leasehold apartments, and private houses. The questionnaire was combined with interviews with eleven households and three building owners. Carlsson-Kanyama and colleagues found that the participating households generally were uninformed about their heating and hot water systems and unengaged in lowering their consumption. In the questionnaire, 88% of all the respondents knew if they could regulate the heating in their homes or not and among those that knew 67% could regulate the heating. This means that among all participants 59% knew that they could regulate the heating, 29% knew that they could not regulate the heating, and 12% were unaware. Many of those eligible to regulate their heating did not do it or did not reflect on the possibility. Some of the interviewed households found the lack of control over the heating disturbing and stated that it resulted in energy waste. During winter, 40% of the respondents aired daily. Households in private houses aired less than households in apartments. Younger respondents aired less than older respondents and older respondent lowered the heating during the night more often than younger respondents (Carlsson-Kanyama et al., 2005).

The preferred indoor temperature is rather well-established and generally lies between 18-23°C independent of climate zone (Palm & Isaksson, 2009). There is however a distinction between preferred indoor temperature and temperatures in which people can make themselves comfortable, as people have been reported being comfortable at much wider temperature spans (6-40°C is suggested by Kuijer and de Jong (2012) in their review of studies and 16-30°C are reported by Clear, Morley, Hazas, Friday, and Bates (2013) in their review of studies). The expectations on indoor temperature have changed during the last few decades and continue to change. The same indoor conditions are now expected everywhere (Chappells & Shove, 2005) and in Sweden the average indoor temperature in homes has increased during the last few years (Ketola, 2001). In the Carlsson-Kanyama et al. (2005) study mentioned above, the youngest group of respondents (aged 25 to 35) preferred a higher indoor temperature than the older age groups.

2.1.2 A SYSTEM PERSPECTIVE ON DISTRICT HEATING

District heating can be seen as a separate technical system with the aim of moving thermal energy. In these system boundaries, residents' energy demand is the input to the system while heating and hot water represent the output from the system. The input has traditionally been seen as non-dynamic, as a boundary condition, and thus energy use lies beyond the system boundaries (cf. Jonsson et al., 2011).

District heating can also be seen as an important type of energy carrier within a technical and economical national energy system, including different types fuels used for different types of energy demand (i.e. heating, cooling, and electricity),

which manages recourses as efficiently as possible. Energy use is however still considered to be an external phenomenon (Jonsson et al., 2011). With the development of 'smart' energy networks, it will probably be more important to understand the connections between district heating and other energy systems. These grids are smart in the sense that they can collect and interpret information about energy supply, distribution, and consumption to improve, amongst other factors, sustainability of an energy system (Kensby, 2015). In smart energy grids, residents will be able to provide more complex input information to the system and in return the output to them will be optimised based on that complex input, although this does not necessarily mean that residents are seen as a part of the system. In smart grid visions and initiatives, residents are perceived as consumers, producers, or both (prosumers), but, as Katzeff and Wangel (2015) point out, few of the smart grid visions and initiatives have recognised and included the socio-material complexity of residents' energy use.

Based on the records of differences in how residents relate to district heating presented above, seeing residents as a part of the district heating system seems like a more fitting approach. In effect this means that instead of seeing district heating as a technical system that provides thermal comfort to residents, seeing district heating as a socio-technical system where thermal comfort is achieved together with the residents. Such system boundaries would emphasise the social conditions, highlight the role of technologies, and acknowledge the context in which it takes place (cf. Palm & Isaksson, 2009; Summerton, 1992).

Socio-technical systems however are not easily approached in a design perspective, as it is difficult to take such complex and interdependent relationships into account during a design process (Joore & Brezet, 2015). To give an overview of the different system levels a designer must relate to it in the design of technologies, Joore and Brezet (2015) developed a multi-level design model. In the model a societal system, such as the energy system, has four levels: societal system, socio-technical system, product-service system, and product-technology system. The societal system is "a combination of material, organizational, policy, legal, social, cultural or infrastructural elements" (Joore & Brezet, 2015, p. 96). The socio-technical system is "a cluster of aligned elements, including artefacts, technology, knowledge, user practices and markets, regulation, cultural meaning, infrastructure, maintenance networks and supply networks, that together fulfil a specific societal function" (Geels, 2005 as cited in Joore & Brezet, 2015, p. 96). The product-service system consists of physical elements and organisational components that only together can fulfil definable functions. The product-technology system is a combination of physical objects and systems that fulfil clearly distinguishable functions. Re-designs can be made on all of these levels and as such, redesigning on the product-service system level results in a new product-service system, for instance. As a first step of such a re-design process, the designer reflects on problems on each level. In figure 5 in section 2.4, I have defined district heating in regard to each of these four levels. The multilevel design model comprises more than described herein (see Joore & Brezet, 2015).

2.1.3 REFLECTION ON DISTRICT HEATING

Summing up the background above, district heating as an energy supply method differs compared to many other supply methods employed globally. In Sweden, it primarily utilises locally available heat sources such as excess heat, waste incineration, and biofuels, and to a smaller extent fossil fuel. Thermal energy from district heating is therefore inexpensive compared to other energy sources, but with a high cost for distribution. District heating can only be connected to homes with a hydronic central heating system. The production of district heating is rather inflexible and therefore differences in heat load are undesirable. Essentially, residents in apartments have little control over their heating and hot water and do not gain financially from reduced consumption. Due to these specific circumstances not all research on residents' perspectives on their heating systems are applicable in the context of district heating in Sweden.

Despite the above reported differences in how residents relate to thermal energy in everyday life and the implications that the differences have on heating consumption, this area is still underexplored (Palm & Isaksson, 2009). Palm and Isaksson (2009) point to some specific themes of interest: how residents learn about their heating system, how heat use relates to different everyday activities, and how residents interact with their heating systems. In this licentiate thesis, these themes are explored in the context of district heating through research question 2: How do people make sense of and make use of district heating in everyday life? Are there any specific factors influencing people's understanding and use and if so, which ones?

2.2 THERMAL COMFORT

Thermal comfort can be interpreted in different ways (see e.g. de Dear et al., 2013; Kuijer & de Jong, 2012); as a universal physiological construct where thermal comfort is provided through an optimal thermal environment and as a product produced by the heating and cooling industry (Fanger, 1970). To determine which indoor environment will create optimal thermal conditions for the highest possible percentage of a group of occupants, Fanger (1970) developed a model called Predictive Mean Vote. The model makes use of a comfort equation to calculate how the parameters activity level, clothing, air temperature, mean radiant temperature, relative air velocity, and air humidity influence occupants' thermal sensation. It can also be used to calculate a recommended set point temperature, if the other parameters are given. At that set point temperature 5% of the occupants will be dissatisfied. At the set point temperature +/-0,5°C 10% of the occupants will be dissatisfied and at +/-2°C almost 80% will be dissatisfied, according to the model. The reason for this is that although one person is comfortable within a temperature interval, in a group of people personal intervals will vary and mismatch (Fanger, 1973). Therefore Fanger (1973) argues for providing a specific temperature, a comfort point, and not a temperature span, a comfort zone. Fanger (1973) gives

examples of using his model in non-private places occupied by groups of people: offices, warehouses, and busses. In Fanger's, work the focus thus is, as Kuijer (2014, p. 146) puts it, "on averages, standardizations and uniformity". Psychological phenomenon such as how different interior designs influence the feeling of warmth is to some extent recognised but not included in the models in which thermal comfort is seen as a physiological construct (Kuijer & de Jong, 2012).

Thermal comfort can also be understood as a negotiable socio-cultural construct (Chappells & Shove, 2005) where thermal comfort is something occupants achieve if they have the necessary control over the environment (Nicol & Humphreys, 2009; Shove, 2003; Shove, Chappells, Lutzenhiser, & Hackett, 2008). In this understanding of thermal comfort, which is called the adaptive approach, personal comfort is considered to be the occupants' goal. The building should then provide the means for occupants to achieve thermal comfort (Shove 2003, as cited in Nicol & Humphreys, 2009; Shove et al., 2008). It is a comfort-as-goal approach instead of a comfort-as-product approach (Nicol & Humphreys, 2009). Means for personal thermal comfort can be blankets, clothing, hot drinks, adjustment of windows, or ventilation etc. (cf. Clear, Friday, Hazas, & Lord, 2014). Over the last two decades, the adaptive approach has gained recognition and there are now international standards based on both types of approaches to thermal comfort (de Dear et al., 2013).

In an overview of field studies on thermal comfort Mishra and Ramgopal (2013) categorised and ranked people's adaptive adjustments into three categories. First people will try to alter the environment (such as open or close windows); secondly they will make adaptations affecting the person (such as changing clothes, showering or ingesting hot drinks); and thirdly they will change location. According to Mishra and Ramgopal (2013) the perceived ease with which these means can be enacted determines what action people take. Note however, that in the overview only a few studies were carried out in the snow climate zone to which Sweden belongs (Kottek, Grieser, Beck, Rudolf, & Rubel, 2006).

2.2.1 REFLECTION ON THERMAL COMFORT

District heating companies consider comfort as a product, as something that can be delivered to residents. Alternatively, if regarding district heating through the lens of the adaptive comfort approach and investigating the role district heating play in the everyday pursuit of thermal comfort, new understandings of district heating may be uncovered. In this licentiate thesis this was achieved through research question 1: What role does district heating play in people's everyday pursuit of thermal comfort?

2.3 APPROACHING ENERGY THROUGH DESIGN

Within design disciplines, and especially within industrial product design,

sustainability issues have been recognised at least since the 1970s and since the 1990s as a field of research (see historical overview in Kuijer, 2014). From first focusing on end-of-pipe solutions to sustainability issues, a product's complete life span was then acknowledged, for instance in Life Cycle Assessment studies. Through such studies it was realised that the major share of the environmental impact could be attributed to the use phase for many energy-reliant products. An example of such products are cold appliances where 80-90% of the total environmental impact result from the use phase (Rüdenauer & Gensch, 2007). A new approach to sustainable design focusing on reducing the resource consumption of products while in use followed this realisation (see hisctorical overview in Kuijer, 2014).

Within design research, the resource consumption of products while in use have been approached in two distinctively different ways (Kuijer & Bakker, 2015): one which focus on resource efficient interactions with products, often referred to as Design for Sustainable Behaviour (e.g. Lilley, 2009) and one focusing on use of social practice theory in sustainable design (e.g. Kuijer, 2014). In both of these approaches energy and energy use have been addressed in different ways.

In the interaction-focused design approach, energy have been addressed to create awareness around energy consumption (e.g. Laschke, Hassenzahl, Diefenbach, & Tippkämper, 2011) and to influence how people use energy consuming products and systems (e.g. Selvefors, 2014; Wilson, 2013).

In the practice-focused design approach energy has been studied to challenge the view of residents as rational energy users and decision makers (e.g. Strengers, 2011, 2014), design concepts for altering everyday practices (e.g. Pierce & Paulos, 2012), or design elements in new reconfigurations of performances of practices (Kuijer, 2014).

In both design approaches energy is addressed in general. It is not always specified if a project concern electricity use in electric appliances, space heating, or domestic hot water. Use of electric appliances embedded differently in everyday life to heating and hot water consumption, and therefore not all design studies on energy are relevant from a district heating perspective (see mapping of different types of resrouce consumption behaviours in Strömberg, Selvefors, & Renström, 2015). In addition, only a few studies have been made in the context of district heating. Outside academia there is however a collection of communication, product design, and architectural work aiming at increasing general knowledge of district heating.

One example, for instance, is a project by Göteborg Energi and the City of Gothenburg that has removed a section of the street surface in central Gothenburg and exchanged it with a glass plate to allow the general public to view the exposed underground pipes necessary for providing homes with district heating, electricity, water, natural gas, and broadband, see figure 3 (Göteborg Energi, n.d.-c).

Figure 3. A removed section in the street exposing underground pipes on a street in Gothenburg (photo: Göteborg Energi)

Figure 4. Waste incineration plant in Vienna with a façade designed by Friedensreich Hundertwasser (photo: Lukas Riebling)

Another example of design is public benches heated with district heating. For instance, such benches are present in the city of Borås (Svensk Fjärrvärme, n.d.-d). The actual heat supply units have also been of used to increase knowledge about district heating. In Vienna, the artist Friedensreich Hundertwasser redesigned the façade of a waste incineration plant in 1988-1992, see figure 4 (Hundertwasser Non-Profit Foundation, n.d.). The Swedish District Heating Association has two campaigns directed to the public with different slogans: "we are warming each other up" (my translation, "vi värmer varandra" in Swedish) and more recently "make use of the energy" (my translation, "ta vara på energin" in Swedish). In relation to theses slogans the Swedish District Heating Association present films about local heat sources utilised in different district heating systems in Sweden, for instance a film about how preschools are heated with excess heat from steelworks in the city of Luleå (Svensk Fjärrvärme, n.d.-a). This idea has been developed further in an online heating map of Sweden where district heating companies in Sweden can record how they make use of thermal energy that would otherwise go to waste (Svensk Fjärrvärme, n.d.-e). The title of the heating map reads "Who warms who up where you live?" (my translation, "Vem värmer vem där du bor?" in Swedish). Information about different local heat sources utilised and some indications of the types of buildings heated with district heating is also provided. The map is not complete yet as only a few district heating companies have recorded their information on the map at present.

There are to my knowledge three design projects going beyond making district heating more known aimed at redesigning the district heating interface for people. The first project is a smart phone application called Green IT Homes with which residents in private houses can monitor their district heating and electricity use and control their heating (IMCG, 2012).

The second project is by de Jong, Balksjö, and Katzeff (2013). They designed a smart thermostat and a water meter, which was each combined with a digital application visualising district energy as well as environmental implications of use. One of the design features of the smart thermostat is that users receive a set amount of energy they can use (eco-points). The smart thermostat then makes suggestions regarding the temperature based on calculations of the whole building.

In the third project, Göteborg Energi assisted in the renovation of a private house and employed district heating for as many energy-reliant appliances as possible (Zinko, 2006). The house is called The District Heating House (my translation, "Fjärrvärmehuset" in Swedish). In this house, electricity has been replaced by district heating in the dishwasher, washing machine, and the tumble dryer. District heating was used to increase thermal comfort through the air-conditioning running on district heating. Further, district heating was also used to heat an atrium and an outdoor hot tub. The dishwasher, washing machine, tumble dryer, and a drying cabinet were later further developed and commercialised (Persson & Renström, 2013).

There is a wide range of research projects involving design concepts directed at domestic heating and hot water use generally, but none specifically on district heating. Some concepts, including the three district heating concepts mentioned above, are presented in appendix 1 in which I briefly describe the concepts and report on if they have been evaluated in any way.

2.3.3 REFLECTIONS ON DESIGN APPROACHES TO ENERGY

Energy in general and electricity in particular has so far been the focus for design research aiming at exploring ways of doing with less environmental impact. With regard to district heating, the majority of the projects outside academia have been aimed at making district heating more known, and to make people more knowledgeable of district heating. People have thus been addressed in their role as citizens. In the three attempts of redesigning the district heating interface for people in their role as residents presented above, there are indications of the possibilities of such redesigns. These possibilities could be further explored, which I have done through research question 3: What possibilities are there in redesigning the district heating interface for people?

2.4 OVERVIEW OF BACKGROUND

To sum up the background, I listed the identified problems in the district heating system on district heating's different system levels. I mapped the different heating and hot water design concepts for each level, in accordance with which level was addressed. For that reason, a concept was in some cases put on two levels. All concepts were organised on each level with regard to whether they focus on reduced environmental impact (up), increased satisfaction (down), or both (in the middle horizontally), and depending on whether they encourage (left), enable (right) something, or both (in the middle vertically). A concept was considered to encourage something if one of the concept's major aims is to influence people's intention and/or willingness to do something (DEFRA, 2005). A concept was considered to enable something if one of the concept's major aims is to influence people's ability to do something (DEFRA, 2005). This overview can be seen in figure 5. Although the number of problems (but not their magnitude) does not differ much between the levels, the number of design concepts varies. Fewer design concepts are found on the socio-technical and societal system level.

Societal System | The national energy system and to some extent the international energy system, including energy systems links to the economic system, taxes, and international agreements.

Societal Problems

Use of fossil fuels (peak hours)

Use of waste incineration

Use of recovered excess heat from fossil-dependent industries e.g. oil refineries

The power of the regime (district heating) might render difficulties for new technical niches to develop (cf. Geels, 2002)

Socio-Technical System | The different types of heating and hot water systems and their inter-links, the (household's) lifestyle, norms regarding energy, and shared social practices related to heating, hot water and energy in general.

System Deficiences

Warm homes are associated with cosiness and a welcoming feeling (Gram-Hanssen, 2010)

The understanding of comfort is energy intensive (Aune, 2007)

Increasing expectations on comfort (Carlsson-Kanyama et al., 2004)

Lack of knowledge on how to preserve heat (Carlsson-Kanyama et al., 2004)

Differences in needs of warmth (for instance elderly with low metabolism may need over 22°C (Socialstyrelsen, 2005)

Product-Service System | The household's heating and hot water system (including payment structure (separate bill or included in the rent) and ownership) and use, and related activities.

Functional Problems

Residents are uniformed about consumption (Carlsson-Kanyama et al., 2004)

Heating costs more than covered by rent (and thus building owners and managers do not have incentives for saving) (Carlsson-Kanyama et al., 2004)

Residents lack of satisfactory control over heating (Carlsson-Kanyama et al., 2004)

Building owners and managers want to keep control over the heating (Carlsson-Kanyama et al., 2004)

Airing daily during winter time (Carlsson-Kanyama et al., 2004)

Product-Technology System | The technical system, within a building, that provides homes with district heating, (e.g., radiators, floor heating, taps, showers and baths) including how the technical system is used and the experiences of using it.

Operational Problems

Heating systems are perceived as difficult to use (Carlsson-Kanyama et al., 2004) despite access to manuals (Sernhet & Pyrko, 2006)

Thermostats are difficult to understand and use (Combe et al., 2012; Shipworth et al., 2010)

The heat source (i.e. the distirct heatting substation) and different components are often hidden (Ketola, 2001)

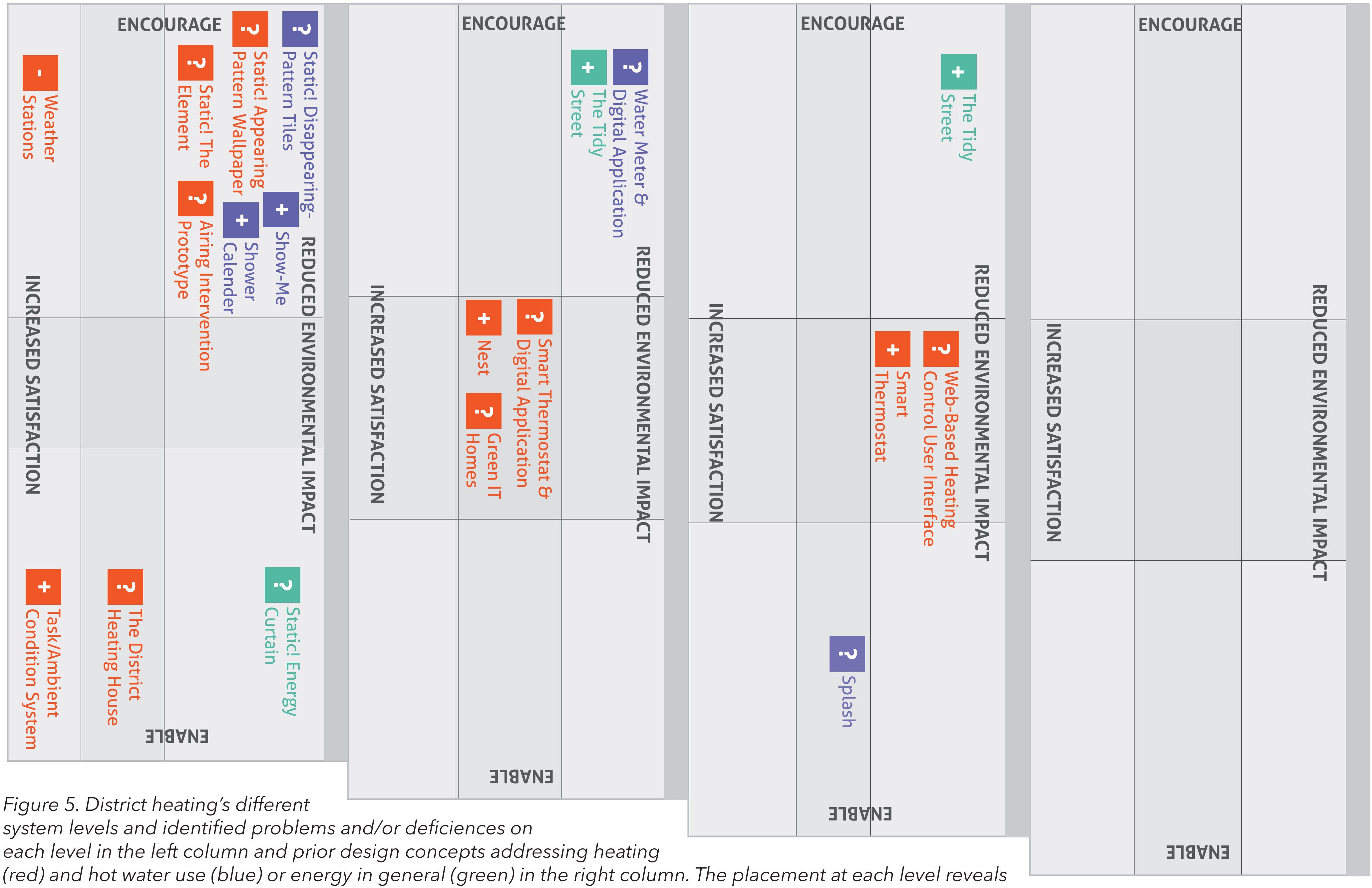


Figure 5. District heating's different system levels and identified problems and/or deficiences on each level in the left column and prior design concepts addressing heating (red) and hot water use (blue) or energy in general (green) in the right column. The placement at each level reveals if a concept encouraged (left) or enabled (right) something, or both (middle vertically), and whether it focused on reduced environmental impact (up), increased satisfaction (down), or both (middle horizontally). '+' represents a positive outcome of a user test, '-' a negative outcome of a user test, and '?' that no user test has been made or that the outcome was ambiguous. See appendix 1 for details on the prior design concepts.


Den här grejen ger mig:
värme
varmvatten
Jag tror att den här grejen använder mycket energi.
Kommentarer?

3 RESEARCH APPROACH

In this chapter I will present the overall research methodology in this licentiate work as well as the types of research methods used. To put my methodological decisions in context, I will begin with a description of my personal background.

3.1 PERSONAL CONTEXT

My educational background, Bachelor and Master of Science Degrees in Industrial Design Engineering from Chalmers including a study exchange at Design for Interaction at Delft University of Technology in the Netherlands, influences the research presented in this licentiate thesis. Both universities mix traditional engineering subjects with industrial design training and both teach a people-centred approach to product development and design, putting people and their needs, concerns, and abilities at centre-stage throughout the design process.

At Chalmers, I was trained in understanding the relationship between people and products through an activity theoretical framework (as intepretated by Engelbrektsson, 2004). Looking at everyday life through that framework, people engage in different activities distinguishable from each other by different motives (Engelbrektsson, 2004; Karlsson, 1999). In all activities, people use different artefacts as mediating tools to support their motive. Therefore, in the design process designers cannot focus on the artefacts as such but must instead consider the relationships between people, the context of use, and the motives for the activity (Engelbrektsson, 2004). This perspective on activities is not explicitly employed in my research as a theoretical framework but is presented as an underlying understanding of the nature of the relationship between people and artefacts. At Delft University of Technology, I adopted a broad, technology-independent understanding of what interaction is; to me interaction is everything from how people understand and use artefacts, to how they experience them.

During my undergraduate education I became more and more aware of the disastrous consequences technological development has on the planet, and thus on people. The ingenuity of engineers and designers has created marvellous things, but the global effects are often unacceptable. With one foot in engineering and one in design I see it as my personal responsibility, at least to a certain degree, to contribute to a shift towards increasing sustainable development. From my perspective this requires the development of environmental and social conditions which indefinitely support people's security, wellbeing, and health (based on the definition by McMichael, Butler, and Folke (2003), as understood by Thorpe (2007)).

Even though I have been trained both in engineering and industrial design I currently work within the field of design research. I agree with Fallman (2003,

p. 225) that "…design is a matter of *making*; it is an attitude to research that involves the researcher in creating and giving form to something not previously there" (emphasis in original). Based on this view of design, I believe that my strength as a design researcher is not primarily to increase the understanding of issues related to sustainable development (descriptive research) but to suggest design concepts or design implications (prescriptive research) on issues related to sustainable development. Yet, I can only make such suggestions if I increase my own understanding of the issues at hand, which is why descriptive research are important and integral parts of what I do.

3.2 RESEARCH METHODOLOGY

In this work presented here I have used research through design as an overall methodological approach. In research through design, design researchers integrate knowledge from models and theories in behavioural sciences and knowledge about technical opportunities with findings from the field to create the *right* thing, in an iterative design process (Zimmerman, Forlizzi, & Evenson, 2007, emphasis in original). The *right* thing is "a product that transforms the world from its current state to a preferred state" (Zimmerman et al., 2007, p. 493, emphasis in original). In the iterative design process, the design researcher's understanding of the world is constantly reframed as design concepts fitting or challenging the design researcher's understanding are created and discarded. The final output of research through design is "concrete problem framing and articulation of the preferred state, and a series of artifacts – models, prototypes, products, and documentation of the design process" (Zimmerman et al., 2007, p. 497). To me the word 'problem' is related to difficulties, yet, I believe this research approach fits just as well for missed opportunities. Therefore, in my terminology I use the more over-arching wording 'design challenge' instead.

I recognise that research through design is not yet a well-defined approach with processes, procedures, and activities ready to apply (Zimmerman, Stolterman, & Forlizzi, 2010). Therefore, I have used research through design as a way of unfolding my underlying attempt of making the *right* thing (cf. prescriptive approach above), as a guide to what type of research output to aim for, and to discuss the quality of my work (see chapter 7). I have also used research through design to organise my research work into two parts: (part A) exploration of the current situation and (part B) integration of knowledge about the current situation into design concepts. These two parts correspond to the two things designers do best: "to study the world and then make things intended to affect change" (Zimmerman et al., 2007, p. 7). The bridge between part A and part B are design challenges, and thus this way of bridging the two parts links to the research through the design approach.

Part A, exploration of current situations, corresponds to the first part of the aim of this licentiate thesis: exploring people's perspectives on district heating. Part

B, integration of knowledge about the current situation into design concepts, corresponds to the second part of the aim: investigating the potentials of redesigning the district heating interface for people.

The overall research approach can be seen figure 6 and in table 3. In part A, I explored people's perspectives on district heating with residents in two separate research studies, study 1 and 2. The data from study 1 and 2 were then compared and related to each other in a convergent parallel design, through which initial insights were created (cf. Creswell & Clark, 2011) and communicated in paper 1 and paper 2. Initial insights from both studies were then interpreted in a design brief with initial design challenges, linking part A to part B of my research. ch.

Part B comprised one main study, study 3, preceded by a preparatory design phase. In the preparatory design phase I began by devising a design brief with the initial design challenges from part A. Then I created initial design concepts through iterating between designing and reframing the initial design challenges as described in the brief (see highlighted line to the left in figure 6) (cf. Zimmerman et al., 2007). In study 3, I performed a technology probe field study based on one of the design concepts. The two stages in part B were thus sequential, with study 3 building on the results of the preparatory design phase. The findings from study 3 resulted in paper 3.

The final outcome of this research was generated in part A and part B. In part A the final outcome include general **insights** on people's perspectives on the district heating, **design implications** based on their perspectives, as well as **design challenges**. Although these insights, implications, and design challenges predominantly comprise results from part A, they reached their final state through iteration with the findings in part B (see both highlighted lines in figure 6). The final outcome of part A answers to research questions 1 and 2.

In part B, the final outcome builds on the design challenges defined in part A and are **possibilities** (or preferred states (cf. Zimmerman et al., 2007)) manifested in **design directions** and **design concepts**. The final outcome of part B answers to research question 3.

The situation that I started to explore in part A can be considered a *wicked problem*, a problem that cannot be defined or described in an exact way – an indetermined problem (Buchanan, 1992; Rittel & Webber, 1973). For such problems, the solution, or rather a resolution, is created during the process of formulating the problems(Rittel & Webber, 1973). So, for example, if lack of information to the public about district heating would be a problem, or a challenge, more information would be one type of resolution. Hence, I did not set out with a clear challenge; instead, one type of final output of this research is defined design challenges in the studied situation. Thus, I did not use design primarily as problem solving but as problem, or challenge, setting (cf. problem-solving vs. problem setting in Babapour, 2015). Similarly, the research questions evolved into their final shape as the research proceeded.

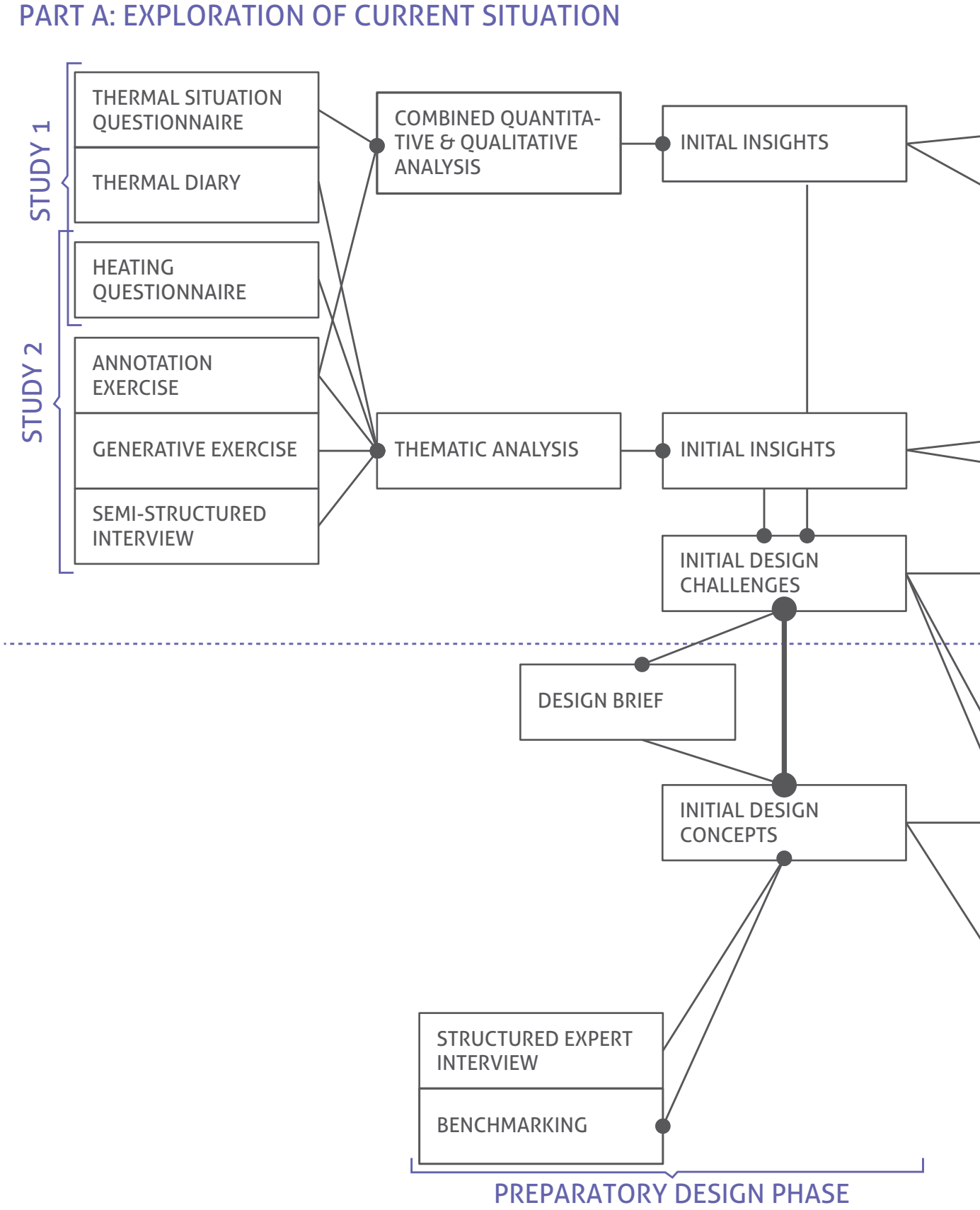


Figure 6. Overall research approach

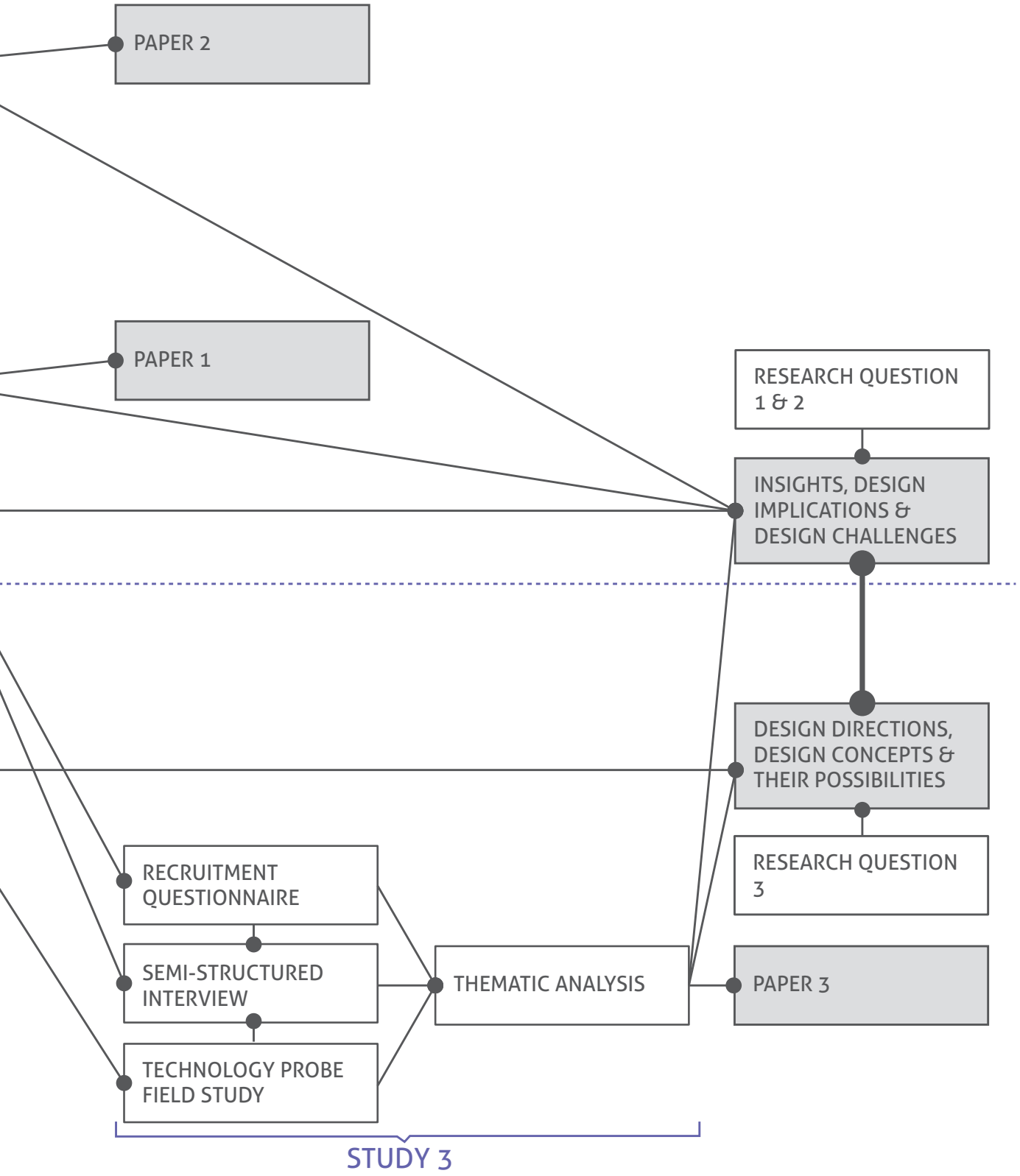

PAPER 2
PAPER 1
RESEARCH QUESTION 1 & 2
INSIGHTS, DESIGN IMPLICATIONS & DESIGN CHALLENGES
DESIGN DIRECTIONS, DESIGN CONCEPTS & THEIR POSSIBILITIES
RESEARCH QUESTION 3
PAPER 3
RECRUITMENT QUESTIONNAIRE
SEMI-STRUCTURED INTERVIEW
TECHNOLOGY PROBE FIELD STUDY
THEMATIC ANALYSIS
STUDY 3

Table 3. Overall research approach

PART	PART A		PART B	
AIM	Explore people's perspectives on district heating		Investigate potentials of redesigning the district heating interface for people	
STUDY	Study 1	Study 2	Preparatory design phase	Study 3
RESEARCH QUESTIONS ADDRESSED	RQ 1: What role does district heating play in people's everyday pursuit of thermal comfort? RQ 2: How do people make sense of and make use of district heating in everyday life? Are there any specific factors that influence people's understanding and use and if so, which ones?		RQ 3: What possibilities are there in redesigning the district heating interface for people?	
PARTICIPANTS	35 residents	35 residents	5 district heating experts	18 (156) residents
TYPE OF DWELLING	All types of dwellings with and without district heating	Rental apartments, leasehold apartments, and houses, all with district heating	-	Leasehold apartments with district heating
RESEARCH METHODS	Thermal diary Thermal situation questionnaire	Annotation exercise Generative exercise Semi-structured interview	Design brief Structured expert interview Benchmarking	Recruitment questionnaire Technology probe field study Semi-structured interview
	Heating questionnaire			
DATA ANALYSIS	Mixed-methods approach (combined qualitative and quantitative data)		–	Thematic analysis (qualitative data)
APPENDED PUBLICATIONS	Paper 1 and paper 2		-	Paper 3

3.3.1 RESEARCH METHODS

Overall, I applied mixed method research (Creswell & Clark, 2011) resulting in both quantitative and qualitative data. The main part of my research has involved people in one way or another, foremost residents but also district heating experts. In the preparatory design phase of Part B, I also did exploration and knowledge integration more typical for design research.

One aspect that must be mentioned in relation to employment of methods is seasonality. The need, use, and experience of district heating vary through the seasons and this is likely to influence the results of the studies. Study 1 was done in late winter, study 2 in late spring, and study 3 in early spring.

research with people

Methods for carrying out research with people can be categorised based on the types of knowledge that can be gathered: explicit knowledge about what people say and think, observable knowledge of what people do and use, and tacit or latent knowledge about what people know, feel, and dream (Sleeswijk Visser, Stappers, van der Lugt, & Sanders, 2005). Methods for research with people can further be sorted into low, medium, and high contact depending on the degree of interaction with the people and the depth to which insights are explored (Norwegian Design Council, 2012).

The different types of methods used in this research are presented according to these two categories, see figure 7. Methods accessing different levels of knowledge were used to gain a broad understanding. A combination of different degrees of interaction was applied to achieve many of the insights (low contact) as well as examining those insights thoroughly (high contact).

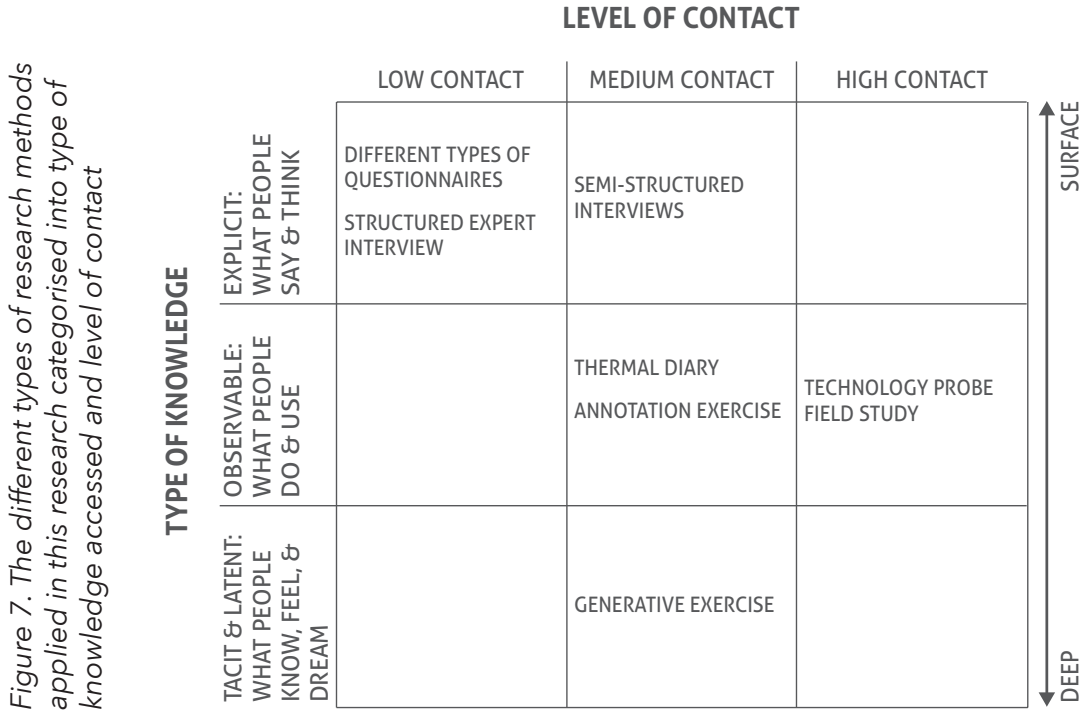


Figure 7. The different types of research methods applied in this research categorised into type of knowledge accessed and level of contact

The methods for research with people resulted in both quantitative and qualitative data. The quantitative datasets were analysed with descriptive statistics (i.e. summaries about the sample and about the observations, such as demographics), and with statistical tests based on questions or hypotheses (cf. Creswell & Clark, 2011). For some of the descriptive statistics and for all the statistical tests the software SPSS was used.

The qualitative data have been interpreted differently according to the type of knowledge they represent, see figure 7. Different types of interviews and questionnaires have thus been interpreted as what people say and think. Data from the diaries, annotation exercises, and the technology probe field study has been interpreted as what people do and what artefacts they use. The generative exercises have been interpreted primarily as something people know. Further, the qualitative data have been transcribed (if applicable), coded, and grouped into broader themes (cf. Creswell & Clark, 2011). I did not use pre-defined codes and themes, but the themes emerged from the data – an explorative onset. For the interviews I used the qualitative data analysis computer software NVivo. When possible, the themes that emerged from the qualitative data were compared with or related to insights from the quantitative data. The interpretation of the themes was made in an attempt to organise the insights into answers to the research questions, to define design challenges, and to give design implications

design research

In the preparatory design phase of part B, I drafted initial concepts, partially in conjunction with design practitioners. In this process we externalised our ideas (sketches and rough models) and (explicitly or implicitly) interpreted them, thereby exploring the potential for redesigning the district heating interface for people. In this way we iteratively evaluated and reframed the challenges and reconsidered the possibilities, as well as redesigned the concepts.

Design-oriented research has truth or knowledge as its main contribution (Fallman, 2003). Are design concepts however really knowledge? I believe that knowledge can appear in different forms with different levels of abstraction, where general theories are the most abstract (cf. Löwgren, 2013). Höök and Löwgren (Höök & Löwgren, 2012; Löwgren, 2013) suggest different ways of presenting intermediate-level knowledge in design-oriented research: design methods and tools, design guidelines, design patterns, strong concepts, and design concepts.

Zimmerman et al. (2007) point to the importance for design researchers to design the *right* artefact, instead of designing a *commercially successful* artefact, which would be a task for the design practitioners (emphasis in original). Such right research artefacts should be considerably innovative and aspects connected with commercialising should be de-emphasised (Zimmerman et al., 2007). In the design concepts I have produced, aspects of economics and manufacturability are de-emphasised, and throughout the process I sought an innovative dimension.

4 PART A: STUDY 1 & STUDY 2

In the first part of this project I explored people's perspectives on district heating through addressing the first and second research question, which was done in two studies, study 1 and study 2. In this chapter, a short overview outlining the procedures in these two studies and the findings from both are highlighted. Further, three design challenges are identified and described that link this part of the project, part A, to the subsequent part of the project, part B. The complete report of these two studies, summarised below, can be found in paper 1 and paper 2 (appended).

4.1 PROCEDURES OF PART A

In both study 1 and 2, a combination of methods was used to explore different topics related to the first two research questions, see table 4. In both studies the participants responded to a questionnaire on heating, as described below. Thirty-five participants took part in study 1 out of which 11 volunteered to participate in study 2 as well. In total 30 households took part in study 2

4.1.1 PROCEDURES OF STUDY 1

The participants in study 1 were recruited through advertisements in the local newspaper, libraries, and supermarkets (n=19), through e-mails to university students and employees (n=14), and through social media (n=5). Participants with different types of homes and heating systems were recruited.

Three separate methods were applied in study 1: heating questionnaire, thermal situation questionnaire, and thermal diaries. The study commenced with meetings at Chalmers where the participants completed the two different types of questionnaires and were introduced to the thermal diaries. The participants returned the diaries after one week.

thermal diary

The thermal diaries explored how thermal comfort is achieved in everyday life in order to understand what role district heating plays in that pursuit (cf. research question 1). The participants were asked to make one entry in the diary whenever they experienced thermal discomfort during the span of one week. The diary, a small paper diary to increase accessibility and handling, had room for 35 entries with check boxes, free text questions, and an outline of a human body, see figure 8. The diary is described in detail in paper 1.

Table 4. The different themes explored in study 1 and study 2 in relation to the addressed research questions

RESEARCH QUESTIONS	TOPICS EXPLORED (& METHODS USED) IN STUDY 1	TOPICS EXPLORED (& METHODS USED) IN STUDY 2	TOPICS EXPLORED (& METHODS USED) IN BOTH STUDIES
RQ1: What role does district heating play in people's everyday pursuit of thermal comfort?	How thermal comfort is achieved in everyday life (thermal diary) Emotional reactions elicited in different thermal situations (thermal situation questionnaire)	People's thoughts about what they utilise to stay warm and to get hot water in relation to energy (annotation exercise)	Background information about the participants and their homes (heating questionnaire)
RQ2: How do people make sense and make use of district heating in everyday life? Are there specific factors influencing people's understanding and use and if so, which ones?	–	People's understanding of their heat and hot water system, and consumption (generative exercise & semi-structured interview) People's interactions with the heating and hot water system (semi-structured interview) Technological barriers and other types of barriers for altered energy consumption (semi-structured interview)	

All the diary entries were inserted into the statistical software SPSS. The number of instances of thermal discomfort was calculated together with the participant's location and activity at the time of the recorded instances, which body parts were affected, and whether any means to achieve thermal comfort had been utilised. The different means of achieving thermal comfort were coded using thematic analysis and the occurrence of each approach was calculated. A research assistant, Fredrik Axelsson, contributed to analysing the thermal diaries.

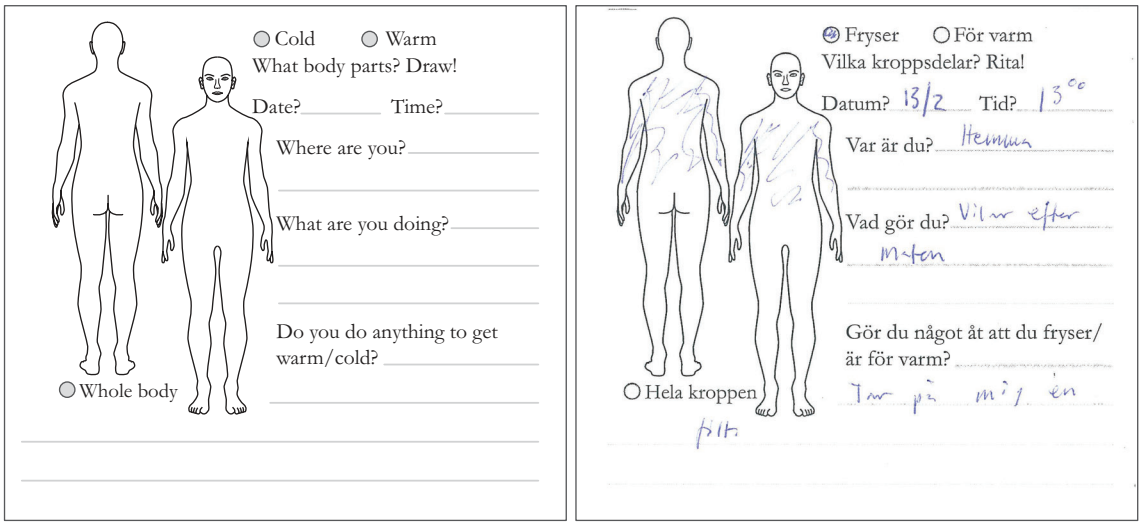


Figure 8. Layout of the thermal diary and an example of a completed entry (Cold | Where are you? At home | What are you doing? Resting after eating | Do you do anything to get warm/cold? Cover myself with a blanket)

thermal situation questionnaires

To achieve a wider perspective on thermal comfort, I investigated what emotional reactions were elicited in different thermal situations and which evaluation words best described the characteristics of the situations. This was done through what I defined as 'thermal situation questionnaires'. The results of the thermal situation questionnaire were not directly used in the research presented in this licentiate thesis. However, paper 2 describes the thermal situation questionnaire and the results in detail.

heating questionnaires

The heating questionnaires provided information about the participants and their homes in order to understand the background to the data collected through other methods. The heating questionnaires included demographic characteristics, information about the participants heating and hot water system, their energy consumption, interaction with heating and hot water systems, opinions about the heating in their homes, as well as their attitudes towards energy consumption in general. All participants from study 1 and study 2 completed the heating questionnaire (n=59).

The results of the heating questionnaire were first compiled separately for the participants in study 1 and study 2, followed by a summary. Descriptive statistical methods were applied in the software Excel. No inferential statistical methods were employed.

4.1.2 PROCEDURES OF STUDY 2

Study 2 explored how residents in homes equipped with district heating understand and make use of district heating. In a literature review on district

heating consumption Palm and Isaksson (2009) found some differences in different types of dwellings. Therefore I decided to include residents of the three predominating types of dwellings in Sweden: rental apartments (n=10, leasehold apartments (n=9), and houses (n=11). Eleven participants in 10 households volunteered to participate in study 2 as well. The remainder were recruited through Göteborg Energi's customer data base (n=8), through emails to close and distant friends and acquaintances (n=9), and through posters in apartment building (n=2). In six households, two members partook, resulting in a total of 35 participants.

annotation exercise, generative exercises & interview

In study 2, three different methods were applied in the following order: annotation exercise, generative exercise, and semi-structured interview. They took place in the participants' homes (except for three participants who specifically wanted to meet at Chalmers). The duration was around one and a half hour per household.

All participants received the annotation exercises in advance via mail. Included in the material for the annotation exercises was a packet with arrow-shaped notes with five statements about energy which was inspired by Lockton and colleagues (Lockton et al., 2011; Lockton, Nicholson, Cain, & Harrison, 2014). In an enclosed letter, the participants were asked to label items they use to stay warm and get hot water, which I later used to explore people's opinions on energy use in relation to artefacts utilised for obtaining heating and hot water.

Then, approximately after one week, I visited the participants who showed me what they had annotated and told their stories about those items (see also Lockton, Renström, et al., 2014 (not appended)). This was followed by the generative exercises in which people were asked to sketch their understanding of their heating

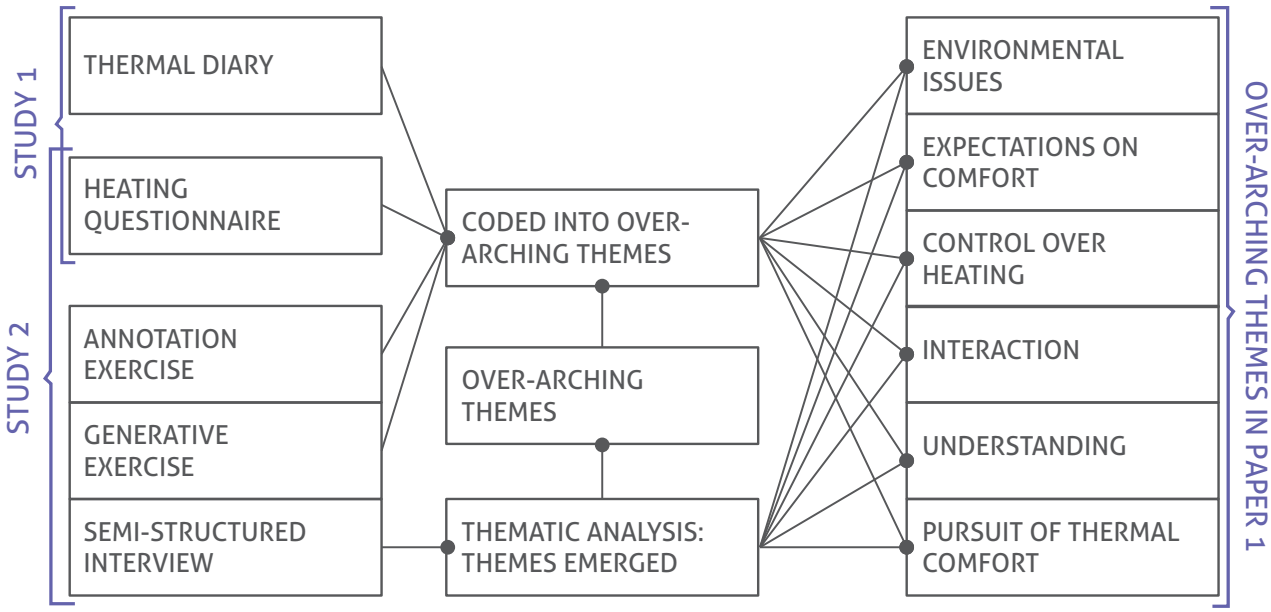


Figure 9. Thematic analysis made for paper 1

and hot water system, including the energy supply method, see paper 1 for more details. They were also asked to sketch their understanding of their daily and annual heating and hot water consumption in an energy graph.

The generative exercises were followed by a semi-structured interview. The interview guide covered four areas: the participants' interaction with the heating and hot water system, view of their heating and hot water consumption, how technologies in the home relate to consumption, and other barriers for reducing consumption. The interviews were recorded by audio and I also took notes.

The results from the interviews were coded into emerging categories in the qualitative data analysis software NVivo. Based on these emerging categories, six over-arching themes were defined. The results from both the annotation exercise and the generative exercise were then categorised according to the themes. For a more detailed description of the analysis, see paper 1.

4.1.3 JOINT ANALYSIS OF STUDY 1 & STUDY 2

For paper 1, the results from the thermal diaries and the heating questionnaires as well as the results from study 2 were then categorised into the six over-arching themes described above. The themes include: environmental issues (in relation to energy consumption), expectations on (thermal) comfort, control over heating,

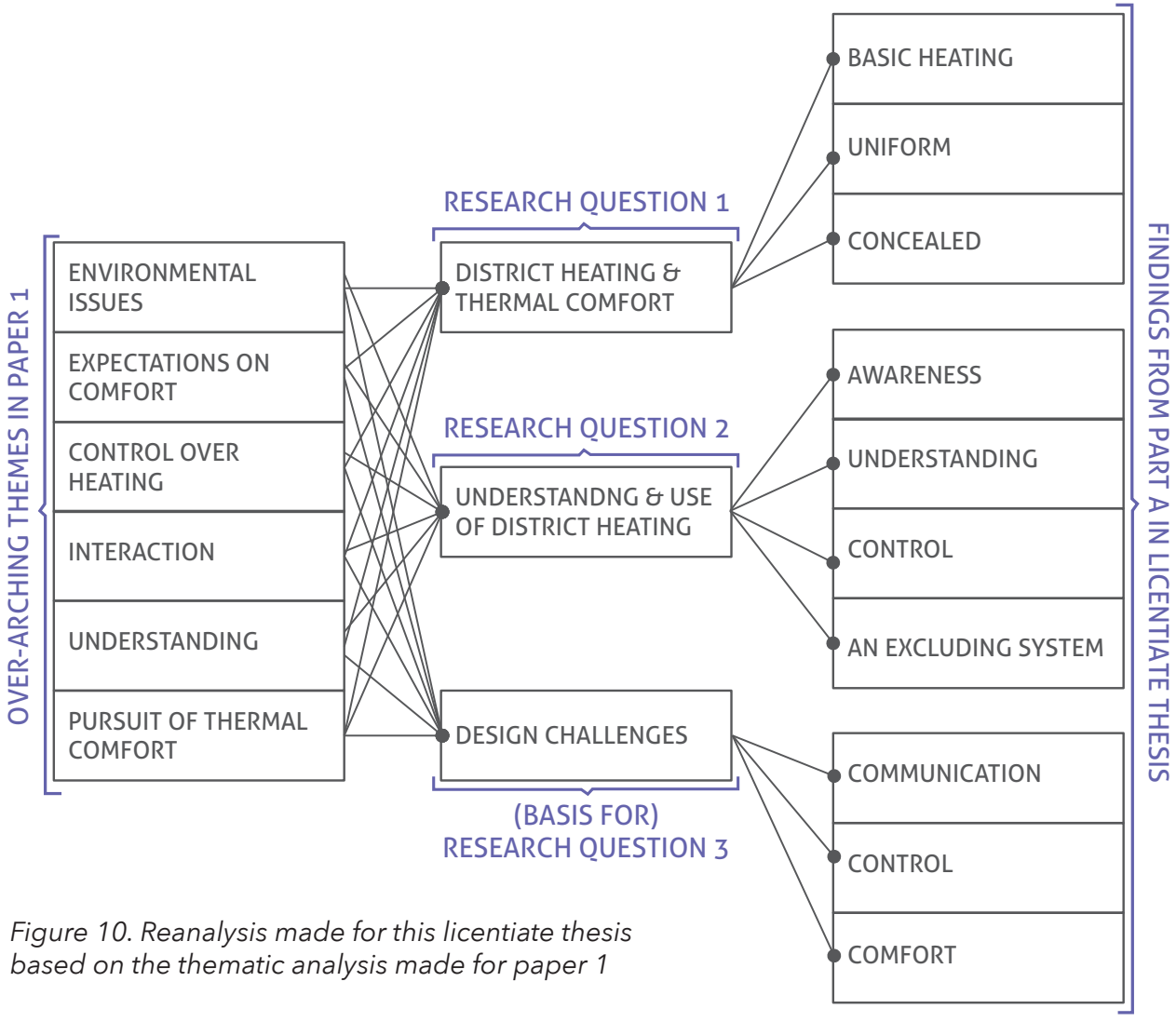


Figure 10. Reanalysis made for this licentiate thesis based on the thematic analysis made for paper 1

interaction (with heating and hot water systems), understanding (of heating and hot water systems), and pursuit of thermal comfort (see figure 9).

For this licentiate thesis, the over-arching themes were re-analysed in order to better correspond to research questions 1 and 2, as well as to provide a foundation for research question 3. In that analysis, some new or reformulated themes emerged, which answered the research questions better, see figure 10. Based on these new themes I defined three design challenges for district heating interface for people.

Some of the findings from study 1 and study 2 could be interpreted either as specific problems or deficiencies in the interaction space between district heating and people at different levels of the multi-level design model (described in chapter 2). Therefore I mapped the findings that represented specific problems or deficiencies in the different levels of the multi-level design model.

4.2 FINDINGS FROM PART A

In the findings from part A presented below I initially present three themes – basic, uniform, and concealed heating – related to research question 1: What role does district heating play in people's everyday pursuit of thermal comfort?

In the second section I present three themes – awareness, understanding, and control – that are related to the first part of research question 2: How do people make sense and make use of district heating in everyday life? Lastly, I present one factor – district heating as an excluding system – as an answer to the second part of research question 2: Are there specific factors influencing people's understanding and use and if so, which ones?

In the third section I describe three design challenges: communication, control, and convenience. In the fourth section I present the mapping of specific problems and deficiencies in the multi-level design model.

4.2.1 THE ROLE OF DISTRICT HEATING IN THERMAL COMFORT

In the thermal diaries, the participants reported between four and 35 instances with thermal discomfort during the one week span studied. The median number of instances per person was 25. The majority of diary entries were made in the Gothenburg area of Sweden, in the winter of 2012. The mean outdoor temperature during the period was 1°C. In total, 831 instances of thermal discomfort were reported. Some of the characteristics of these instances are shown in figure 11. The participants reported more instances of being too cold than too warm, yet quite often warm (35% of the reported instances of thermal discomfort). Most times, participants acted on the thermal discomfort. From a design perspective it is interesting that most instances of thermal discomfort concerned only parts of the body. Thermal discomfort concerning body parts makes local means for thermal comfort suitable rather than changes in the environment. In the thermal diaries, the participants reported most instances of thermal discomfort at home. However,

the inconvenience of completing the thermal diaries elsewhere may have influenced this effect.

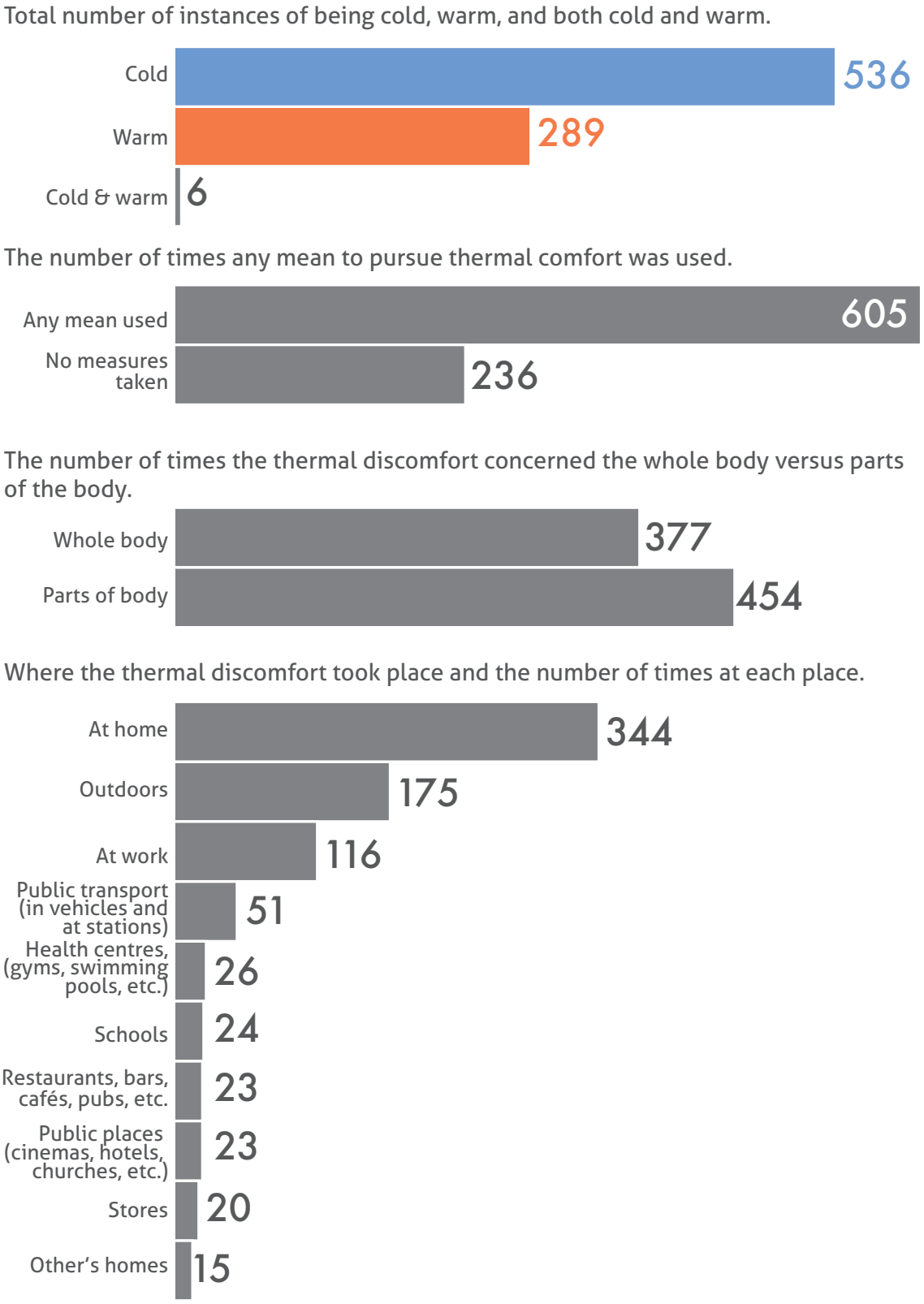


Figure 11. Characteristics of the instances of thermal discomfort, as reported in the thermal diaries

The thermal diaries showed that the participants utilised a wide variety of means to achieve thermal comfort in everyday life see figure 12. Similar means were reported in the interviews and in the annotation exercise, yet with a few additions, which included shutting air vents, pulling down blinds, draught proofing, closing doors, wheat pillows, and footbaths. More extreme measures were also mentioned in the interviews such as heating up the kitchen with the oven, removing thermostatic radiator valves, sitting by the towel-drying radiator, and heating up the air in a bathroom, where the heating was deliberately kept off, with hot water from the shower. These measures were implemented less often and evidently no one resorted to any of them during the limited time that they were completing the thermal

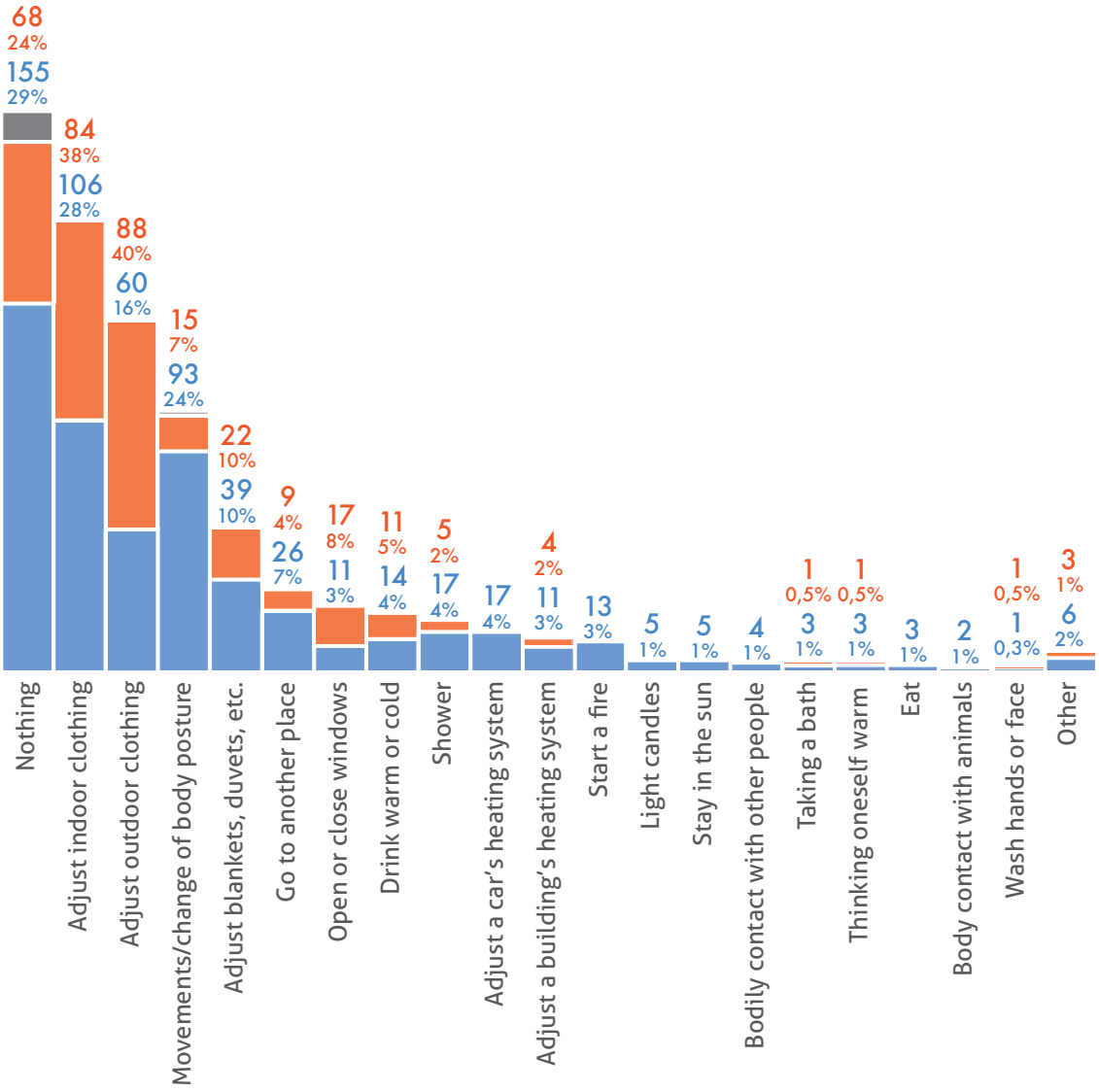


Figure 12. Different means to pursue thermal comfort, as reported in the thermal diaries. The blue parts of the bars and the corresponding figures show the number of times people used a mean for thermal comfort when being uncomfortably cold, the red parts when being uncomfortably warm, and the grey parts for uncompleted instances. The blue (red) percentage how common it was to use that mean when being uncomfortably cold (warm), or how common it was to not do anything.

diaries. These findings imply that district heating in the shape of space heating was not enough for the participants to achieve thermal comfort, or that district heating did not provide thermal comfort in a satisfactory way. The findings thus suggest that **district heating provides basic heating although additional means are needed to achieve thermal comfort, or that additional means are preferred.**

In total, the participants in study 1 took 190 measures to get warmer and 96 to get colder in their respective homes. From the perspective of district heating it is interesting to note that few of these events concern the heating system, for example adjusting thermostats. In total the participants in study 1 reported only 15 instances of adjusting the heating system inside a building, 11 times because they were uncomfortably cold and four times because they were uncomfortably warm. Fourteen of these instances took place in the participants' homes and one of the instances of being too cold was at work. Thus, only 10 measures were recorded for getting warmer at home considered the heating system, representing 5% of all measures taken if uncomfortably cold at home (10/190). In nine of these instances the participants also utilised additional means. According to the thermal diaries, it was thus more common to adjust the heating system in a car than at home, despite much more instances of being uncomfortably cold at home than in a car. At home, it was more common to light a fire than to adjust the heating system.

In the thermal diaries, eight different participants recorded having adjusted the heating at home while one other participant adjusted it at the office. As mentioned, not all of the participants in study 1 was connected to the district heating and among the ones that adjusted the heating at home, five were connected to district heating and three had other types of heating. Similarly, the thermal questionnaire reported that most respondents adjusted the heating: never (n=15), a couple of times per year (n=30), or a couple of times per month (n=10). A few did it a couple of times per week (n=6) or daily (n=3). One reason for this might be that, as mentioned by some participants in the interviews, they often checked that the heating was on maximum when being uncomfortably cold, unless they already knew that it always was on maximum. The participants might not have thought it worth mentioning in their thermal diary that they occasionally checked if the heating was on maximum. Hence, one reason for not interacting with the heating system may be due to it being consistently set to maximum. In the thermal questionnaire a few participants also mentioned this as the reason for infrequent interaction with the district heating. Although I am not certain why, the findings suggest that most of the participants do not adjust their heating system frequently. Therefore it seems that in most homes, **district heating was (almost) always on, aiming for a constant set point temperature, and rarely adjusted. In this way, district heating played a uniform role in the participants' pursuit of thermal comfort.**

Another reason for infrequent interaction with the heating system might be, as discussed in paper 1, the time it takes to achieve thermal comfort through the different means. A heating system is slow compared to adjusting textiles or taking

a shower. Feedback on some of the additional means is more distinct and clear (the draught from an opened window is perceived immediately and the window stays open) which might add to the sense of usefulness of any additional means to achieve thermal comfort.

In the thermal diaries, two different participants lit candles when being uncomfortably cold. One of them in combination with other means (textiles or pets) while the other found it the only thing to get warmer. Combining a more symbolic and visual action such as lighting a candle with a more steadfast action, such as covering with a duvet, might be another way of getting distinct and clear multisensory feedback, a way of visualising the warmth.

The different measures the participants took to pursue thermal comfort varied in type of energy used, thermal or electric, and in energy intensity, from energy intensive appliances such as ovens, to measures that do not require energy during use, such as blankets. Other energy intensive rebound effects of a cold home mentioned were turning on the oven to heat up the home and heating up a cold bathroom through running a hot shower (discussed in paper 1).

All the actions a resident can take to pursue thermal comfort can be seen as a personal heating system. District heating plays a part in this personal heating system, but for most of the participants, additional means are more frequently and actively used. Infrequent interaction with the heating system and **additional means to achieve thermal comfort is not a problem per se**, but, as discussed also in paper 1, it seems as if it may **conceal the role district heating plays in a resident's personal heating systems**.

Personal heating systems include means for thermal comfort with different characteristics: some means are directed to different body parts and some to the whole body; some means are fast and effective while others are slow; some are energy intensive while others are not; some use district heating and others electricity; and some also have emotional qualities (as discussed in paper 2). Here lies an opportunity for district heating companies to investigate if residents' personal heating systems can be improved by making use of district heating, and how. **Non-resource intensive, temporary, and fast ways of getting warmer or cooler that are useful for the whole body as well as body parts could be explored further.**

4.2.2 UNDERSTANDING & MAKING USE OF DISTRICT HEATING

The participants in the two studies who were living in apartments lacked apparent ways of knowing if a particular space was heated with district heating or not. In study 1, 12 out of the 25 participants living in leasehold and rental apartments did not know what type of thermal energy supply method they had in their homes (i.e. if they had district heating or not). Some of the participants in leasehold apartments reported that they were only informed about the thermal energy supply method in their apartment through the sales brochure the estate agent provided.

In the interviews many participants revealed that their heating and hot water consumption is not something they reflect on in everyday life. It is not, as one of them said "top of the mind". A few participants mentioned that it has been brought up as a topic in the family. In line with this unawareness, most of them never (n=29) or seldom (n =13) lowered the heating when going away for a weekend or longer. A few interviewees mentioned turning off or down floor heating but not the radiators, indicating that they were more aware of their floor heating. Floor heating is a further appreciated source for thermal comfort and some of the participants who do not have it, stated that they would like to have it.

Reducing electricity use was generally considered more important than saving on district heating, and further measures had been taken to reduce electricity consumption, for instance through low-energy light bulbs. In relation to inefficient use of district heating, the participants often mentioned activities relating to the kitchen and bathroom. Examples include keeping the water running when brushing teeth or washing-up, rinsing empty packages with hot water, and rinsing dinnerware before washing it in the dishwasher.

Residents seemed to be more aware of district heating when utilised in unexpected ways or when utilised to heat the body more directly. Examples of the former include getting butter to room temperature by slowly heating it on the floor heating, defrosting food on radiators, or drying clothes on radiators. Examples of the latter include heating themselves up by sitting close to towel dryers or warming their feet on radiators.

In study 2, 20 out of 29 interviewees showed some awareness or understanding of the district heating system when asked to sketch it. Almost all of those 20 participants knew that waste incineration was involved and many of them also knew the names of some different heating plants in the city. Interestingly, two of the three participants who did not know if they had district heating in their homes still showed an understanding of the system as a whole. People living close to Rosenlund, one of the centrally located reserve heat plants in Gothenburg, drew this particular plant, although it only operates occasionally. Almost all of the participants included pipes underground as a part of the system.

To sum up, the participants did generally not seem to be aware of the district heating as a system in their everyday life. The findings suggest that the **participants are more aware of and/or understand more about district heating as a phenomenon or system in the city**, in the shape of waste incineration, the physical buildings, and the underground pipes, **than as a supplier of thermal comfort in their homes**. With regard to the home, the **participants seemed to be more aware of some of the artefacts that distribute district heating than of others**. They were either **more aware of the objects they frequently had to interact with** (e.g. taps and showers) **or the things they could sense with the body**, see figure 13.

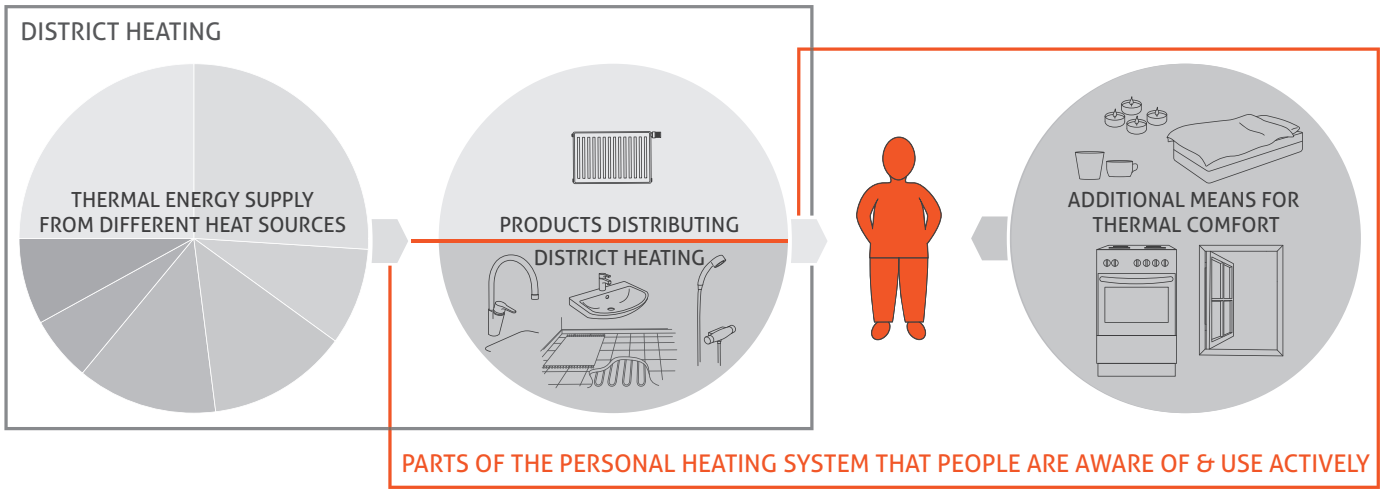


Figure 13. Parts of the personal heating system that residents are aware of and use actively

The participants in study 2 found the district heating substations (those living in houses), radiators, and thermostatic radiator valves difficult to understand and the participants' interaction patterns with their heating systems seemed to be formed by these struggles. For floor heating and towel dryers it was also unclear to some participants if the appliances used district heating or electricity. Furthermore, participants did not have in-depth knowledge of the household energy use and which heat sources the district heating system utilised. In some cases and for some aspects participants also had mental models that were not helpful to them. For example, that thermostatic radiator valves only indicate the temperature and never any other types of indications, such as 1-5.

The participants' understanding of the district heating system, including the technology in the home, is a result of the type of information and feedback that they have been provided with. For most participants the information is sparse, especially for those living in apartments. Therefore, the participants rely on the type of feedback they receive, such as the warmth of the radiators (misleading feedback as radiators can function properly without being hot) and sound from the radiators (often a result of slight malfunction). Sometimes the personal thermal comfort level was the only available type of heating feedback. As mentioned, the participants living in apartments were not properly informed about whether or not they had district heating. The results from study 2 also suggest other types of information, such as who controls the heating and how, the duty of different key players, if residents are eligible to adjust the controls, how the technology works in the home, the household energy consumption, and the state of the whole district heating system (i.e. mix of heat sources currently used and which heat production plants are running).

The participants in study 2 were often uncertain of what, if any, control they had over the heating, about the duty of different key players, and whom or what control the temperature (although some mentioned sensors). Most of the participants in apartments would prefer more control over their heating, and one of them

specifically mentioned that he would lower the heating when going away if he was able to. It was difficult to ascertain what level of control each participant actually have as that depends on the local conditions of each particular building as well as how well the heating system is maintained; for instance, the state of the radiator valves in each apartment. The findings do however imply that **the participants lack perceivable control possibilities and that they often lack actual control possibilities as well**. Additionally, if the heating is always adjusted to maximum as described above, control possibilities in practice become limited.

The above-mentioned uncertainty of their eligibility to control the system was reflected in comments from the participants, such as, "I think they have turned the heating off now" without being able to specify who they thought 'they' are. In addition, the participants were uncertain about the state of the heating system, resulting in questions like "Is the heating on?". Another example of uncertainty was described by a participant who sometimes adjusts the setting of the thermostatic radiator valves back and forth to establish if she has any control. While some of the participants used these different ways of gaining an understanding and control over the system most of them did the opposite – they rarely interacted with their heating system at all.

an excluding system

One way of explaining why the participants in my studies as well as in other studies (see chapter 2) are unaware, uninterested, uninformed, and lacking (perceivable) control possibilities of the district heating, is because residents in apartments are excluded from the district heating system. They are excluded in the sense that they seem to be considered as a homogenous group of passive beneficiaries without personal preferences and not as active stakeholders within the system. Such exclusion presents itself in a complete lack of need for any sort of action from the residents. Their interaction is not demanded, neither with the heating system nor the district heating system: settings or adjustments of the heating system are not required on a daily or annual basis, there are no bills due, and agreements or contracts do not need to be signed at any point. The exclusion is also observed in a lack of (perceivable) control possibilities, perceived as if the residents are not expected to have any personal preferences with regard to heating. Further, missing feedback about the state of the heating system and processes, as well as lack of information about consumption and current mix of heat sources, can be interpreted as if residents are not expected to be interested in this type of information and seen as unable to contribute to the performance of the system, through load balancing, for instance. The consequence of viewing residents in apartments this way may be that business models aimed at building owners increasing residents' potential for control not being very common.

In contrast, residents in private houses are obliged to interact with the system, informed about their consumption, and are in control of the heating, although the system is not easily understood and accessed. Thus, they are not excluded

in the same way, yet, they can be regarded as excluded as they are not informed about current mix of heat sources and not given the possibility to contribute to the performance of the district heating system through load balancing, for instance.

4.2.3 THREE DESIGN CHALLENGES

Based on the over-arching themes presented in paper 1, I defined three design challenges, meaning challenges that can be further explored and addressed with design solutions: communication, control, and comfort. All three design challenges represent points of missed opportunities in the relationship between people (as citizens, residents, occupants, and/or users) and the district heating system. The challenges are not independent of each other, they are interdependent and to some extent overlapping, yet, they do represent different perspectives of the interaction space of people and district heating.

communication

One design related challenge is lack of communication about district heating to people as residents, as users of district heating in need of space heating and hot water. Instead, the communication concerns district heating as a principle and is directed to people in their role as citizens. This creates some awareness and understanding of district heating as a concept or as a manifestation in the city, but not as the main provider of thermal comfort. People are aware that district heating exists but not necessarily the magnitude of the system, its contribution to the whole energy system, and some of its specific qualities, for instance use of excess heat from industries. As mentioned in the introduction, people's unawareness is not a particular obstacle for how district heating companies make business at present but it will become more challenging in the future, as the energy landscape is changing towards more user-oriented energy systems.

The participants in study 2 did not describe lack of communication about district heating as a provider of thermal comfort as a difficulty in everyday life. Although some of them were interested in energy conservation, they seemed more aware of their electricity consumption, which implies that there is a missed opportunity to engage people in their district heating use as well.

control

One other problem that could be addressed through design is lack of (perceivable) control over the heating in the home and lack of feedback about the state of the heating system (Is it on?) and processes (Is the temperature changing?). This is a problem primarily for residents in apartments, and those residents generally wanting increased control. There are reasons why residents in apartments have not been given more control than they have been. Building owners and managers can often manage and steer the heating system easier and more efficiently with tighter central control. Yet, there are missed opportunities for reducing energy

consumption if residents do not reduce the heating when leaving for holidays or when residents leave bedroom windows open throughout the winter. In addition there are rebound effects that end up on building owners' and managers' bills (e.g. showers and baths). For building owners and managers as well as for property caretakers, another time-consuming effect of lack of (perceivable) control may include be complaints from residents. Lack of (perceivable) control over heating might not be a direct concern for district heating companies, but it could be seen as an opportunity for new business models for the future. In addition, lack of (perceivable) control means that people are not able to contribute to load balancing, for instance.

comfort

District heating is a system for delivering thermal comfort, and it is optimised towards delivering a stable indoor temperature in the sense that it runs most efficiently if it delivers a stable indoor temperature. In the differences between the aim of the system with regard to thermal comfort and the mean of a stable indoor temperature, there is a risk of suboptimisation as thermal comfort may be achieved at different temperatures depending on what people are doing at home, for example. Such suboptimisation can make it more difficult to achieve thermal comfort. The suboptimisation can further result in missed opportunities of reducing energy consumption or rebound effects as explained above. Further, it can be seen as a missed opportunity for district heating providers, as district heating might not be perceived as the main provider of thermal comfort.

Finally, positive thermal experiences are attractive in everyday life. Today, only experiences with high demands of energy are available through the district heating system (e.g. showering) even though positive thermal experiences do not necessarily demand energy-intensity.

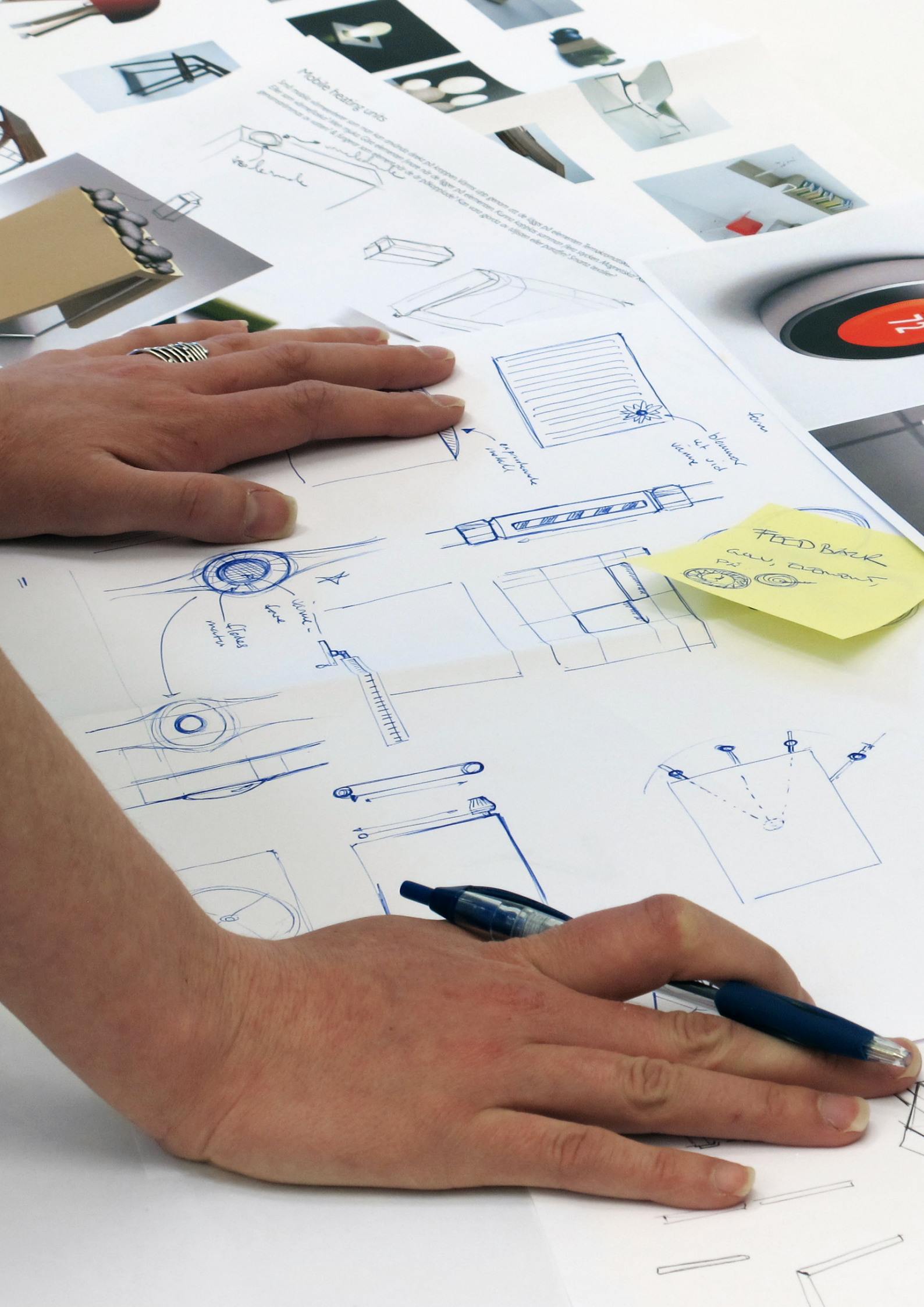
4.2.4 FINDINGS RELATED TO THE MULTI-LEVEL DESIGN MODEL

Table 6 presents the mapping of specific problems or deficiencies in the interaction space of district heating and people (as citizens, residents, occupants, and/or users) on different levels of the multi-level design model. The mapping shows that my exploration revealed more problems or deficiencies on the three lower levels and fewer on the highest level.

Table 6. Findings understood as specific problems or deficiencies in the interaction space of district heating and people (as citizens, residents, occupants, and/or users) on different levels of the multi-level design model

LEVELS	SPECIFIC PROBLEMS/DEFICIENCIES ON DIFFERENT LEVELS
Societal System The national energy system and to some extent the international energy system, including energy systems links to the economic system, taxes, and international agreements.	**Societal Problems** Some residents were sceptic towards waste import
Socio-Technical System The different types of heating and hot water systems and their interlinks, the (household's) lifestyle, norms regarding energy, and shared social practices related to heating, hot water and energy in general.	**System Deficiencies** Daily showers indicate energy intensive norms regarding cleanliness Residents reported rebound use of hot water and electricity (showering/bathing, using electric heaters, turning on the oven, etc., when too cold or showering when too warm) Residents were generally not knowledgably in how to reduce heating Residents were generally not aware of/not thinking about their district heating consumption Residents were generally not aware of the environmental effects of district heating consumption Saving electricity was generally considered to be more important Residents preferred warm homes Some residents wants to come home to a warm home There were sometimes conflicting opinions regarding indoor temperature and heating strategies within households Similarly, guest may have a different heating need (may be complaining that it is too cold or too warm) Lack of need for interaction makes it possible for residents to be completely unaware of the system (in apartments) Most residents consider themselves moderate users of heating and hot water There is a seemingly endless supply of heating and hot water Residents are sometimes worried or annoyed when guests shower for too long or take a bath (in private houses)

LEVELS	SPECIFIC PROBLEMS/DEFICIENCIES ON DIFFERENT LEVELS
Product-Service System The household's heating and hot water system (including payment structure (separate bill or included in the rent) and ownership) and use, and related activities.	**Functional Problems** Residents are not informed about what type of heat source (e.g. district heating) they are connected to Residents are not informed about their district heating consumption Residents are not informed about their responsibilities and of the other key players responsibilities Residents are not benefitting from reduced consumption or reduced peak load consumption Residents lack (perceivable) control over heating Residents are at times too cold or too warm in their homes Many residents always have the heating on maximum Some energy efficiency measures result in increased rent (i.e. new windows with better insulation are regarded as increased standard and thus qualify for a rent increase) The use of heating and hot water is partly determined by working hours which are similar for a large proportion of inhabitants of Gothenburg
Product-Technology System The technical system, within a building, that provides homes with district heating, (e.g., radiators, floor heating, taps, showers and baths) including how the technical system is used and the experiences of using it.	**Operational Problems** Heating systems are difficult to understand and use There is no feedback of the status of the heating system and processes There is no feedback on the status of the district heating system The heating system is not adapted to heating parts of the body The heating system does not give fast heating and cooling There are few possibilities for pleasurable thermal experiences without intensive energy use with the district heating system Residents generally air their homes without turning off radiators The products distributing district heating are not encouraging awareness ("I usually forget that radiators exist") The heating system does not offer different temperatures in different rooms Few residents turn off the heating when leaving for holidays Residents are reduced to unreliable sources of feedback (sound, touching radiators) and not all residents have thermometers Some residents do not appreciate low flow shower heads There are inconsistent use of numbers and symbols on thermostatic radiator valves Some residents, according to themselves, waste hot water when doing the dishes


Mobile heating units
FEED BACK

5 PART B: PREPARATORY DESIGN PHASE

The three design challenges formulated in part A were further explored in a design process resulting in a range of design concepts. These concepts were categorised into three different design directions where each direction corresponded to one of the design challenges.

5.1 PROCEDURES OF THE PREPARATORY DESIGN PHASE

In the preparatory design phase I started with exploring the perspectives the district heating experts have on district heating. Further, through an iterative design process the design challenges I defined in part A were developed into ideas, concepts, and design directions.

5.1.2 STRUCTURED EXPERT INTERVIEWS

The design challenges defined in part A were based on people's perspectives on district heating. To get another perspective on district heating, I did a structured interview via e-mail with a group of district heating experts at Göteborg Energi working with innovations related to district heating, as well as with one former research manager at Göteborg Energi. The questions covered what they considered to be unique, positive aspects of district heating and what aspects of district heating that they would like people to be aware of.

The e-mail was sent out to 10 experts out of which five replied. The first respondent forwarded his answers to all in the e-mail list and subsequent replies were added as comments to the prior respondent's answers, with some added points. In this way I learnt what was consensus among the group of expert and where their opinions differed. Over all, however, they agreed with each other and mostly elaborated on each other's responses. The responses were summarised and used as insights and inspiration in the design process.

5.1.3 DESIGN PROCESS

The design process began when I created a design brief including missions for the design, background to these design missions, insights regarding residents that could be useful in fulfilling the missions, and finally inspirational user insights. The design brief is appended to this thesis, see appendix 2. The design brief was used as a personal document to focus my work and when I later involved external design practitioners they also used the design brief.

Based on the brief, I came up with a set of design ideas. All of these ideas were then

compared with existing solutions and ideas in academic literature, public records of daily life (e.g. blogs), regular stores, second hand stores, design concepts presented online, and in webshops, etc. I created one document including all ideas and examples of how it had been done it (had it been previously done).

Then, I developed the ideas further together with design practitioners at Boid, a design bureau affiliated to Chalmers where I worked with David Lamm, Katharina Merl, and Mikael Sundgren. In that teamwork the design brief and the collection of ideas and examples served as a starting point for further design explorations.

In the collaborative design work we externalised ideas to put them to test, to make sense of them, and to interpret them (cf. Fallman, 2003). What would happen if we do this? What about this instead? The design efforts were directed towards the missions in the design brief, yet, allowing the missions to evolve into the three design challenges as the design ideas evolved. In the end, as a team we had a range of design concepts which we grouped into three design directions, a principal design idea, where each direction corresponded to one of the design challenges.

As I wanted to explore design ideas in-situ more efforts were directed towards ideas that could be prototyped within the time and budget of this licentiate thesis work.

5.2 FINDINGS FROM THE PREPARATORY DESIGN PHASE

Findings from the design process include district heating expert's perspectives on district heating and a range of design concepts categorised into three design directions.

5.2.1 FINDINGS FROM THE STRUCTURED EXPERT INTERVIEWS

In general the five district heating experts held a common view on district heating. The key findings from the interviews are listed below.

- District heating delivery is highly reliable. District heating is a stable and secure system where an entire organisation is working day and night to maintain continuous delivery and fixing problems.
- Homes connected to district heating have a constant supply of domestic hot water, something that is not possible with hot water storage tanks.
- For the residents it is a carefree system.
- District heating is cheap.
- In Gothenburg, introduction of the district heating system reduced emissions as it replaced heat produced at local furnaces.
- A district heating system can make use of sources of thermal energy (i.e. excess heat from industrial processes) which no other energy system can utilise. In Gothenburg 50-60% of the heating is derived from waste incineration

and other sources of surplus heat, and that energy could not have been used without a district heating system.

- With district heating the heat can be used several times, for instance first as heating in homes and then as heating in the ground. In this way district heating can reuse heat within the system.
- The district heating system is continuously being innovated in the sense that there is an entire organisation constantly ensuring that the cheapest and the most environmentally friendly heat sources available are used. As a customer you always buy the most recently available district heating. District heating can thus be seen as "innovation flowing in pipes" (as quoted by one of the experts).
- The district heating system in Gothenburg is from a technological perspective a leading example.
- If residents do not even know if they are connected to district heating, and do not even know what it is, that must, in the residents' perspective, be the most unique feature of district heating, "no other thermal energy supply method is this unknown" (as quote quoted by one of the experts).

As stated by the experts, the delivery of district heating is highly reliable although when residents experience thermal discomfort in their homes, this reliability of heating delivery is not translated into a high reliability of thermal comfort delivery.

Several of the aspects of district heating mentioned by the experts contribute to the inconspicuousness of the system in homes and in daily life. A careless, stable, and secure system does not need any attention. If you are not a direct costumer of a district heating company, the entire organisation that makes highly reliable heating delivery possible is not obvious to you. In addition, cheap energy and endless supply encourage conscious consumption. Thus, with regard to being known by the people in general, the benefits of district heating benefits can easily be turned into weaknesses.

The innovations in heat sources and advancements in the technology development are not visible in homes, where the heating and hot water are delivered in the same way, through the same products and giving the same experience, independent of all innovations. In addition, innovations such as white goods powered with district heating, are not easily perceived as different from white goods powered with electricity.

To sum up, there is a discrepancy between the benefits of district heating that experts see and what residents can perceive through the service they receive, which is the domestic heating and hot water supply.

5.2.2 DESIGN DIRECTIONS

The design ideas were, as described above, developed into concepts which were then grouped into three design directions, each with one principal design idea. The three design directions were:

- use district heating in additional, unexpected, innovative, sensible, and perceivable ways;
- enable residents to be informed of the status and in control of the processes in the local heating system as well as in the district heating system; and
- optimise the way district heating is turned into thermal comfort through newly designed tools for thermal comfort and pleasurable thermal experiences.

Table 6 presents links from the design challenges to the design directions, via design goals and possibilities for each direction. Within each design direction there are a number of design concepts that embody some of the design goals. The concepts and reflections on each of them are listed in appendix 3.

Table 6. Design challenges, design goals and possibilities, as well as design directions

DESIGN CHALLENGE	DESIGN GOALS & POSSIBILITIES	DESIGN DIRECTIONS
Communication Communication about district heating to people as citizens has created awareness and understanding of district heating as a concept or as manifestation in the city, but not as the main provider of thermal comfort. Residents are aware that district heating exists in the area but not necessarily of the magnitude of the system, its contribution to the entire energy system, and some of its specific qualities. Residents do not necessarily know if they are connected to district heating.	Make the presence of district heating in homes and in daily lives easily perceivable. A possibility is that people's awareness of district heating as a provider of everyday services will increase. Communicate specific qualities of district heating to people. A possibility is that their knowledge of the benefits of district heating will increase at the same time as their appreciation of district heating.	**Additional ways of making use of district heating** Instead of communicating about district heating start communicating the presence and qualities of district heating by using district heating for more than indoor space heating and domestic hot water, preferably in unexpected, innovative, sensible and perceivable ways where district heating can replace other energy sources (e.g. electricity and gas).

DESIGN CHALLENGE	DESIGN GOALS & POSSIBILITIES	DESIGN DIRECTIONS
Control Lack of (perceivable) control over the heating in the home and lack of feedback on the heating status of the system status (Is it on?) and processes (Is the temperature changing?). In addition, this means that residents are not able to contribute to load balancing.	Provide clear information about how the heating system and the district heating system function. Possibilities include that people's understanding of their systems and their control over the systems will increase. Provide accessible control over the heating and enable people to influence their energy use. A possibility is that people's awareness and appreciation of their heating as well as of district heating will increase. Give feedback on district heating use as well as the status of the district heating system and the status and processes of the building's central heating system. A possibility is that people's awareness and appreciation of heating will increase, and consequently of district heating as well. Another possibility is that people will be encouraged to influence their energy use.	**Informed and in control** To enable people to be informed of the status and in control of the processes in the building's central heating system as well as in the district heating system.

DESIGN CHALLENGE	DESIGN GOALS & POSSIBILITIES	DESIGN DIRECTIONS
Comfort District heating is not optimised for energy efficient thermal comfort but for energy efficient delivery of a specific room temperature, and in this discrepancy there is a risk of suboptimisation.	Offer people non energy-intensive ways of achieving positive thermal experiences by using district heating. A possibility is that the usefulness of district heating for people will increase without increasing energy use considerably. Offer people means to rapidly and temporarily avoid thermal discomfort in non-energy intensive ways. One possibility is that rebound effects of low indoor temperatures can be avoided and that the usefulness of district heating for people will increase without a considerable increase in energy use. Heat the whole body as well as particular body parts. A possibility is again that the usefulness of district heating usefulness for people will increase without a considerable increase in energy use. Extend the idea of district heating systems to also include additional means for thermal comfort. A possibility is that suboptimisation can be avoided and if so the usefulness of district heating for people again would increase without a considerable increase in energy use	**Thermal comfort and pleasurable thermal experiences** To optimise the way district heating is turned into thermal comfort through designing means for thermal comfort and pleasurable thermal experiences that make use of district heating.

further development of concepts within the design directions

Concepts within all three design directions were developed further. Concepts within the two first directions were further developed separately from the project this licentiate work is based on. One of the concepts within the third direction was further developed within this research; see the following chapter (chapter 6).

shared greenhouse

One of the concepts within the first design direction was a shared green house for apartment buildings heated with reused heat from the building. This concept was developed into a more concrete concept by two teams of master thesis students (Farrouche & Kihlström, 2014; Lindahl & Lindqvist, 2014), see figures 14 and 15.

Figure 14. A shared modular greenhouse that can be heated with recycled district heat already used in the house to enable growing of vegetables all year around (image: Lisa Kihlström and Charlotte Farrouche, 2014)

Figure 15. Planter modules designed for urban farming in shared greenhouses (image: Anna Lindahl & Elina Lindqvist, 2014)

'activity organizer'

One of the concepts within the second design direction was feedback and control related to the different heat sources utilised in the district heating system. If feedback is given in real time or relates to the time of consumption, then residents would become aware of the difference between showering at off and on peak hours, for instance. However, feedback in itself is not enough, residents must also be given the option to act on the feedback; thus a feedback system should be combined with control options that take the complexity of everyday life into account. In collaboration with Boid, a design bureau affiliated to Chalmers, I took part in a separate project, in which we developed a design concept for feedback and control relating to heat sources and attempting to acknowledge the complexity of everyday life. In this project we came as far as designing the user interface and defining functionalities of a concept called the Activity Organizer (see figures 16 and 17). Through the Activity Organizer's user interface and functionalities, people are given the option to set personal thresholds for electricity and district heating use, based on availability of energy from different energy sources. Further, they can schedule energy-reliant products and services to off-peak hours, as well as access and plan energy use according to energy forecasts and their personal energy threshold.

Figure 16 (top, opposite page). Overview of the main interface in the Activity Organizer. Here the user can see current energy use in relation to the personal energy threshold and a forecast on the same.

2014-2016, Chalmers University of Technology and Boid, "Smart use as the missing link in district energy development: a user-centred approach to system operation and management", IEA DHC Annex XI project, preliminary results.

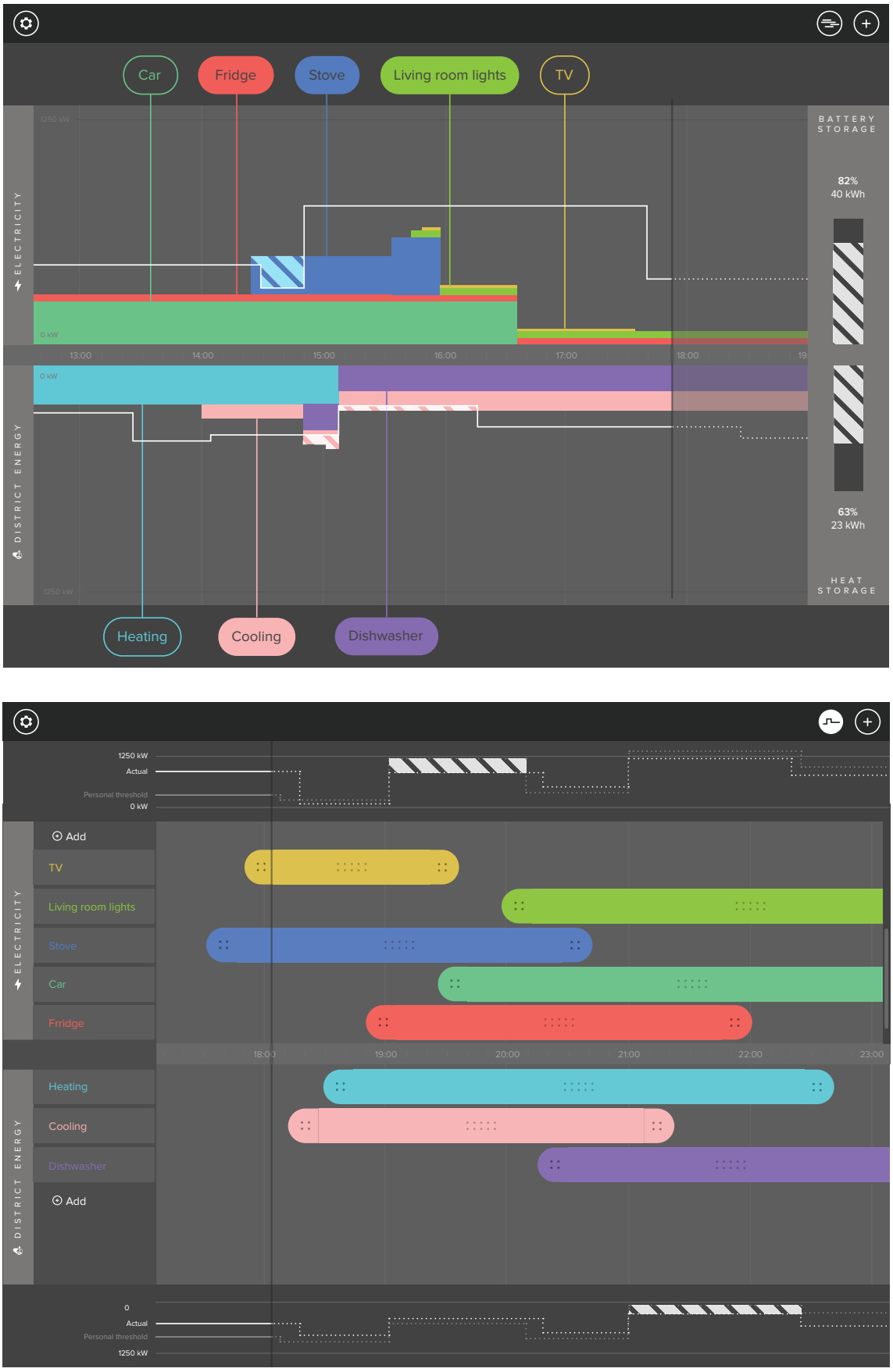


Figure 17 (bottom). In this part of the user interface users of the Activity Organizer can schedule energy-reliant products and services in the home in relation to a forecast on energy availability and the personal energy threshold.

portable district heating devices

One of the concepts within the third direction is a portable heating device that can be heated on different available heat sources in the home or through the building's heating system. In the former case, the way of heating the device is analogue to the way district heating make use of available heat sources in the region and in the latter case, the device is indirectly heated with district heating. The purpose of the heating device is to give people the benefit of rapidly avoiding thermal discomfort and is designed to warm up a person who is uncomfortably cold all over their body, while small enough to conveniently heat parts of the body. For convenience and speed, the heating device should always be ready for use. Furthermore, the device should be warm enough to enable users to directly sense that the devices are starting to warm them up, yet, not dangerously hot. This concept was included in this licentiate thesis work.

6 PART B: STUDY 3

One of the design directions, additional ways of making use of district heating, was explored in-situ in a study inspired by technology probes and experience prototyping. The procedures for the so-called technology probe field study and its findings are presented below.

6.1 PROCEDURES OF STUDY 3

Following the preparatory design phase, I carried out a technology probe field study. The study was done as part of a collaboration with Pernilla Hagbert, a fellow doctoral student exploring residents' views on less resource intensive ways of living from an architectural perspective (Hagbert, 2016). Some of the phases of the two studies overlapped, while others were done separately, as described below.

6.1.1 PARTICIPANTS

In the field study I chose to focus on residents in leasehold apartments, as residents do not pay separately for heating and are all invited to attend annual meetings in which they are informed about the association's district heating consumption. Hence, the conditions were deemed similar for leasehold residents as for both residents in rental apartments and private houses.

A group of volunteers were recruited for the field study from one leaseholder association through a paper questionnaire distributed through the letter box to all apartments in a selected leaseholder association (n=306). Enclosed with the paper questionnaire was a link providing individual access to an online version of the questionnaire, a return envelope for those preferring to complete the paper version, and a chocolate bar as a minor incentive. Anyone in the household was eligible to respond to either the online version or the paper version, but only one should be completed. We did not send out any reminders to complete the questionnaire. The questionnaire covered perceptions of domestic heating as well as the home and housing. Questions regarding the respondents' value orientations including biospheric values (de Groot & Steg, 2008; Steg, Perlaviciute, van der Werff, & Lurvink, 2014) were in incorporated in the questionnaire. Further, it included standardised questions from the International Social Survey Programme (ISSP) on environmental opinions, including questions related to priorities, willingness to reduce living standards, and engagement in pro-environmental activities (ISSP, 2012; Svallfors & Edlund, 2011). Questions regarding the household demographics concluded the questionnaire. Then, at the very end of the questionnaire, the respondents were asked to volunteer for a follow-up study including interviews and testing of products, in return for two cinema tickets as compensation. In total 156 responded to the questionnaire (corresponding to a

response rate of 51%) and 67 volunteered for the follow-up field study.

The results of the questionnaire were used to gain an overall understanding of the residents in the leaseholder association as well as to identify those respondents from the whole group of volunteers to whom person heating would be relevant. Volunteers who considered the indoor temperature in their apartments to be somewhat cold, considered themselves to be colder than others, and/or stated that they in some ways act on being too cold, were assumed to find person heating somewhat interesting (n=31). Amongst them, the group was narrowed down to better represent a wide spread in environmental opinions, age, and gender. In total, 25 volunteers were contacted and 20 were able to take part. For Pernilla Hagbert's parallel study, two more participants were recruited. During the technology probe field study, two participants dropped out, due to not having used the probes or not wanting to be interviewed. In two of the closing interviews two household members took part, resulting in a total of 20 interviewees from 18 different households.

about the respondents

Based on the questionnaire it was also possible to gain insights into socio-demographics, environmental opinions, and pro-environmental behaviour of the residents in the leaseholder association. Pernilla Hagbert did the analysis of these parts of the questionnaire, details on the analysis as well as on the results can be found in Hagbert (2016) as well as in an internal Chalmers report written by Pernilla Hagbert. The analysis was mainly done in the statistical software SPSS using descriptive statistics and analytical statistics with a non-parametric statistical approach, not assuming that the data followed normal distribution. If suitable, the data was compared to the international ISSP survey data (ISSP, 2012). The description below is based on Pernilla Hagbert's analysis.

The mean age of the respondents was 55 years, slightly older than the mean age in ISSP 2010 national data at 50 years. Almost 61% of the respondents (n=95) were female, 33% were male (n=51), and 6% did not wish to answer (n=10). Among the residents 53% (n=82) were educated at university. This figure is higher than the sample in ISSP 2010 national data where less than 40% had attended university (Svallfors & Edlund, 2011). Over half of the respondents live alone (n=71), one third of the respondents live with someone else (n=52), and one tenth live in three-person households (n=17). In the national data a majority lives in two-person households.

With regard to biospheric values, a majority of the respondents believe that it is vital to "respect the earth". Around half the respondents deem it of utmost importance to protect the environment (n=79). Slightly fewer respondents than in the national data believe that science will provide a solution without considerable changes in current ways of living, 5% in the sample compared to 8% in the national data (Svallfors & Edlund, 2011). However, with regard to environmental orientation in general, the analysis of the questionnaire revealed that the

respondents are not considerably different to the national average in the ISSP data, but reported figures for awareness and concern are higher than in international data (ISSP, 2012).

6.1.2 TECHNOLOGY PROBE FIELD STUDY

The aim of this field study was to explore one of the design directions, additional ways of making use of district heating, suggested in chapter 5. The field study was inspired by technology probe studies (Hutchinson et al., 2003) and experience prototyping (Buchenau & Suri, 2000), described in paper 3. Based on these two methods, I designed prototypes for a portable person heating device and compiled a technology prototype kit described in short below and in detail in paper 3.

After recruiting participants and designing the kit, it was delivered personally to all the participants. At that occasion I told the participants that the items included in the kit could be used by themselves or other householders to the extent and in any way they preferred.

The participants received the kit early in March and had access to it until early April, when the closing interviews were held. The closing interviews consisted of two parts, whereof only the first part regarding the technology probe kit, is relevant for this thesis. Pernilla Hagbert and I were both present for both parts of the interviews, supporting each other with follow-up questions. The set-up for the first part was semi-structured interviews. The interview guide covered if and how the participants had used any of the items in the kit, why they had used and how they had experienced using them, if anything had changed as a result, and what changes they would like see in the prototypes. The first part of the interview lasted approximately 15 to 30 minutes. Interviews in the homes of the participants were encouraged, although some preferred to meet at the leaseholder association office or at the university instead.

The interviews were recorded and later transcribed and analysed with the software NVivo. The analysis combined predefined themes based on the topics in the interview guide and emerging subthemes within each of the predefined themes.

6.1.3 TECHNOLOGY PROBE KIT

The technology probe kit came in a cardboard box with the following content:

- four heating pads with phase change material that can be heated on warm spots hotter than 32°C;
- a fleece cover with four pouches for the heating pads;
- a thermometer encouraged to be used to find warm spots for heating the heating pads;
- a hot water bottle in an unusual design;

- an information sheet;
- simple booklet for note taking during the study;
- a disposable camera; and
- recommendations for free photo and note taking applications for smart phones.

The complete kit can be seen in figure 18 and both sides of the information sheet in figure 19 (in Swedish). For details on the kit, see paper 3.

Figure 18. The complete content of the technology probe kit

Besides information on how to use the different items in the kit, the information sheet provided a short description of what district heating is, including that it is partially obtained through excess heat from industries and waste incineration. The analogy of how the district heating system moves heat in the city and the way heating pads can move heat in the home was described. In the information sheet, the aim of the study was formulated as to see if and how people would like to use portable heating devices. The participants were recommended to use the portable heating devices when feeling uncomfortably cold instead of turning the heating up and, finally, they were encouraged to consider lowering their heating.

6.2 FINDINGS FROM STUDY 3

The leaseholder association apartments were generally considered to be at a suitable indoor temperature. The majority of the respondents did not consider themselves to be warmer or colder than others. The majority also stated that it is

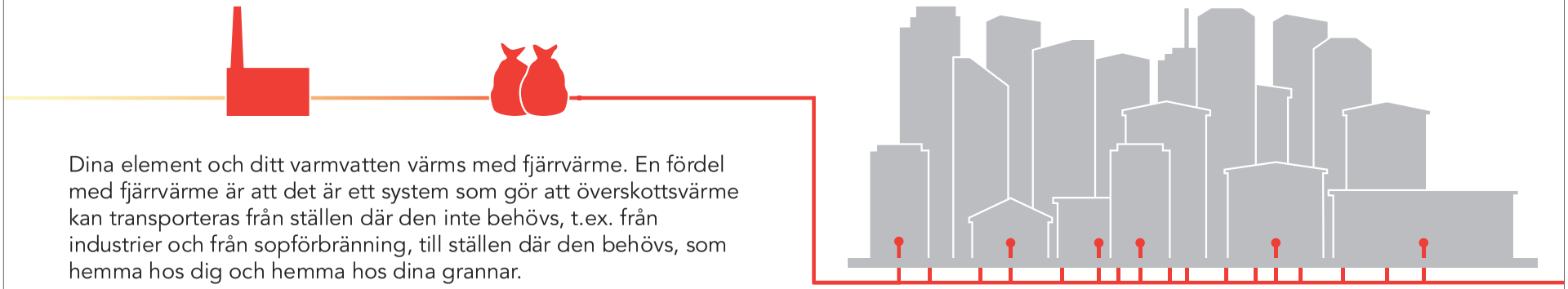
unpleasant to be too warm or too cold and in those situations they generally do simple things such as adjusting clothing, to achieve thermal comfort. Pleasurable thermal experiences in daily life, such as walking on a heated floor when cold, were generally considered somewhat important or important, while one fourth were impartial to those types of experiences. A majority of the respondents thought that the monthly housing fee has either a large impact or some impact on the household's economy. Regarding expenses for the leaseholder association, 46 respondents thought that heating was the largest expense (expressed as "heating", "heating and water", "heating and electricity", "energy", "management", and "management and maintenance"), 22 respondents though that it was the second largest expense, and 9 respondents thought that it was the third largest. Note however, that 21 respondents did not answer the question regarding expenses in the leaseholder association. For details on the result from the recruitment questionnaire, see figure 20.

6.2.1 USE OF TECHNOLOGY PROBE KITS

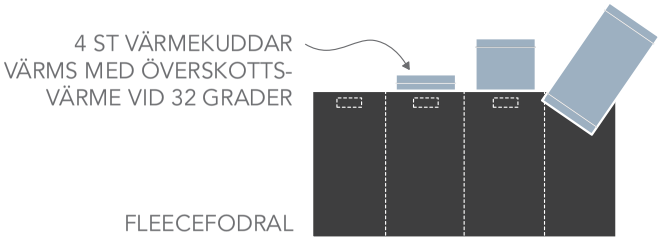
Seven participants used one or both portable heating device(s) with some regularity. One of them used the hot water bottle the most, three of them used the heating pads the most, and three of them used both. The main reason for using the portable heating devices were their positive characteristics or that they addressed needs they already had or needs they discovered during the study. It was appreciated to be able to move heat in the home with the heating pads. Eight participants used one or both heating device(s) occasionally and five participants tried the heating devices only once or twice, or not at all. One of the most common reasons for not using the heating devices occasionally or once or twice was that it had not been uncomfortably cold in the apartment. The participants thought that they would have used them more during late autumn or winter. Difficulties to find warm enough spots to heat up the heating pads and other technological deficiencies were also mentioned.

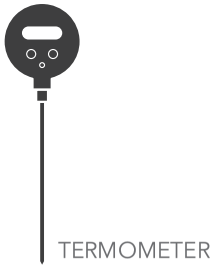
The heating devices seemed to play four roles in relation to thermal comfort pursuit: (1) a complement to unsatisfactory space heating, (2) a substitute to space heating, (3) a substitute for additional means for thermal comfort, and (4) a complement to unsatisfactory clothing outdoors.

Two participants used the thermometers in the technology probe kit, one of them once and the other one frequently. As a result, the first one lowered her indoor temperature and the other one realised that her thermal experiences were not correlated to the indoor temperature.



Dina element och ditt varmvatten värms med fjärrvärme. En fördel med fjärrvärme är att det är ett system som gör att överskottsvärme kan transporteras från ställen där den inte behövs, t.ex. från industrier och från sopförbränning, till ställen där den behövs, som hemma hos dig och hemma hos dina grannar.





Med värmekuddarna som du får i den här lådan kan du göra samma sak hemma hos dig. Du kan transportera överskottsvärme till ställen där den behövs bättre, t.ex. för att värma dina fötter, dina händer eller din nacke. Överskottsvärmen kan du hitta på många olika ställen. Kanske kan du använda eftervärmen i ugnen, någon elektronikprodukt som blir varm, överblivet varmvatten eller elementen? Vilka ställen med överskottsvärme finns där du brukar vara? Leta efter varma ställen med termometern. När du utnyttjar överskottsvärme kan man säga att du gör din egen fjärrvärme.

Värmekuddarna är gjorda av en saltblandning som lagrar värme. Kuddarna blir mjuka vid 32 grader och därför fungerar de bäst om de värms på ett ställe som är mellan 32 grader och 100 grader (men se till att du inte bränner dig). Du kan använda termometern för att mäta hur varmt det är på olika ställen. Du kan använda värmekuddarna både med och utan fleecefodralet. Värmekuddarna tål vatten och de värms lättast upp utan fleecefodralet. Använd dem ej i mikrovågsugn.

Du kan också transportera värme till din kropp genom fylla värmeflaskan med varmvatten från kranen.

Du får använda värmeflaskan och värmekuddarna både hemma och utanför hemmet, inomhus så väl som utomhus. Du får använda produkterna hur mycket och hur lite du vill och vem som helst i ditt hushåll får använda dem. Du kan också låna ut dem till andra. Du kan helt enkelt använda produkterna på det sätt som passar dig bäst. Experimentera gärna!

Syftet med den här studien är att undersöka om boende i lägenheter vill använda sig av produkter för att värma kroppen och i så fall hur de vill använda dem. Tanken med det är att det är effektivare att värma kroppen än att värma upp en hel lägenhet så när du behöver ha det lite extra varmt kan du använda värmeflaskan eller värmekuddarna istället för att höja värmen. Kan du till och med tänka dig att sänka värmen nu?

Figure 19. The information sheet in the technology probe kit (front and back)

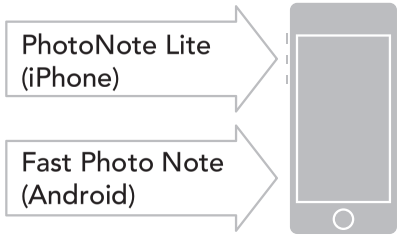
Under de här veckorna vill jag att du ibland dokumenterar hur du använder grejerna du fått, t.ex. kan du notera:

- var du hittar överskottsvärme till värmekuddarna
- när du använder de olika produkterna
- vad du tycker om att använda dem
- vem som använder dem

Du kan skriva noteringar för hand i anteckningsboken.

Om du har en smartphone kan du både ta foton och skriva anteckningar i appen **PhotoNote Lite** (för iPhone-telefoner) eller appen **Fast Photo Note** (för Android-telefoner).

Om du inte har en smartphone kan du använda digitalkamera eller engångskamera för att ta foton.



Stort tack för att du deltar i den här studien! Om du har några frågor eller synpunkter får du gärna kontakta mig.

Sara Renström

Doktorand
Avdelningen Design & Human Factors
Institutionen Produkt- och produktionsutveckling
Chalmers tekniska högskola

sara.renstrom@chalmers.se
031 772 1106 (fast telefon) 073 02 92 111 (mobil)

CHALMERS

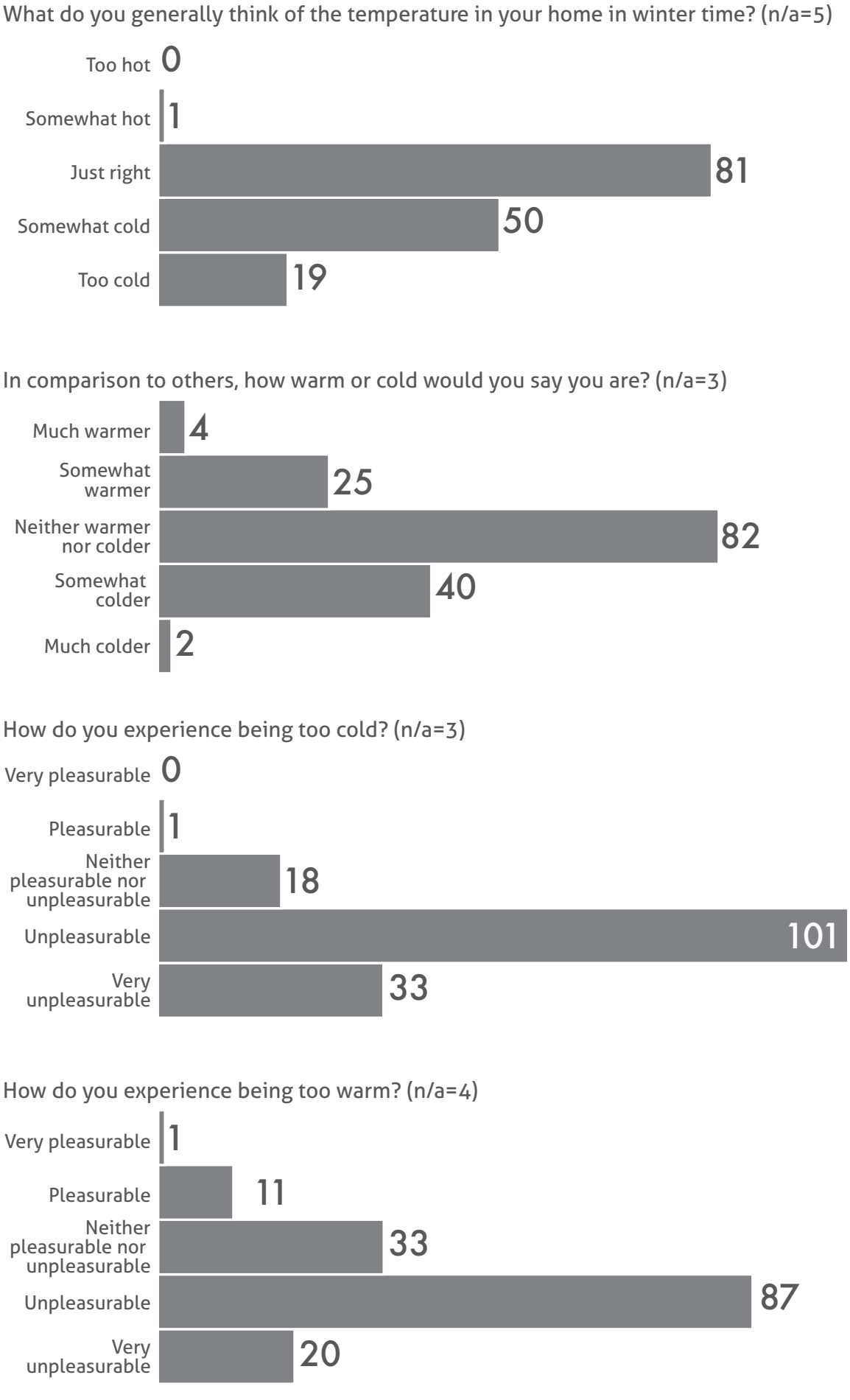
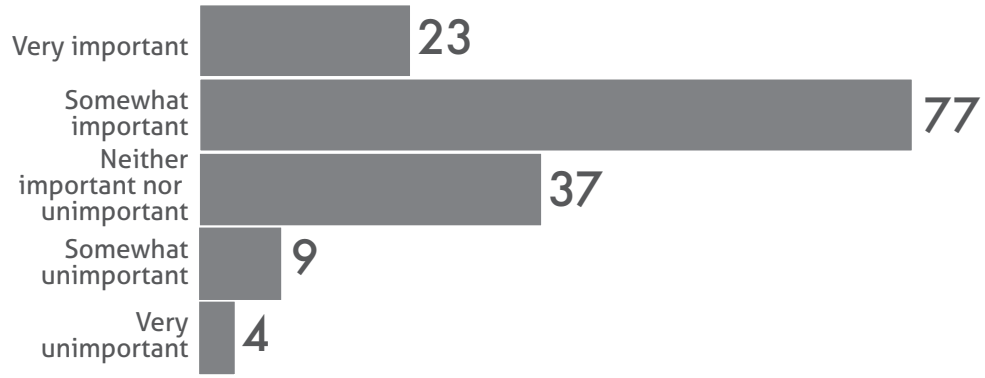


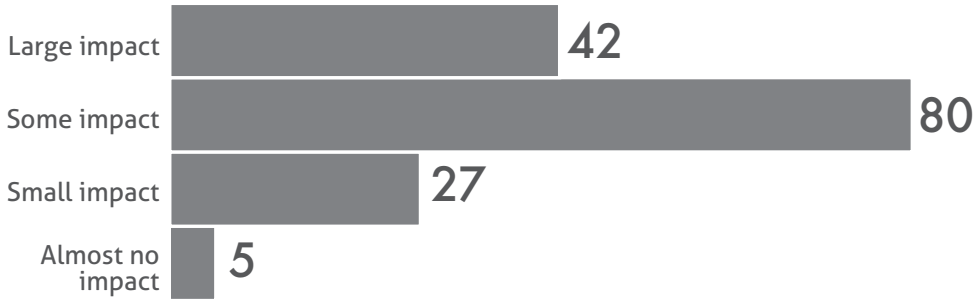
Figure 20. Result from the recruitment questionnaire

Pleasurable thermal experiences can, when being cold, be to walk on heated floors or take a hot bath or, when being warm, be to cool off by a fan or to splash oneself with cold water.

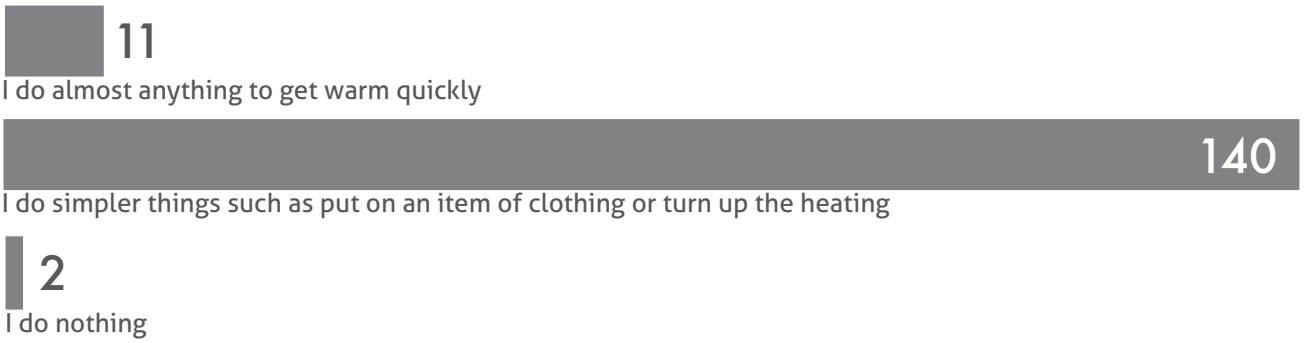
How important is it for you to have pleasurable thermal experiences in daily life? (n/a=6)



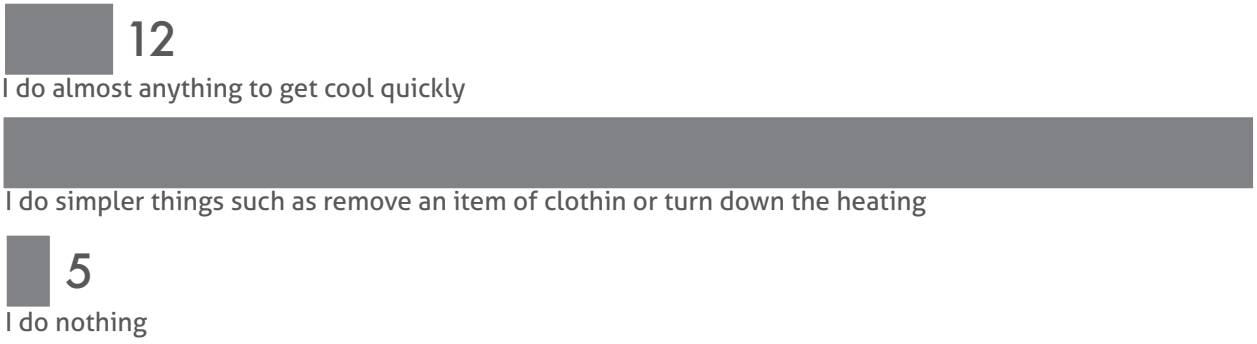
What is the impact of the monthly housing fee on your household's economy? (n/a=2)



How do you usually act when you are too cold? (n/a=3)



How do you usually act when you are too warm? (n/a=4)



6.2.2 MORE CONSCIOUS ROLES

Nine participants, five from the group with some regularity in their use, two from the group with moderate use, and one from the group with limited use, developed a more conscious role vis-à-vis their heating system. These new roles encompassed new actions (such as lowering heating and less airing), new or pronounced strategies and plans for efficient home heating and waste recycling, increased awareness of heat sources in the home, and ideas for the board of the leaseholder association. Apart from becoming aware, the roles seemed to have different additional characteristics: active (i.e. making sure that no excess heat is wasted), responsibility-taking (i.e. airing less), and self-sacrificing (i.e. suggesting to the board to gradually decrease the heating). In most cases the changes in roles concerned the participants' own heating system, but some of the actions and new responsibilities reached beyond their own heating systems to the board of the leaseholder association and to the recycling system.

One way of interpreting these results is that the technology probe kit facilitated new ways of understanding, making use of, and controlling the heating. The participants were thus actively included in the heating system in the sense that their individual pursuit of thermal comfort was acknowledged through the availability of portable district heating devices, which encouraged them to lower the space heating without jeopardising their personal thermal comfort, and that they were given the assignment to, analogous with the district heating system, move heat in the home.

The technology probe kit did not however seem to invite people to play an active role in the larger district heating system and only two participants stated that they now had a more favourable opinion of district heating. Both of them thought that utilising excess heat is positive. Although the heating system and the district heating system are connected, mentioned in the information sheet, and could be experienced via the pads through which the heat was transferred, the participants did not take on a conscious role towards the district heating system to a larger extent.

7 DISCUSSION

The discussion starts with a reflection on my research approach, partially based on a suggestion for how research through design can be evaluated, followed by a discussion of the key findings in relation to the three design challenges, as well as in relation to district heating as an excluding system. Finally, I reflect on potential future research.

7.1 DISCUSSION ON THE RESEARCH APPROACH

There are different approaches to investigating the interaction space of people and district heating. Berker (2013) for instance analysed visual representations of bathrooms in interior magazines and real estate advertisements. I chose to explore people's perspectives on district heating as this is underexplored (Palm & Isaksson, 2009). Through this perspective, some system boundaries that are important from a technical viewpoint seemed to fade away and others emerged, such as people's personal heating systems.

I have only investigated the participants' personal perspective on their own district heating consumption and have not in any way measured their energy use due to the inherent difficulties in fully establishing exact figures for consumption of district heating, especially in apartments

As mentioned in the personal context section (section 3.1) I recognise that people engage in different activities with different motives. I see technologies as tools people use to mediate activities, and that the tools and the activities shape each other. I consider my role as a designer to, *with intent* (cf. Lockton, Harrison, & Stanton, 2010), shape technologies, the tools people use, while understanding that I thereby set the preconditions for acting with technology (Selvefors, Strömberg, & Renström, forthcoming). In this research I have with intent tried to mediate people's activities in new ways and to set new preconditions for making use and making sense of district heating.

7.1.1 DISCUSSION ON RESEARCH THROUGH DESIGN

A central question in research through design is whether design artefacts reify some sort of knowledge (see chapter 3). Do the design concepts in this licentiate represent knowledge? In my view, the range of design concepts within the design directions, together with the design challenges and the possibilities with each direction, outline a design space. In my view, that design space holds knowledge about the district heating interface for people in the sense that it contains ideas for redesigning the district heating interface for people and possible effects of such redesigns. In line with this way of arguing, I think that the outlined design space, to which the design concepts are one contribution, is the answer to the third

research question: What possibilities are there in redesigning the district heating interface for people?

Research through design is not yet a well-defined approach and there is still a need to develop measures for success (Zimmerman et al., 2010). Zimmerman et al. (2007) do however suggest four criteria for evaluating design research through design: process, invention, relevance, and extensibility.

In judging the **process**, scrutinising choice of methods and the thoroughness of their employment is key. I have therefore tried to present the rationales for my choice of methods and reported on how I used them, and how I analysed and interpreted the results. I chose to investigate the interaction space of residents and district heating with different types of methods (see chapter 3) generating both qualitative and quantitative data. By applying a mixed methods approach I wanted to help overcome weaknesses inherently present in all different types of methods. The specific methods are discussed in more detail in the appended papers.

The second criteria Zimmerman et al. (2007) mention is **invention**; research design contribution should be a significant invention. The level of invention varies amongst the design concepts (see appendix 3) within the three design directions and there are concepts in my contribution that show novelty in relation to existing ideas and solutions that I have found. Examples of this novelty are expressing three of district heating's characteristics (shared green house), focusing on the current mix of heat sources in the district heating system, and linking the pursuit of thermal comfort in the home with how district heating function (portable district heating devices).

In part A, I explored people's perspectives on district heating which resulted in three described design challenges. Once they were defined, I did not explore them any further, for example with research methods including generative techniques suitable for experience-oriented design (Sleeswijk Visser et al., 2005). User experience is a dimension of design invention that has not specifically been investigated here.

In research through design, validity is not considered to be an applicable evaluation criteria and Zimmerman et al. (2007) suggest **relevance** instead. Relevance is created by relating the design to the real world; by motivating the design through grounding it in current situations and preferred future states. In this licentiate thesis I have motivated my designs through defining and describing the addressed design challenges (see section 4.2.3) and the possibilities with each design direction (see section 5). The relevance of the designs in this thesis should be understood in relation to the interaction space of people and district heating, rather than in relation to the much wider scope of a fossil-free energy future, touched upon in chapter 1. I will return to the design directions, and how they could relate to aspects of the real world challenges in section 7.3.

The final criterion for successful research through design is **extensibility**; the extent to which other researchers can build on the outcomes of the results (Zimmerman et

al., 2007). To some degree, others have already built on the results of my research, for instance when master students developed the green house concept further.

7.2 DISCUSSION ON KEY FINDINGS

As mentioned in section 2.3, district heating companies and The District Heating Association have focused on presenting information about the phenomenon of district heating and its general benefits to people in their role as citizens. In this licentiate thesis I have chosen to explore another path. In the three design directions the design concepts focus on the service-side of district heating, on delivering heating and hot water, and on new possible services. In this way the design concepts foremost address people in their role as users and occupants. Instead of making district heating known and appreciated as a concept to generate a general demand for its services, my idea is to use district heating services to increase people's awareness and appreciation of it, also as a concept.

The findings from study 3 seem to indicate that this kind of reverse approach would be viable, as the more conscious role people took sometimes reached beyond people's own heating systems to the board of the housing association and to the recycling system. Yet, for that consciousness to also reach the district heating system the connection between heating as such and district heating must be explicit, which might be feasible by combining concepts from the different design directions. However, sensible combinations would often require alterations in the district heating system.

7.2.1 EXPERIENCING DISTRICT HEATING

District heating is used in homes to provide basic heating, meaning that additional means often are used to achieve thermal comfort. District heating thus plays a part in what I refer to as people's personal heating systems. District heating provides this basic heating in a uniform manner in the sense that it is (almost) always on, aiming for the same set point temperature, and rarely adjusted.

The idea of a personal heating system with a variety of means to pursue thermal comfort fits well with the adaptive approach to thermal comfort in which buildings should provide "conditions in which people are able to make themselves comfortable" (Clear et al., 2013, p. 1). In the adaptive approach, comfort is not something that can be provided by an environment(comfort-as-product) but it is something that occupants pursue as a part of everyday life (comfort-as-goal) (Clear et al., 2013; Nicol & Humphreys, 2009). The fact that thermal discomfort often concerns only parts of the body further emphasises the usefulness of additional means instead of changes to the environment.

Thermal comfort seen as something residents pursue through means available to them suggests that I can consider products delivering district heating as part of the district heating system itself. However, a challenge here is that different

heating industry operators are responsible for the conditions involved, but as of today, the different operators have little or no contact with each other. District heating companies supply thermal energy; product producers design and sell the products the district heating is delivered through (e.g. radiators); builders who choose among these products; building managers decide on the district heating use of the building; people adjust the heating to the extent they (perceive that they) can, and people include additional means in their personal heating system (such as wheat pillows) depending on what is available on the market, etc. Putting district heating in an even wider context, it can be seen as a system used for creating a cosy, welcoming, and warm (in a figurative sense) home.

Daily variation in indoor temperature is usually problematic for a district heating system (Fredriksen & Werner, 2013). Yet, as mentioned in section 2.1, recent pilot tests in the district heating system in Gothenburg have shown that by deliberately varying the indoor temperature in apartments, apartment buildings can serve as temporary thermal energy storage and reduce the daily heat load variation, in other words shaving peaks in the power demand (Kensby, 2015). In the pilot tests, a temperature variation of +/- 0.5°C was used, a decision based on Fanger (1973) ideas of a comfort point instead of a comfort zone. Fanger (1973) emphasised the importance of using a comfort point for groups of occupants as their personal comfort zones might mismatch. There is however usually not that many occupants in a home, and larger temperature intervals might be used, especially if people are able to set the temperature intervals themselves to fit their personal comfort zones. In addition, my studies indicate that comfort is not simply delivered to the people anyway; it is something people actively pursue as suggested by the adaptive approach to thermal comfort.

The different means of pursuing thermal comfort, adopted by the participants in my studies largely coincide with means found in other studies (see e.g. Baker & Standeven, 1996; Karjalainen, 2009; Tweed, Dixon, Hinton, & Bickerstaff, 2014). However, lighting candles, physical contact with others, and thinking oneself warm were not mentioned in the reviewed studies, nor were the more extreme measures such as using the oven to heat up the kitchen, removing thermostatic radiator valves, sitting by the towel-drying radiator, and heating up bathrooms, deliberately kept cold, with a hot shower. I see three possible reasons for this discrepancy. Firstly, many studies have been carried out in offices where some means for pursuing thermal comfort are less accessible or might be perceived as less appropriate. Secondly, in the study by Karjalainen (2009), the respondents reported their principal action when feeling uncomfortably cold or hot, which might not include lighting candles. Thirdly, the more extreme measures taken were mentioned only in the interviews and not in the thermal diaries, suggesting that these measures are not taken often, yet, the participants do remember and can describe them. I understand such measures as a sign of desperation – at times presumably the only available option for people with little (perceived) control over the heating.

As mentioned in chapter 2, Mishra and Ramgopal (2013) categorised and ranked the adaptive adjustments people make: (1) alter the environment, (2) make adaptations affecting the person, and (3) change location. The perceived ease with which these means can be enacted determines what people will do (Mishra & Ramgopal, 2013) and this suggests that the participants in my studies did not find it easy to alter the thermal conditions inside their homes. The low frequency of adjusting the heating referred to as adaptive adjustments in the thermal diaries differ notably from a Finnish study (Karjalainen, 2009). When being uncomfortably cold at home the participants in my studies regulated the heating representing 5% of all the actions taken while in the Finnish study adjusting the heating was the principal action when being uncomfortably cold for 22% of the respondents at home (Karjalainen, 2009). If being uncomfortably hot at home, opening a window was the principal action in the Finnish study, but not in the thermal diaries, although this might be related to a cold period of the year during the time of the thermal diary study. Even though the Finnish survey comprised a higher percentage of houses (rather than apartments), I still think that the difference is notable between the frequencies of interaction with the heating system in the two studies.

The frequency of making adaptations affecting the person does not differ substantially. In the thermal diaries adjusting clothing was the most common action and similarly in the Finnish study 52% of the respondents had recorded adjusting their clothing as their principal action when being uncomfortably cold at home and 58% in the office (Karjalainen, 2009).

As discussed above, the findings from my studies seem to suggest that when being uncomfortably cold or warm, the space heating do not suffice to the same extent as reported in previous studies (e.g. Karjalainen, 2009; Mishra & Ramgopal, 2013), and additional means are instead used to pursue thermal comfort. Any additional means require active involvement and are generally used more frequently and therefore, the additional means seem to be on top of people's mind. Hence, the additional means can be seen as final providers of thermal comfort. On the other hand, district heating in the form of hot tap water is used as a final provider of thermal comfort, for instance through showers and baths.

Findings from study 3 showed that portable devices for person heating, heated indirectly with district heating, can represent means in people's pursuit of thermal comfort in four ways: (1) complementing unsatisfactory space heating, (2) substituting space heating, (3) substituting additional means for thermal comfort, and (4) complementing unsatisfactory clothing outdoors. The technology probe kit that the portable heating devices were part of seemed to invite people to take on a more conscious role vis-à-vis their *heating* system. On the other hand, the technology probe kit did not to any greater extent seem to invite people to play a more active role vis-à-vis *district* heating. The findings from study 3 also revealed that portable heating devices are not for everyone and the participants in study 3 thought that they would be more useful during late autumn and winter. This is yet

to be investigated. Convenience, rapidity, and ease of use are important features in further development of portable district heating devices for person heating. Further, focusing on the services district heating provides seemed to be one way of making interaction with the heating systems relevant for people in everyday life. Portable district heating devices for person heating could serve as a competitive advantage of district heating in choice of thermal energy supply method and become small-scale heat storages to be used at times of peak demand.

People already use additional means for thermal comfort, so why are portable devices for person heating heated indirectly with district heating relevant? From the perspective of the role district heating play in a personal heating system, portable district heating devices are relevant as they can enable people to use district heating services also for person heating. In this way, district heating can provide basic, uniform space heating but also be used to complement space heating with means for active, personal pursuit of thermal comfort. In this way, portable district heating devices has the potential to serve as a bridge between space heating, which district heating provides today, and means for thermal comfort pursuit, which district heating could aim at providing.

In the perspective of district heating as an excluding system, portable district heating devices seem to be relevant as a way of giving people new ways of interacting with so-far largely inaccessible systems: the building's heating system and the district heating system. Yet, as just two of the participants did increase their appreciation for the district heating system a much more explicit connection between heating as such and district heating systems is required. A clearer connection might be achieved by combining concepts from the different design directions. Inspiration from how availability of renewable electricity has been presented to people may be useful (e.g. Alan, Shann, Costanza, Ramchurn, & Seuken, forthcoming; Pierce & Paulos, 2012; Simm et al., 2015).

To the best of my knowledge, prior attempts of redesigning heating system's interface for people have not in the same way reported findings related to people's consciousness vis-à-vis their heating system and their thermal energy supply method. Instead, they have reported on findings related to indoor temperature, airing, use of additional means of thermal comfort, and overall satisfaction, for instance (see e.g. Bauman, Carter, & Baughman, 1998; Clear et al., 2014; Gaver et al., 2013; Kuijer & de Jong, 2012), see paper 3 for details.

An interesting aspect is that the participants in study 3 that took a more conscious role did so without any feedback on their consumption and financial incentives. Yet, the conservation actions some of them made were the same as mentioned in a review of 150 projects of individual metering and billing: lowering their indoor temperature from a very high level and ceasing frequent airing (cf. Berndtsson, 2003). The findings from study 3 show that it is possible, at least temporarily, to achieve these actions without individual metering and billing. Considering that it is expensive to install district heating meters, these other paths could be investigated further.

Perhaps district heating companies are not the most prudent producer and provider of portable district heating devices. Instead, new types of industry partnerships and business models ought to be considered to follow this path.

7.2.2 CONTROLLING DISTRICT HEATING

For residents in all types of dwellings connected to district heating there is a lack of accessible control over the heating that is easy to understand as well as provides feedback on the state of the heating system and processes. In study 2 the participants reported that they made use of whatever type of feedback they got from the heating system: how warm the radiators were to touch or the sounds they made. The importance of sensation of warmth as feedback has been found also in other studies (Löfström, 2008; Smith & Pett, 2005). Although this feedback is misleading as radiators may function properly despite feeling cold to touch, stresses the importance of other forms of feedback on the state of the system and processes.

For people in apartments, apart from a lack of accessible control over the heating, there is also a lack of perceivable control over the heating, and often a lack of actual control as well. This lack of perceivable and accessible control is important for people's level of comfort as there is a strong connection between occupants' perceived comfort and their perceived control over the heating (Bauman et al., 1998; Boerstra, Loomans, & Hensen, 2013; de Dear et al., 2013). In a study by Bauman et al. (1998), mentioned also in chapter 2, the results indicated that the privilege of control was more important than actually making controlled adjustments as rather few adjustments were made. Thus, giving people more control over their heating is one way of making them more satisfied. In addition, more actual control over the heating makes interaction with the heating system useful and might increase the interaction frequency. As people seemed to be more aware of the district heating products they frequently interacted with, more control might increase people's awareness of heating. Allowing people more control is also a signal that they are considered included and that their personal thermal comfort is the purpose of district heating.

It is however important to note that availability of different types of temperature controls is not correlated with perceived control over temperature (Boerstra et al., 2013) and that people do not always seem to realise that they have room thermostats, for instance (Shipworth et al., 2010). Further, even knowing that you have control does not always help as many heating controls have severe usability problems (Combe et al., 2012). More specifically for district heating, a study comprising private houses recently connected to district heating showed that the majority of participants were uncertain of how to handle the system, despite instruction at installation and access to a manual (Sernhet & Pyrko, 2006). To be in control, people thus need more than just access to control panels and instructions. Here, the ease of use of 'smart' heating controls shows at least some promise (Alan et al., forthcoming; Clear et al., 2014; Yang & Newman, 2013).

Allow control relative to the current temperature (i.e. 'warmer' or 'cooler') could be one such simplifying feature (Clear et al., 2013). Yet, with many 'smart' features, for instance machine learning, frequent interaction becomes less and less important as the machine learns and over time, and along with less interaction, interest seems to fade (Yang, Newman, & Forlizzi, 2014). To sum up, giving residents accessible control over the heating is a way of increasing their perceived and actual control. By doing so, their comfort will increase, and, as argued above, their sense of inclusion will likely also increase. Whether or not the benefits of these solutions would exceed the costs are however still to be investigated.

Certainly, energy visualisation and feedback could also be a part of the solution. Several studies within different domains of energy use have shown that feedback on usage often result in 5 to 12% reduction (Darby, 2006; Fischer, 2008). Selvefors, Karlsson, and Rahe (2013) studied the effects of feedback on energy use and also explored other effects than reduction in energy use. Their findings seems to suggest that feedback can increase people's understanding and sense of self-efficacy, however due to a small sample these results were not statistically significant.

As described in section 2.1, house owners and managers restrict the control that people in apartments have over the heating. Excellent design solutions are therefore not enough to give people in apartments more (perceivable) control. To overcome this I suggest that district heating companies ought to offer business models in which people in apartments are given more control. In such offers, increased control could be combined with control over a temperature interval instead of temperature points, as this could be useful when using buildings as short term thermal energy storage.

Control over heating combined with feedback on peaks in power demand would be a way of enabling people to lower their use in general and during peak demand. This represents a fourth way for district heating to be more sustainable, an addition to the three existing possibilities: eco-labelling, climate compensation for fossil based emissions, and allocating fossil free district heating for specific customers (Larsson & Persson, 2012).

7.2.3 COMMUNICATING DISTRICT HEATING

District heating and hydraulic central heating systems work inefficiently if the set point temperature is changed often and the response to change is slow. Therefore, from a technical perspective it is suitable to use additional means to fine-tune the basic heating that the district heating provides. Yet, I argue that the use of additional means to adjust the basic heating in order to achieve thermal comfort seems to conceal the role district heating plays in people's personal heating systems. A situation that further conceals district heating is that all the products that deliver district heating (radiators, towel dryers, floor heating, showerheads, and taps) look the same, regardless of the energy supply method. Not even in the user interface of the recently commercialised washing machines and tumble dryers is it visible

to the eye that they are powered by district heating. One of the benefits of district heating, its convenience, has a contrary effect in concealing it even more. District heating in private houses is so convenient to have and to use that people do not care about understanding and interacting with it (Palm & Isaksson, 2009). In addition, there is no apparent way of knowing if a particular space is heated with district heating apart from written information at point of purchase (leasehold apartments only) and occasional small stickers in the entrance of blocks of apartments with the anonymous acronym "FV" (from the Swedish word for district heating, 'fjärrvärme'), however these indications are not meant to inform people in their role as residents but as indications for district heating professionals.

The participants in study 2 did not seem to be aware of district heating as a system in their everyday life but more aware of district heating as a phenomenon or as manifested in the city. Possibly related, the attempts to inform people about district heating by the District Heating Association and Göteborg Energi are often concerned with describing the system as a whole, such as the online heating map and the viewing area in a street in Gothenburg (described in section 2.3). Nevertheless, in study 2 the participants still had a limited understanding of district heating as a phenomenon. This seems to suggest that communication about district heating as a concept does not completely get across to people. Instead, I suggest that district heating companies ought to investigate ways of raising awareness among people that their homes are heated with energy from a district heating system. To provide people with this information, the different key operators within the district heating industry (district heating companies, building owners and managers, producers of products, etc.) need to cooperate.

The type of heat sources used in a district heating system determines the environmental impact of any district heating consumption. Heat sources were further something the participants in study 2 mentioned and they were also more aware of some heat sources than others. In two campaigns the District Heating Association focused on informing about the heat sources used in the different district energy systems. The possibility of using available thermal energy, such as excess heat, is also one of the unique advantages of district heating. With these arguments, I consider it important to communicate to people the currant mix of heat sources. The participants in study 2 were both most aware of and most sceptical about waste incineration. Only a few knew about the use of recovered excess heat from industrial processes and fuel refineries, yet, once aware they were positive towards this type of heat source. Therefore, I think it is important to clearly point this out.

As mentioned, making use if district heating in more types of appliances than space heating and tap water is something district heating suppliers are working on, mostly in smaller showcases such as The District Heating House but also in commercial products such as white goods. Yet, as exemplified in the white goods, it is not always clear that such appliances are powered by district heating. Similarly, the green house designed in master thesis projects in affiliation to this licentiate

work did not manage to make the heat source clearly distinguishable. As discussed above, the same is true for common products in homes such as radiators, towel dryers, floor heating, taps, and showers.

Still, new types of products do receive attention, at least from early adopters. Therefore, it can be argued that the use of district heating in more types of appliances is one way of making people more aware of the potentials of district heating and thus increase people's understanding of district heating. Then it would be an advantage if the solutions designwise differ clearly from standard electrical appliances by making use of district heating's characteristic features, such as visualising that district heating can be reused within the district heating system (e.g. first in radiators and then in ground heating). In addition, products that users have active control of, such as washing machines, increase the frequency of interaction with the district heating system, thus keeping it more at the top of their minds. Yet, to achieve this, district heating's role in these products must become clearly visible and possible to control. Appliances powered with district heating can have less environmental impact than if powered by electricity, especially during periods of low heat demand (e.g. summers). As district energy costs are lower per kilowatt-hour than electricity costs, financial gains can also be made, given the same energy efficiency. Appliances powered by district heating could be a way of increasing the value of installing district heating in buildings, especially as there is a trend towards more efficient heating systems (Göransson et al., 2009). It can also become a competitive advantage, as this cannot be offered with any other thermal energy supply methods.

7.2.4 PERSPECTIVES ON EXCLUSION

It is not surprising that people in apartments with little control over the heating, no financial incentives to save, and no feedback on their use are uninformed about their heating and hot water systems and disengaged in energy savings (Carlsson-Kanyama et al. (2004). Without much control opportunities, people will of course become passive towards the system. Further, passivity is in many cases convenient for people.

A way of interpreting this passivity is to consider people in their role as residents as excluded from the building's heating system and thus from the district heating system. People in apartments are excluded from the two interconnected systems in the sense that they get output in the form of district heating services, being space heating and hot water, but they are not able to give much input to any of the systems. For instance, they are not given satisfactory levels of control over the heating and are not clearly informed about their control options. In addition they are not given the option to contribute to the district heating system, for instance through load balancing. They do not get any other type of output from the systems than the services, indicating that they are not expected to be interested in anything besides that. People could, for instance, be interested in the state of the heating

system and processes, their district heating consumption, the state of the district heating, current mix of heat sources used, and the most basic of all, if they have district heating or not. Information from district heating companies and the District Heating Association shows that these organisations on the other hand seem to expect people, in their role as citizens, to be interested in district heating as a concept.

People in private houses are excluded from the district heating system in the sense that district heating companies do not inform about current mix of heat sources and do not give them the option to contribute to the district heating system, for instance through load balancing.

Inefficient use of district heating (i.e. keeping bedroom windows open throughout the year) can be seen as one consequence of that exclusion. Another consequence is that people do not know much about district heating.

For the participants in the studies who lived in apartments, the clearest signs of being excluded from the heating system were lacking information about the state and processes of the heating system in the building, and not perceiving satisfactory levels of control. Being informed about the state of the system in the home (if the heating is 'on') and its processes (such as if the heating is increasing the temperature) are functions that can be seen in more advanced thermostats on the market (e.g. Nest). In contrast, this is not found in many homes connected to district heating. Providing these functions might be one way of involving people. There are however no thermostats on the market that also include real-time information about the district heating system, such as, whether it is set to peak demand hours or off-peak demand hours, what the current mix of heat sources is, and which production plants that are running. Some of this information is available through the website of Göteborg Energi, but just being presented there does not make it a part of everyday life. In what way such information would influence the situation is yet to be investigated.

When the participants in study 3 seemed to be more included they also took on a more conscious role vis-à-vis their heating system. Is that a desired path? In more and more areas related to sustainability people are expected to make informed decisions and to take personal responsibility (Soneryd & Uggla, 2011). District heating has been one of the few areas left where people in apartments do not have to make informed decisions and take personal responsibility, simply as they do not have much control; they have been excluded from the system in this sense as well. Also from this perspective, exclusion can be convenient for people; it means one thing less to take care of in everyday life. On the other hand, the district heating systems also currently excludes people who are already interested in taking more responsibility. I do not have an answer to this dilemma, but I can say that the design of the interaction possibilities within the interaction space of people and district heating influences what roles people perceive and can take.

7.3 FUTURE RESEARCH

With regard to the different design directions suggested in this thesis there is still much to be investigated, as indicated in the discussions above. What would happen when people start interacting with a redesigned district heating interface? What would be the drawbacks of such redesigns? How do they compare with other solutions, for instance individual metering and billing? These are questions that need to be answered in-situ, through testing more advanced prototypes than in this research. Many of the proposed design concepts require operators to cooperate in new ways as costs and benefits may be tied to different operators. In addition, the benefits of redesigning the district heating interface may be slow and difficult to measure, while the costs might be high. Can district heating companies afford trying to include residents through new design solutions? Or, can they afford not doing it?

I have interviewed a non-random sample of a total of 53 participants, 35 in study 2 and 18 in study 3. Due to the number of participants and sampling techniques no statistical analysis can be made on the basis of these interviews, although the findings can be used to sketch different types of residents, so called personas, and the magnitude of these personas can be investigated with, questionnaires, for instance, that could give statistically significant results.

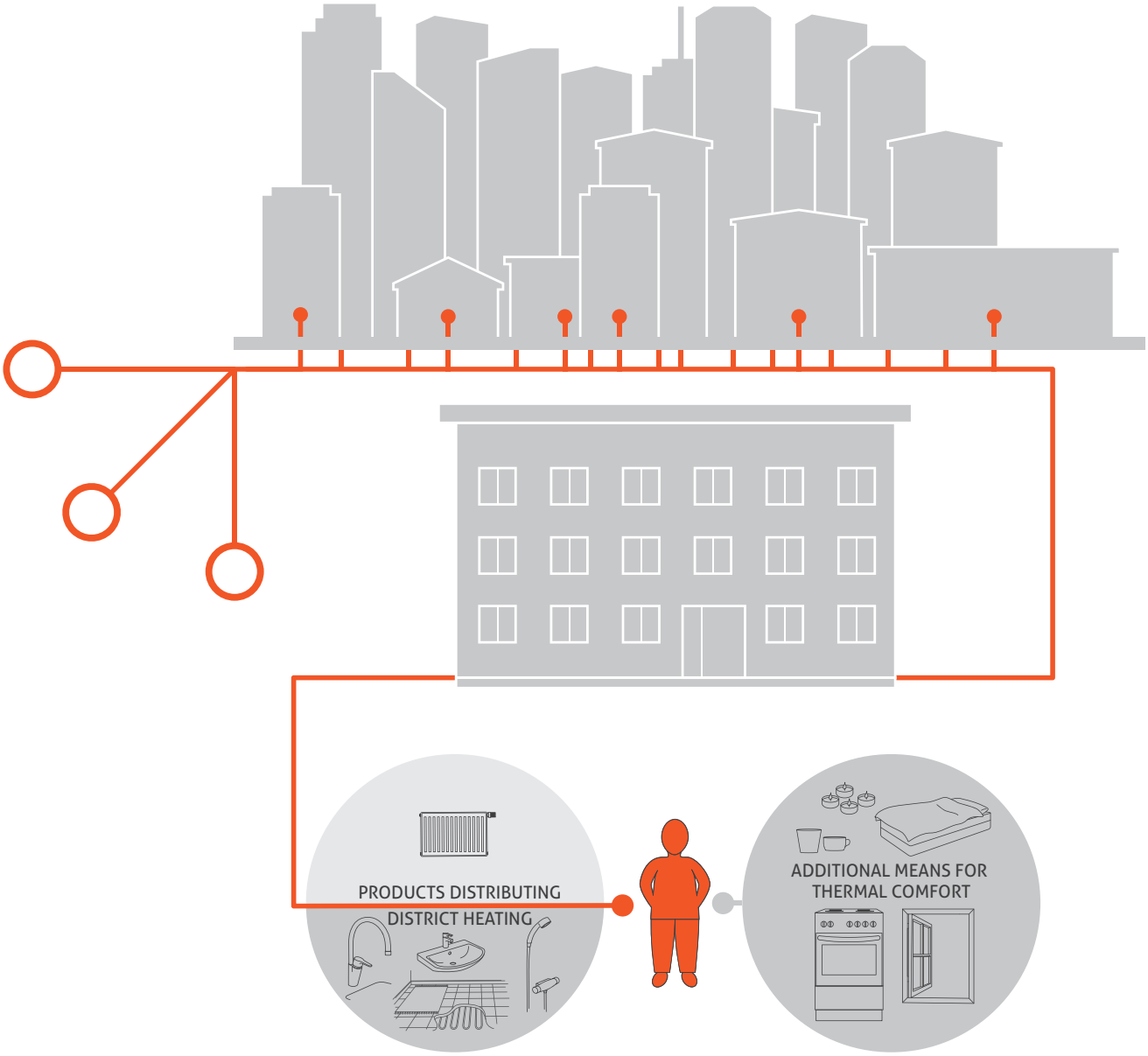
With the resident-centric approach used in this project all the resulting design directions are, as mentioned, related to the individual residents. But other design directions could be just as relevant. One example is collective solutions, such as information and control solutions within a housing association or a collective agreement to shift to fossil-free district heating. Addressing other operators, such as building owners and managers, boards of leaseholder associations, or representatives from the council can create more types of design directions. With a wider scope than individual residents, bigger steps might be viable.

The findings presented here can in the long run contribute to developing the district heating interface for people. Such development of the interface might indirectly strengthen district heating's potential of contributing to less fossil-depending energy future. If some of the suggested design concepts actually would have any direct effect on energy use during peaks in demand is still to be found out, yet, based on previous studies the effects can be expected to be rather small. However, findings from study 3 indicate that district heating's position can be strengthened indirectly by allowing residents to directly play a part in the system, by including the residents. This connection must however be investigated more rigorously than was possible in study 3.

The research in this licentiate thesis has been done in a Swedish context. In Europe, where district heating is less common, an expansion of district heating could decrease the use of fossil fuels considerably (Connolly et al., 2012). In the process of expanding district heating, the findings from my studies could be used

to design a district heating interface enabling people to make sense and make good use of district heating and thereby indirectly contribute to the expansion of district heating.

Another research challenge to take into account is 'smart' energy grid technology that integrates district heating, district cooling, and electricity, mentioned briefly in section 2.1. This development would influence the interaction space of residents and district heating considerably. Future research should look into the different roles people might play in such smart energy grids, the possibilities of these, and investigate which design solutions are needed for people to be able to play those roles.


PRODUCTS DISTRIBUTING
DISTRICT HEATING
ADDITIONAL MEANS FOR
THERMAL COMFORT

8 CONCLUSIONS & IMPLICATIONS

For each of the three research questions, below I present my conclusions and emphasise implications for district heating companies. Each research question is repeated below.

RQ 1: What role does district heating play in people's everyday pursuit of thermal comfort?

RQ 2: How do people make sense and make use of district heating in everyday life? Are there specific factors influencing people's understanding and use and if so, which ones?

RQ 3: What possibilities are there in redesigning the district heating interface for people?

8.1 THERMAL COMFORT PURSUIT

All the things people use to pursue thermal comfort can be seen as a personal heating system. District heating plays a part in this personal heating system, but the findings show that additional means are also used to achieve thermal comfort. District heating thus provides basic heating in people's personal heating systems, but to achieve personal thermal comfort this basic heating often needs to be completed through use of additional means. This understanding of thermal comfort pursuit fits well with the adaptive approach, in which comfort is not regarded as provided by the environment but as something that people themselves achieve actively through means available to them.

District heating provides basic heating in a uniform manner in the sense that it is (almost) always on, aiming for a constant set point temperature, and rarely adjusted. The findings seem to suggest that infrequent interaction with the heating system, and frequent use of additional means to achieve thermal comfort, conceal the role district heating plays in people' personal heating systems. This role is further concealed, as the artefacts that deliver district heating (radiators, towel dryers, floor heating, showerheads, and taps) look the same regardless of thermal energy supply method.

- Since people use additional means to achieve thermal comfort anyway, a temperature span instead of a set point temperature could be used. By using a temperature span, buildings can be utilised as temporary thermal energy storage (Kensby, 2015; Kensby, Trüschel, & Dalenbäck, 2015).
- Some of the means people make use of to achieve thermal comfort are energy intensive. Here lies an opportunity to instead make use of district heating not only for space heating but also for person heating. Such solutions should be non-energy intensive alternatives of achieving thermal comfort suitable for the

whole or parts of the body. Further, such solutions should be temporary and fast, give clear and distinct feedback, and the experience of using them should preferably have emotional qualities.

- The use of additional means to achieve thermal comfort fits well with the technological conditions of district heating and hydronic central space heating systems. Therefore, in communication about district heating to people, for instance through advertisements, district heating could be described as a thermal energy supply system that combines well with additional means for thermal comfort.

8.2 MAKING SENSE & MAKING USE

The findings suggest that the participants in the studies generally did not seem to be aware of district heating as a provider of thermal services in their everyday life. Not surprising, as far from everyone knows that they have district heating. Especially people in apartments are not properly informed about what energy supply method their homes have.

The participants seemed to be slightly more aware of some the artefacts that distribute district heating than of others. They were more aware of either the objects they frequently had to interact with (e.g. taps and showers) or the things they could sense with the body (e.g. floor heating). Further, the participants seemed to be more aware of and more knowledgeable of district heating as a phenomenon and/or system in the city in the shape of occurrence of waste incineration, physical buildings, and underground pipes.

The artefacts used in the distribution of district heating, for instance district heating substations, radiators, and thermostatic radiator valves are considered difficult to understand and use, partly due to lacking information and feedback. In apartments, the participants often seemed to be uncertain of what level of control they have over the heating, if any and most of them would have liked to have more control. Lack of (perceivable) control could in addition contribute to infrequent interaction with the heating system and thereby also to concealing the services that district heating brings.

Seeing people as excluded from the district heating system is one way of understanding people's ways of making sense and making use of district heating. In apartments, people are excluded from the building's heating system and the district heating system in the sense that they are not able to give much input to the two interconnected systems and that they are not given any output besides the district heating services. In private houses, people are excluded from the district heating system in the sense that they are not informed about current mix of heat sources and are not given the option of contributing to the district heating system, for instance through load balancing. In the perspective of energy efficiency, exclusion can contribute to inefficient use due to lack of control over heating. For district

heating companies, the findings from my studies seems to suggest that exclusion contribute to the inconspicuousness of district heating.

On the other hand, exclusion can be convenient for people, as they are relieved from having to interact with or take care of the system. Furthermore, they are not expected to take personal responsibility for their personal district heating consumption, as people in many other areas of resource consumption are.

- A first step is to clearly inform people about what energy supply method their homes are connected to. Additionally, provide information about the different stakeholders and their responsibilities, the technology in the home, and the real-time status of the district heating system (e.g. which heat production plants that are running and mix of heat sources currently used), might also be of use to people.
- Enable people to have control over the heating in their homes and inform people about their level of control. Feedback indicating the state of the heating system (if the heating is on) and its processes (if the temperature is changing) seems to be of interest to people.
- Invite people to play part in the district heating system, instead of excluding people in their role as residents. This could make district heating more relevant for people in their everyday life.

8.3 INVITING INTERACTION

In this research I defined three design directions that have the potential to influence people's preconditions for making sense and making use of district heating in different ways. The first direction represent making use of district heating in more ways than currently is available. Possibilities with this direction might be increased awareness of the role of district heating in everyday life and increased understanding of the qualities of district heating.

The second direction concerns enabling people to inform themselves of the current status of the district heating system and be more in control over the building's central heating system. Besides increased control and thus increased satisfaction, there might be possibilities of increased awareness and understanding, which can influence people's energy use.

The third direction is about designing means for thermal comfort and pleasurable thermal experiences that make use of district heating. With such solutions, it might be possible to increase district heating's usefulness to people without considerable increase in energy use.

In the three design directions the design concepts predominantly address people in their roles as residents, users, and occupants, by focusing on district heating's current and future services. Thus, instead of making district heating known and appreciated as a concept to generate a general demand for its services, I have tried

to emphasise district heating services in order to make it known and appreciated also as a concept. The findings from study 3 seem to suggest that this might be possible. Yet, an explicit connection between the services and the district heating system is required.

- District heating companies and associations could direct their communication efforts to people in their roles as users, occupants, and residents, not only to people in their role as citizens, which could, for instance, be achieved through district heating's current and future services.
- The different heat sources utilised in the district heating system are to some extent already communicated to people by the district heating company. Such communication needs to be more specific in, for instance differentiating between waste incineration and excess heat from industries. In addition, real-time information about the current mix of heat sources could be made readily available to people, which might influence people's energy use during peaks in demand.
- District heating companies could invite people to play a role in the district heating system by redesigning the district heating interface for people. By focusing on the services district heating provides, a redesign of the district heating interface could be made relevant for people in everyday life.

REFERENCES

Alan, A. T., Shann, M., Costanza, E., Ramchurn, S., & Seuken, S. (forthcoming). I*t is too hot: an in-situ study of three designs for heating.* Paper presented at the CHI conference, San Jose, California, USA.

Aune, M. (2007). Energy comes home. E*nergy policy*, 35(11), 5457-5465.

Babapour, M. (2015). *Pensieri - An Inquiry into Sketching and Modelling in Design.* Thesis for the degree of Licentiate of Engineering, Chalmers University of Technology, Gothenburg.

Baker, N., & Standeven, M. (1996). Thermal comfort for free-running buildings. E*nergy and Buildings*, 23(3), 175-182.

Bauman, F., Carter, T., & Baughman, A. (1998). Field study of the impact of a desktop task/ambient conditioning system in office buildings. *ASHRAE Transactions*, 104(1), 2-19.

Berker, T. (2013). "In the morning I just need a long, hot shower:" a sociological exploration of energy sensibilities in Norwegian bathrooms. *Sustainability: Science, Practice, & Policy*, 9(1), 1-7.

Berndtsson, L. (2003). *Individuell värmemätning i svenska flerbostadshusen: lägesrapport.* Statens Energimyndighet.

Boerstra, A. C., Loomans, M. G. L. C., & Hensen, J. L. M. (2013). Personal control over temperature in winter in Dutch office buildings. *HVAC&R Research*, 19(8), 1033-1050. doi:10.1080/10789669.2013.843961

Buchanan, R. (1992). Wicked problems in design thinking. *Design Issues*, 8(2), 5-21.

Buchenau, M., & Suri, J. F. (2000). *Experience prototyping.* Paper presented at the Proceedings of the 3rd conference on Designing interactive systems: processes, practices, methods, and techniques.

Carlsson-Kanyama, A., Lindén, A.-L., & Eriksson, B. (2004). *Hushållskunder på elmarknaden*. Department of Sociology, Lund University.

Carlsson-Kanyama, A., Lindén, A.-L., & Eriksson, B. (2005). Residential energy behaviour: does generation matter? *International journal of consumer studies*, 29(3), 239.

Chappells, H., & Shove, E. (2005). Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment. *Building Research & Information*, 33(1), 32-40. doi:10.1080/0961321042000322762

Clear, A. K., Friday, A., Hazas, M., & Lord, C. (2014). *Catch my drift? Achieving comfort more sustainably in conventionally heated buildings*. Paper presented at the 2014 conference on Designing interactive systems, Vancouver, BC, Canada.

Clear, A. K., Morley, J., Hazas, M., Friday, A., & Bates, O. (2013). *Understanding adaptive thermal comfort: new directions for UbiComp*. Paper presented at the

Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing, Zurich, Switzerland.

Combe, N., Harrison, D., Craig, S., & Young, M. (2012). An investigation into usability and exclusivity issues of digital programmable thermostats. *Journal of Engineering Design*, 23(5), 401.

Connolly, D., Vad Mathiesen, B., Alberg Østergaard, P., Möller, B., Nielsen, S., Lund, H., . . . Trier, S. (2012). *Heat Roadmap Europe 2050: Study for the EU27*. Euroheat & Power.

Creswell, J. W., & Clark, V. L. P. (2011). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, California: SAGE Publications.

Darby, S. (2006). *The effectiveness of feedback on energy consumption - A review for DEFRA of the literature on metering, billing and direct displays*. Environmental Change Institute, University of Oxford

de Dear, R. J., Akimoto, T., Arens, E. A., Brager, G., Candido, C., Cheong, K. W. D., . . . Zhu, Y. (2013). Progress in thermal comfort research over the last twenty years. *Indoor Air*, 23(6), 442-461.

de Groot, J. I. M., & Steg, L. (2008). Value Orientations to Explain Beliefs Related to Environmental Significant Behavior: How to Measure Egoistic, Altruistic, and Biospheric Value Orientations. *Environment and behavior*, 40(3), 330-354. doi:10.1177/0013916506297831

de Jong, A., Balksjö, T., & Katzeff, C. (2013). *Challenges in Energy Awarness: a Swedish case of heating consumption in households*. Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies Isanbul, Turkey.

DEFRA. (2005). *Securing the future*. Department for Environment, Food and Rural Affairs.

E.ON. (n.d.). 100Koll - Styr din elförbrukning oavsett var du befinner dig. Webpage: https://www.eon.se/privat/for-hemmet/100koll/om-100koll.html (accessed 9 May 2016).

Energimyndigheten. (2009). *Mätning av kall- och varmvattenanvändning i 44 hushåll* (ER 2009:26). Energimyndigheten.

Energimyndigheten. (n.d.). Energikalkylen. Webpage: http://energikalkylen.energimyndigheten.se/sv/smahus/ (accessed 21 April 2016).

Engelbrektsson, P. (2004). *Enabiling the User – Exploring ethodological effects on user requirement elicitation*. Thesis for the degree of Doctor of Philosophy, Chalmers University of Technology, Gothenburg.

Fallman, D. (2003, 5-10 April 2003). *Design-Orienten Human-Computer Interaction*. Paper presented at the CHI, Ft. Lauderdale, Florida, USA.

Fanger, P. O. (1970). *Thermal Comfort Analysis and Applications in Environmental*

Engineering. New York: McGrew-Hill.

Fanger, P. O. (1973). Assessment of man's thermal comfort in practice. *British journal of industrial medicine*, 30(4), 313-324.

Farrouche, C., & Kihlström, L. (2014). *Go City Grow - Building communities by growing together in greenhouses adapted to the climate of Gothenburg*. Thesis for the degree of Master of Science, Chalmers University of Technology, Gothenburg.

Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency*, 1(1), 79-104.

Fredriksen, S., & Werner, S. (2013). *District Heating and Cooling.* Lund: Studentlitteratur.

Gaver, W. W., Bowers, J., Boehner, K., Boucher, A., Cameron, D. W., Hauenstein, M., . . . Pennington, S. (2013). *Indoor weather stations: investigating a ludic approach to environmental HCI through batch prototyping*. Paper presented at the SIGCHI Conference on Human Factors in Computing Systems.

Geelen, D., Reinders, A., & Keyson, D. (2013). Empowering the end-user in smart grids: Recommendations for the design of products and services. *Energy policy*, 61(0), 151-161. doi:http://dx.doi.org/10.1016/j.enpol.2013.05.107

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8-9), 1257-1274. doi:http://dx.doi.org/10.1016/S0048-7333(02)00062-8

Gram-Hanssen, K. (2010). Residential heat comfort practices: understanding users. *Building Research & Information*, 38(2), 175-186.

Göransson, A., Johnsson, J., Sköldsberg, H., Stridsman, D., Unger, T., & Westholm, E. (2009). *Fjärrvärmen i framtiden – Behovet*. Svensk fjärrvärme.

Göteborg Energi. (n.d.-a). Fjärrvärme. Webpage: http://www.goteborgenergi.se/Privat/Produkter_och_priser/Fjarrvarme/Miljo (accessed 18 April 2016).

Göteborg Energi. (n.d.-b). Fjärrvärme som uppvärmning. Webpage: http://www.goteborgenergi.se/Privat/Produkter_och_priser/Fjarrvarme (accessed 18 April 2016).

Göteborg Energi. (n.d.-c). Titthålet. Webpage: http://www.titthalet.se (accessed 19 April 2016).

Hagbert, P. (2016). "It's Just a Matter of Adjustment": Residents' Perceptions and the Potential for Low-impact Home Practices. *Housing, Theory and Society*, 1-17. doi:10.1080/14036096.2016.1141797

Herngren, E., & Làzaro Morales, C. (2013). *Fjärrvärmen 2030*. Svensk Fjärrvärme.

Hundertwasser Non-Profit Foundation. (n.d.). District Heating Plant. Webpage: http://www.hundertwasser.at/english/oeuvre/arch/arch_fernwaerme.php (accessed 18 April 2016).

Hutchinson, H., Mackay, W., Westerlund, B., Bederson, B. B., Druin, A., Plaisant, C., . . . Sundblad, Y. (2003). *Technology probes: inspiring design for and with*

families. Paper presented at the SIGCHI Conference on Human Factors in Computing Systems, Ft. Lauderdale, Florida, USA.

Höök, K., & Löwgren, J. (2012). Strong Concepts: Intermediate-Level Knowledge in Interaction Design Research. *ACM Transactions on Computer-Human Interaction*, 19(3).

IEA, (2013). *CO2 Emissions from Fuel Combustions - Highlights*. OECD/IEA (Internationa Energy Agency).

IMCG. (2012). *Green IT Homes*. IMCG.

ISSP. (2012). *International Social Survey Programme: Environment III - ISSP 2010*. Retrieved 16 June 2015, from GESIS Data Archive

Jonsson, D. K., Gustafsson, S., Wangel, J., Höjer, M., Lundqvist, P., & Svane, Ö. (2011). Energy at your service: highlighting energy usage systems in the context of energy efficiency analysis. *Energy Efficiency*, 4(3), 355-369. doi:http://dx.doi.org/10.1007/s12053-010-9103-5

Joore, P., & Brezet, H. (2015). A Multilevel Design Model: the mutual relationship between product-service system development and societal change processes. *Journal of Cleaner Production*, 97, 92-105. doi:http://dx.doi.org/10.1016/j.jclepro.2014.06.043

Karjalainen, S. (2009). Thermal comfort and use of thermostats in Finnish homes and offices. *Building and Environment,* 44(6), 1237-1245. doi:http://dx.doi.org/10.1016/j.buildenv.2008.09.002

Karlsson, I. C. M. (1999). A *Framework for the Study of the Relation between User and Artefact.* In D. Harris (Ed.), Engineering Psychology and Cognitive Ergonomics. Volume 4: Job Design Product Design and Human-Computer Interaction (pp. 379-386). Aldershot: Ashgate Publishing,.

Katzeff, C., & Wangel, J. (2015). *Social Practices, Households, and Design in the Smart Grid.* In L. M. Hilty & B. Aebischer (Eds.), ICT Innovations for Sustainability (pp. 351-365): Springer International Publishing.

Kensby, J. (2015). *Buildings as thermal energy storage - Pilot test and large-scale implementations for district heating systems.* Thesis for the degree of Licentiate of Engineering, Chalmers University of Technology, Gothenburg.

Kensby, J., Trüschel, A., & Dalenbäck, J.-O. (2015). Potential of residential buildings as thermal energy storage in district heating systems - Results from a pilot test. *Applied Energy,* 137, 773-781.

Ketola, A. (2001). *Elen är fri.* Thesis for the degree of Licentiate of Engineering, University of Lund, Lund.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World map of the Köppen-Geiger climate classification updated. *Meteorologische Zeitschrift*, 15(3), 259-263.

Kuijer, L. (2014). *Implications of Social Practice Theory for Sustainable Design*. Thesis for the degree of Doctor of Philosophy, Technische Universiteit Delft.

Kuijer, L., & Bakker, C. (2015). Of chalk and cheese: behaviour change and practice theory in sustainable design. *International Journal of Sustainable Engineering*, 8(3), 219-230. doi:10.1080/19397038.2015.1011729

Kuijer, L., & de Jong, A. (2012). Identifying household opportunities for reduced household resource consumption. *Journal of Design Research*, 10(1/2), 67-85.

Larsson, O., & Persson, A. (2012). *Hur blir fjärrvärmen grönare? Kunddriven utveckling*. Svensk fjärrvärme.

Laschke, M., Hassenzahl, M., Diefenbach, S., & Tippkämper, M. (2011). *With a little help from a friend: a shower calendar to save water*. Paper presented at the CHI'11 Extended Abstracts on Human Factors in Computing Systems.

Lilley, D. (2009). Design for sustainable behaviour: strategies and perceptions. *Design Studies*, 30(6), 704-720.

Lindahl, A., & Lindqvist, E. (2014). *Development of an accessible and flexible planter module for shared greenhouses*. Thesis for the degree of Master of Science, Chalmers University of Technology, Gothenburg.

Lockton, D., Cain, R., Harrison, D., Giudice, S., Nicholson, L., & Jennings, P. (2011). *Behaviour Change at Work: empowering energy efficiency in the workplace through user-centred design*. Paper presented at the Behaviour, Energy and Climat Change Conference, Washington, DC, US. http://www.escholarship.org/uc/item/6ww5h5jm

Lockton, D., Harrison, D., & Stanton, N. (2010). The Design with Intent Method: A design tool for influencing user behaviour. *Applied Ergonomics*, 41(3), 382-392.

Lockton, D., Nicholson, L., Cain, R., & Harrison, D. (2014). Persuasive technology for sustainable workplaces. *interactions*, 21(1), 58-61. doi:10.1145/2544170

Lockton, D., Renström, S., Bowden, F., Rahe, U., Brass, C., & Gheerawo, R. (2014). *Energy storytelling through annotating everyday life*. Paper presented at the Behave Energy Conference 2014., Oxford, UK.

Löfström, E. (2008). *Visualisera energi i hushåll : Avdomesticeringen av sociotekniska system och individ- respektive artefaktbunden energianvändning*. Thesis for the degree of Doctor of Philosophy, Linköping University, Technology and Social Change, Faculty of Arts and Sciences.

Löwgren, J. (2013). Annotated Portfolios and Other Forms of Intermediate-Level Knowledge. *interactions*, 20(1), 30-34.

McMichael, A. J., Butler, C. D., & Folke, C. (2003). New visions for addressing sustainability. *Science*, 302(5652), 1919-1920.

Mishra, A. K., & Ramgopal, M. (2013). Field studies on human thermal comfort — An overview. *Building and Environment*, 64, 94-106. doi:http://dx.doi.org/10.1016/j.buildenv.2013.02.015

Nicol, J., & Humphreys, M. (2009). New standards for comfort and energy use in

buildings. *Building Research & Information*, 37(1), 68-73.

Norwegian Design Council. (2012). *Innovating with People – The business of inclusive design* (2nd ed.): Norwegian Design Council.

Palm, J., & Isaksson, C. (2009). *Värmekunders val och användning – Tidigare forskning och framtida forskningsbehov*. Svensk Fjärrvärme.

Persson, T., & Renström, R. (2013). *Fjärrvärmedrivna vitvaror*. Svensk Fjärrvärme.

Pierce, J., & Paulos, E. (2012). *The Local Energy Indicator: Designing for Wind and Solar Energy Systems in the Home*. Paper presented at the DIS - In the Wild, Newcastle, UK.

Revell, K. M. A., & Stanton, N. A. (2014). Case studies of mental models in home heat control: Searching for feedback, valve, timer and switch theories. *Applied Ergonomics*, 45(3), 363-378. doi:http://dx.doi.org/10.1016/j.apergo.2013.05.001

Revell, K. M. A., & Stanton, N. A. (2016). Mind the gap: Deriving a compatible user mental model of the home heating system to encourage sustainable behaviour. *Applied Ergonomics*.

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy sciences*, 4(2), 155-169.

Rüdenauer, I., & Gensch, C.-O. (2007). *Environmental and economic evaluation of the accelerated replacement of domestic appliances. Case study refrigerators and freezers.* European Committee of Manufacturers of Domestic Equipment, Öko-Institut e.V. Institute for Applied Ecology.

Selvefors, A. (2014). *Understanding Energy Behaviour - A Neccessity for supporting Domestic Energy Conservation Through Design*. Thesis for the degree of Licentiate of Engineering, Chalmers University of Technology, Gothenburg.

Selvefors, A., Karlsson, I. C. M., & Rahe, U. (2013). *What's in it for the user? Effects and perceived user benefits of online interactive energy feedback.* Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies Isanbul, Turkey.

Selvefors, A., Strömberg, H., & Renström, S. (forthcoming). *What a designer can change: a proposal for a categorisation of artefact-related aspects*. Paper presented at the DRS2016 Future Focused Thinking, Brighton, UK.

Sernhet, K., & Pyrko, J. (2006). *Småhusägarnas syn på att köpa fjärrvärme*. Svensk Fjärrvärme.

Shipworth, M., Firth, S., Gentry, M., & Wright, A. (2010). Central heating thermostat settings and timing: building demographics. B*uilding Research & Rnformation*, 38(1), 50-69.

Shove, E. (2003). *Comfort, cleanliness and convenience: The social organization of normality* (Vol. 810): Berg Oxford.

Shove, E., Chappells, H., Lutzenhiser, L., & Hackett, B. (2008). Comfort in a lower carbon society. *Building Research & Information*, 36(4), 307-311.

Simm, W., Ferrario, M. A., Friday, A., Newman, P., Forshaw, S., Hazas, M., & Dix, A. (2015). *Tiree energy pulse: exploring renewable energy forecasts on the edge of the grid.* Paper presented at the 33rd Annual ACM Conference on Human Factors in Computing Systems.

Sleeswijk Visser, F., Stappers, P. J., van der Lugt, R., & Sanders, E. B. N. (2005). Contextmapping: experiences from practice. *CoDesign*, 1(2), 119-149. doi:10.1080/15710880500135987

Smith, W., & Pett, J. (2005). *Energy efficiency refurbishment programmes help, but are the end-users doing their bit*. The European Council for an Energy Efficient Economy (ECEEE).

Socialstyrelsen. (2005). *Temperatur inomhus* (2005-101-6). Socialstyrelsen.

Soneryd, L., & Uggla, Y. (2011). *(O)möjliga livsstilar: samhällsvetenskapliga perspektiv på individualiserat miljöansvar*. Lund: Studentlitteratur.

Statistics Sweden. (2015). *Hushållens boende* (Households' Dwellings). Retrieved 18 April 2016, from Statistics Sweden http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/Hushallens-ekonomi/Inkomster-och-inkomstfordelning/Hushallens-boende/ - c_undefined

Steg, L., Perlaviciute, G., van der Werff, E., & Lurvink, J. (2014). The Significance of Hedonic Values for Environmentally Relevant Attitudes, Preferences, and Actions. *Environment and behavior*, 46(2), 163-192. doi:10.1177/0013916512454730

Strengers, Y. (2011). *Designing eco-feedback systems for everyday life.* Paper presented at the SIGCHI Conference on Human Factors in Computing Systems.

Strengers, Y. (2014). Smart energy in everyday life: are you designing for resource man? *interactions*, 21(4), 24-31.

Strömberg, H., Selvefors, A., & Renström, S. (2015). Mapping out the design opportunities: pathways of sustainable behaviour. I*nternational Journal of Sustainable Engineering*, 8(3), 163-172. doi:10.1080/19397038.2014.1001469

Summerton, J. (1992). *District heating comes to town: The social shaping of an energy system*. Thesis for the degree of Doctor of Philosophy, Linköping Univesity, Linköping.

Svallfors, S., & Edlund, J. (2011). *ISSP 2010 - Åsikter om miljön*. Retrieved 1 March 2015, from Svensk Nationell Datatjänst (SND) http://nesstar.snd.gu.se/

Svensk Fjärrvärme. (n.d.-a). Filmer om fjärrvärme. Webpage: http://www.svenskfjarrvarme.se/Fjarrvarme/Filmer-om-fjarrvarme/ (accessed 18 April 2016).

Svensk Fjärrvärme. (n.d.-b). Fjärrvärmens roll i energisystemet. Webpage: http://www.svenskfjarrvarme.se/Fjarrvarme/Ulrika-Jardfelt-pratar-fjarrvarme/ (accessed 9 May 2016).

Svensk Fjärrvärme. (n.d.-c). Statistik Fjärrvärme - Tillförd energi. Webpage: http://www.svenskfjarrvarme.se/Statistik--Pris/Fjarrvarme/Energitillforsel/ (accessed 25 March 2016).

Svensk Fjärrvärme. (n.d.-d). Ta vara på energin. Webpage: http://svenskfjarrvarme.se/Ta-vara-pa-energin/Bra-exempel/Boras-parkbankar-varms-med-fjarrvarme/ (accessed 18 April 2016).

Svensk Fjärrvärme. (n.d.-e). Värmekartan. Webpage: http://www.svenskfjarrvarme.se/Medlem/Medlemsnyheter1/Satt-ditt-foretag-pa-varmekartan/ (accessed 18 April 2016).

Thorpe, A. (2007). T*he Designer's Atlas of Sustainability.* Washington: Island Press.

Tweed, C., Dixon, D., Hinton, E., & Bickerstaff, K. (2014). Thermal comfort practices in the home and their impact on energy consumption. *Architectural Engineering and Design Management*, 10(1-2), 1-24. doi:10.1080/17452007.2013.837243

Werner, S. (2010). *District Heating in Sweden–Achievements and challenges*. Paper presented at the XIV Polish District Heating Forum, Sept 13-15, 2010.

Wilson, G. T. (2013). *Design for Sustainable Behaviour: Feedback Interventions to Reduce Domestic Energy Consumption*. Thesis for the degree of Doctor of Philosophy, Loughborough University, Loughborough.

Yang, R., & Newman, M. W. (2013). *Learning from a learning thermostat: lessons for intelligent systems for the home*. Paper presented at the 2013 ACM international joint conference on Pervasive and ubiquitous computing.

Yang, R., Newman, M. W., & Forlizzi, J. (2014). *Making sustainability sustainable: challenges in the design of eco-interaction technologies*. Paper presented at the SIGCHI Conference on Human Factors in Computing Systems, Toronto, Ontario, Canada.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). *Research Through Design as a Method for Interaction Design Research in HCI*. Paper presented at the SIGCHI conference on Human factors in computing systems. .

Zimmerman, J., Stolterman, E., & Forlizzi, J. (2010). *An analysis and critique of Research through Design: towards a formalization of a research approach*. Paper presented at the 8th ACM Conference on Designing Interactive Systems.

Zinko, H. (2006). *Demonstrationsprojekt fjärrvärmeanpassade småhus Göteborg - Avancerad fjärrvärmeanvändning i småhus*. Svensk Fjärrvärme.

APPENDIX 1

PRIOR DESIGN CONCEPTS

In research literature, there is a wide range of research projects with design concepts directed towards residents that are related to space heating and hot water use, but nothing specifically on district heating. Some of concepts as well as the three district heating concepts mentioned in section 2.3 are presented in table 1 below.

In the table I briefly describe the concepts and report on if they have been evaluated in any way. Further I emphasise if the concepts encourage something and/or if the concept enables something. A concept encourages something if one of the concept's major aims is to influence people's intention and/or willingness to do something (DEFRA, 2005). A concept enables something if one of the concept's major aims is to influence people's ability to do something (DEFRA, 2005).

Table 1. Prior design concepts directed towards residents that are related to space heating and hot water use

CONCEPT	INTENT – ENCOURAGING AND/OR ENABLING?	EVALUATION
Shower Calendar Shows water consumption in shower per person (Laschke, Hassenzahl, Diefenbach, & Tippkämper, 2011)	Encourages reduced water consumption while showering through feedback	Tested in-situ in two households with six participants in total. It was accepted and reduced consumption for four participants, no change or increase for two participants.
Splash A practice prototype for new bathing practices (Kuijer, 2014; Kuijer & de Jong, 2011)	Enables new bathing practices and thus reduced water consumption	Different types of evaluations were made. In the final evaluation 15 participants had access to Splash. Six did not accept it, three used it but preferred showering, and six preferred it over showering. When in use water use was reduced.
Nest A smart thermostat (evaluated, not designed by, Yang & Newman, 2012)	Encourages reduced heat consumption Enables control of heating also away from home Enables 'away' setting	Six interviews and one diary study with households that had already installed the Nest. Increased awareness and improved interaction with the heating, ventilation, and air condition systems, yet, some of the participants also pursued greater comfort levels.

CONCEPT	INTENT – ENCOURAGING AND/OR ENABLING?	EVALUATION
Airing intervention prototype The prototype signals with LED lights and sounds the radiator's temperature if airing when the radiator is hot (Wilson, 2013; Wilson, Lilley, & Bhamra, 2013)	Encourages turning off heating when airing Encourage awareness of when the heating system is active	Evaluated in-situ in two households and in two focus groups (with in total 10 participants). The prototype did fit the context of use and did change behaviour to some extent.
Indoor Weather Stations Three different indoor weather stations: a wind tunnel, temperature tape, light collector and an online tool (Gaver et al., 2013)	Encourage investigative curiosity of the microclimate of the home Encourage "awareness of the home's microclimate without directly addressing issues of energy usage or carbon footprint" (Gaver et al., 2013, p. 3457)	Evaluated in-situ in twenty households (all 3 stations in each home). The weather stations were accepted and encouraged exploration but necessarily of the microclimate. The ambiguous information the stations provided was not always appreciated.
Water meter and digital application A water meter that gives feedback on water use and shows when it is a peak hour. The digital application has more functionality (de Jong, Balksjö, & Katzeff, 2013)	Encourages avoiding hot water consumption during peak hours in the district heating system	-
Show-Me Shows the amount of water used in one shower (Kappel & Grechenig, 2009)	Encourages reduced water consumption while showering through feedback	Evaluation in-situ in four households with 9 participants during 3 weeks. The mean water consumption decreased with 10 litres. The participants without a goal to be more sustainable did not maintain the new habit.

CONCEPT	INTENT – ENCOURAGING AND/OR ENABLING?	EVALUATION
Smart thermostat & digital application A smart meter that gives the user a set amount of energy they can use (eco-points). The meter gives suggestions regarding temperature based on calculations on the whole building. (de Jong et al., 2013)	Encourages reduced space heating (district heating consumption) through goal-setting and feedback	-
The Tidy Street Several concepts regarding timely energy activities and how this can be socially negotiated with public display of real-time local and national energy demand as well as private display of energy demand. The final concept was Tidy Street, a road display where average community energy usage was compared to city average (Boucher, Cameron, & Jarvis, 2012)	Tidy street encourages reduced energy consumption The other concepts encourage avoiding consumption during peak hours	Evaluated in-situ with volunteering households in a street during one month. It resulted in 15% reduction of energy use.
Static! Energy Curtain "The Energy Curtain collects energy when the sun shines on it, saving and storing energy during the day (to the extent that it is drawn down) for lighting up the room when the sun goes down – requiring a user to make a trade-off between letting the light in during the day or drawing the curtain to save the light for later" (Backlund et al., 2006, p. 4)	Enables energy production and storage	-

CONCEPT	INTENT – ENCOURAGING AND/OR ENABLING?	EVALUATION
Static! The Element A radiator constructed of light bulbs (Backlund et al., 2006)	Encourages understanding of energy and heating through visualising energy consumption Intended to create thoughtful engagement	-
Static! Appearing Pattern Wallpaper A wallpaper with a pattern that appears after long exposure to UV light (Backlund et al., 2006)	Encourages use of sun as a heat source	-
Static! Disappearing-Pattern Tiles Bathroom tiles decorated with a thermochromatic pattern that fades away as the temperature increases (Backlund et al., 2006)	Encourages reduced hot water consumption	-
Green IT Homes An smart phone application with which the user can monitor their energy consumption and control their space heating (IMCG, 2012)	Encourages reduced energy consumption Enables control of heating also away from home Enables 'away' and 'vacation' settings	The usability of the interface and the interest has been evaluated and both were rather positive.
The District Heating House A detached house where district heating is used in as many energy-using appliances as possible (Zinko, 2006)	Enables replacing electricity with district heating Enables increase in comfort	One house was built and in that district heating and a substantial part of the electricity was replaced by district heating. The comfort in the house was increased.

CONCEPT	INTENT – ENCOURAGING AND/OR ENABLING?	EVALUATION
Desktop Task/Ambient Condition System A system that gives individuals control over critical environmental conditions at their workstations (Bauman, Carter, & Baughman, 1998)	Enables control of microclimate	Tested with 42 participants and approximately 35 control participants. The overall satisfaction increased with the system. More than 80% of the users of the system adjusted the controls less than once per day, suggesting that it is more important to have the ability to control the local environment than it is to actually make a large numbers of control adjustments.
New heating system with a web-based heating user interface Heating control that is based on adaptive thermal comfort (Clear, Friday, Hazas, & Lord, 2014). Includes a user interface with new functionalities, for instance make it warmer/cooler buttons that temporarily changes the indoor temperature. The indoor temperature also slowly decreased to 16°C.	Encourages lower indoor temperature Enables other ways of controlling space heating	Evaluated in-situ with eight participants during 50 days with mixed results. Indoor temperatures dropped slightly and fluctuated more. The measurements suggest a potential of energy savings of 19% to 76%. The participants appropriated the system in different ways depending on their previous heating habits. Some changed their airing habits and some increased their use of additional means for thermal comfort. For some, the mere possibility to be able to boost the heating was reassuring
Smart thermostat A smart thermostat with integrated machine learning that automate heating based on real-time price variations. Three different designs were evaluated (Alan, Shann, Costanza, Ramchurn, & Seuken, forthcoming).	Encourages and enables avoiding heat consumption during peak hours	Evaluated in-situ with 30 households. The thermostats were used to effectively respond to real-time prices yet maintaining thermal comfort.

REFERENCES

Alan, A. T., Shann, M., Costanza, E., Ramchurn, S., & Seuken, S. (forthcoming). I*t is too hot: an in-situ study of three designs for heating.* Paper presented at the CHI conference, San Jose, California, USA.

Backlund, S., Gyllenswärd, M., Gustafsson, A., Ilstedt Hjelm, S., Mazé, R., & Redström, J. (2006). *Static! The aesthetics of energy in everyday things.* Paper presented at the Design Research Society Wonderground International Conference 2006.

Bauman, F., Carter, T., & Baughman, A. (1998). Field study of the impact of a desktop task/ambient conditioning system in office buildings. *ASHRAE Transactions*, 104(1), 2-19.

Boucher, A., Cameron, D., & Jarvis, N. (2012). *Power to the people: dynamic energy management through communal cooperation*. Paper presented at the Designing Interactive Systems Conference.

Clear, A. K., Friday, A., Hazas, M., & Lord, C. (2014). *Catch my drift? Achieving comfort more sustainably in conventionally heated buildings*. Paper presented at the 2014 conference on Designing interactive systems, Vancouver, BC, Canada.

de Jong, A., Balksjö, T., & Katzeff, C. (2013). *Challenges in Energy Awarness: a Swedish case of heating consumption in households*. Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies Isanbul, Turkey.

DEFRA. (2005). *Securing the future*. Department for Environment, Food and Rural Affairs.

Gaver, W. W., Bowers, J., Boehner, K., Boucher, A., Cameron, D. W., Hauenstein, M., . . . Pennington, S. (2013). *Indoor weather stations: investigating a ludic approach to environmental HCI through batch prototyping*. Paper presented at the SIGCHI Conference on Human Factors in Computing Systems.

IMCG. (2012). *Green IT Homes*. IMCG.

Kappel, K., & Grechenig, T. (2009). *Show-me: water consumption at a glance to promote water conservation in the shower*. Paper presented at the 4th international conference on persuasive technology.

Kuijer, L. (2014). *Implications of Social Practice Theory for Sustainable Design*. Thesis for the degree of Doctor of Philosophy, Technische Universiteit Delft.

Kuijer, L., & de Jong, A. (2011). *Practice Theory and Human Centred Design: A Sustainable Bathing Example*. Paper presented at the Nordic Design Research Conference Helsinki, Finland.

Laschke, M., Hassenzahl, M., Diefenbach, S., & Tippkämper, M. (2011). *With a little help from a friend: a shower calendar to save water*. Paper presented at the

CHI'11 Extended Abstracts on Human Factors in Computing Systems.

Wilson, G. T. (2013). *Design for Sustainable Behaviour: Feedback Interventions to Reduce Domestic Energy Consumption*. Thesis for the degree of Doctor of Philosophy, Loughborough University, Loughborough.

Wilson, G. T., Lilley, D., & Bhamra, T. (2013). *Design Feedback Interventions for Household Energy Consumotion Reduction*. Paper presented at the 16th Conference of the European Roundtable on Sustainable Consumption and Production (ERSCP) & 7th Conference of the Environmental Management for Sustainable Universities (EMSU): Bridges for a more Sustainable Future Uniting Continents and Societies Isanbul, Turkey.

Yang, R., & Newman, M. W. (2012). *Living with an intelligent thermostat: advanced control for heating and cooling systems*. Paper presented at the 2012 ACM Conference on Ubiquitous Computing.

Zinko, H. (2006). *Demonstrationsprojekt fjärrvärmeanpassade småhus Göteborg - Avancerad fjärrvärmeanvändning i småhus*. Svensk Fjärrvärme.

APPENDIX 2

DESIGN BRIEFING – PREPARATORY DESIGN PHASE

DESIGN BRIEFING

The overall goal for the project was to design competitive products and/or services that contribute to the perception of district heating as an attractive alternative to other heating systems and to more efficient use of district heating through encouraging energy efficient user patterns.

Based on the explorations on people's perspectives on district heating, two alternatives for achieving the goal have been identified, described as two different design missions.

Design mission #1

➔ Design features of the district heating system or additional heating artefacts which enable[1] and encourage[2] less energy demanding ways of achieving positive thermal experiences in everyday life. The way to achieve positive thermal experiences should enable people to rapidly avoid thermal discomfort and to heat the whole body as well as specific body parts through an emotionally satisfying experience.

Positive thermal experiences are attractive in everyday life. Today, only experiences with high demands of energy are available through the district heating system even though positive thermal experiences need not demand high levels of energy. The rebound use of showers and ovens, for instance, is a concrete example of what happens when the possibility of achieving positive thermal experiences through the system is lacking or if the response is slow. As it was revealed that in many cases thermal discomfort concerns only parts of the body, this should be considered when designing new ways of achieving positive thermal experiences.

Design mission #2

➔ Design features of the district heating system or additional products/services that give people a clearer understanding of how their heating system works, increasing their awareness of the system as a whole and of their consumption, and offer people accessible control over the heating. Important aspects include feedback on consumption and about the different processes in the system as well as excellent usability, but also to highlight and enhance the emotional qualities of district heating. A widening of the concept of a heating system to include additional heating and cooling artefacts as well would better fit the user perspective and therefore be beneficial.

The understanding of the system and its parts (thermostatic radiator valves, etc.) is low and the awareness of the system as a whole is very low too in the sense that people never spend time reflecting on it. Parts of the heating systems are sometimes difficult to handle or inconveniently positioned and different components of the heating systems are often covered, in accordance with people's wishes. Direct interaction with the heating systems is generally not frequent, partly due to perceived and actual lack of control and partly due to the fact that there is no need for frequent interaction. In addition, people achieve thermal comfort in many other ways than interacting with their heating system. Infrequent interaction and alternative ways of achieving thermal comfort is not a problem per se, but it may explain the unawareness of the systems in general and of the production of heat. In addition, it may

---

[1] If a concept enables something one of the concept's major aims should be to influence people's **ability** to do something. (According to Defra's 4Es model enable is to remove barriers, give information, provide facilities, provide viable alternatives, educate/train/provide skills and provide capacity (DEFRA, 2005).)

[2] If a concept encourages something one of the concept's major aims should be to influence people's **intention/willingness** to do something. (According to Defra's 4Es model encourage is tax systems, ependitures/grants, reward schemes, recognition/social pressure/league tables and penalties/fines/enforcement action (DEFRA, 2005))

lead low user interaction with the heating system, to taking the heating for granted, and to lack of appreciation for the heating, which could be problematic for the district heating provider, in this case Göteborg Energi. The lack of appreciation may also be related to the view among users and Göteborg Energi that district heating is an instrumental service (a certain room temperature) and not a more experience oriented service provider (delivering cosiness to a home or a safe and secure home, for example). Some additional thermal heating artefacts people use have emotional qualities and can potentially become an integral part of the district heating system.

Problems and insights

When attempting to understand the problems of district heating systems it is important to be aware of the fact that different problems lies on different system levels. District heating can be divided into four system levels and problems and related insights exist on each level.

Levels	Problems and insights
Product-technology systems The technical system, within a building, that provides homes with district heating, (e.g., radiators, floor heating, taps, showers and baths) including how the technical system is used and the experiences of using it.	Operational Problem Difficult to understand and use Lack of feedback on system activities Not heating specific parts of the body Too slow heating/cooling No possibility for pleasant experiences without intensive energy usage Airing without turning off radiators Inconspicuous components/not aware of them (Ketola, 2001) ("I usually forget that radiators exist") Prefer different temperatures in different rooms (i.e. cold bedrooms, the heating turned off in the bedroom and often airing) Very few turn off the heating when leaving for holidays (some because they did not know if they had control over the heating) Some want to come home to a warm home Change the settings on the thermostatic valves from maximum to minimum just to see if something happens Unreliable sources of feedback (sound, touching radiators, no thermometer) Some did not appreciate low flow shower heads Inconsistent use of numbers and symbols on thermostatic radiator valves Washing-up considered to waste hot water Most don not bleed the radiators regularly because they do not know how or when to do it or do not have the right equipment
Product-service system The household's heating and hot water system (including payment structure (separate bill or included in the rent) and ownership) and use, and related activities.	Functional Problem Not knowing what type of heating system Not understanding the heating system Uninformed about consumption (Carlsson-Kanyama, Lindén, & Eriksson, 2004) (lack of consumption feedback) Not benefitting from reduced consumption/off-peak load Heating costs more than covered by rent (Carlsson-Kanyama et al., 2004) No/little (perceived) control over the heating Not aware of who controls the heating (in flats) and who to contact in case of problems

	Dissatisfied users (too cold/warm) (see figure 1) Many users keep the heating on maximum constantly (not able to control or adapt) Energy efficiency measures result in increased rent (i.e. new windows are regarded as increased standard) Heating and hot water consumption is related to working hours that are similar for a large group of the population
Socio-technical system The different types of heating and hot water systems and their interlinks, the (household's) lifestyle, norms regarding energy, and shared social practices related to heating, hot water and energy in general.	System Deficiency Warm homes are associated with cosiness and a welcoming feeling (Gram-Hanssen, 2010) The understanding of comfort is energy intensive (Aune, 2007) Energy intensive norms regarding hygiene and cleanliness Rebound use of hot water and electricity (showering/bathing, using electric heaters or turning on the oven when too cold or showering when too warm) (see figure 1) Lack of knowledge on how to preserve heating (Carlsson-Kanyama et al., 2004) and hot water Lack of knowledge on how to curtail heating Not aware of the environmental effects of heating/hot water usage Electricity curtailment is considered to be more important Increasing expectations on comfort (Chappells & Shove, 2005) Strong preference for warm homes Disagreement among household members Infrequent interaction that lead to users distancing themselves from the system and stay unaware Many consider themselves as moderate users of heating and hot water Endless supply of hot water/heating Guest may have a different need for heating (complaining that it is too cold/warm) Worried/annoyed when guests shower/take a bath (in detached houses)
Societal system The national energy system and to some extent the international energy system, including energy systems links to the economic system, taxes, and international agreements.	Societal Problem Dependency on fossil fuels Dependency on waste Dependency on surplus heat from unsustainable industries e.g. oil refineries The power of the regime renders difficulties for new niches (cf. Geels, 2002)?

Figure 1: A status update from Facebook from a person not involved in any of the studies indicating how dissatisfied users can be with the heating supply and what measures they are ready to take to warm up again, such as showering.

Design opportunities

Emotional qualities in different ways of staying warm

Ho, Bergman, Koizumi, Tajadura-Jiménez, and Kitagawa (2012) showed in an experiment with response time measurements that physical warmth and semantically described warmth were associated with positive emotions faster than coldness. Physical and semantically described coldness was instead associated with negative emotions. Even though these findings support the overall findings in the thermal situation questionnaire, there are also indications that different ways of staying warm could result in different positive emotions and evaluations. A cold environment with an external heat source was rated higher with regard to anticipation than being in a cold environment with insulation, or to be neutral. For the evaluation word cosy, the rating for neutral was significantly higher than for cold with insulation or for cold with heat source, while it was more fascinating with the cold environments. This is interesting, as the thermal situations would differ in energy consumption if they represented indoor thermal situations. Neutral could be said to represent a neutral indoor temperature while cold with heater would represent a cooler indoor temperature, but with individual heating, i.e. using artefacts that heat the body directly, such as hot water bottles or portable electric heaters. Cold with insulation would also represent a cooler indoor temperature but with warm clothes, blankets, or duvets.

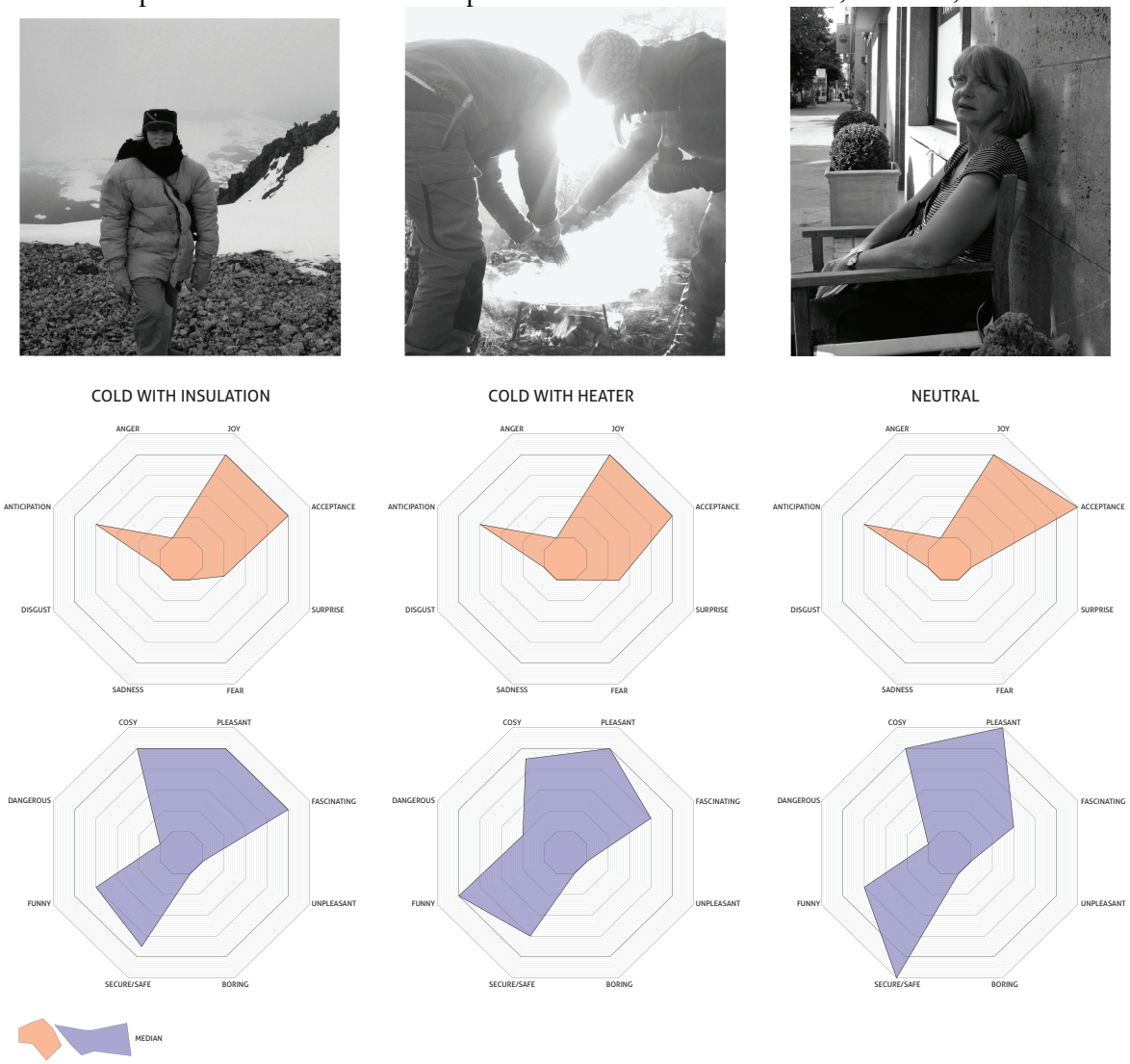


Figure 2: The result for three of the situations in the thermal situation questionnaire.

Emotional qualities of district heating

Heating in homes in cold countries is a basic need that makes our everyday life much more bearable, but it can also provide much more, such as giving a home that homely feeling. In the creation of a home, making it warm and cosy is very important to some residents (Aune, 2007), and a high indoor temperature is for some associated to a cosy and welcoming home (Gram-Hanssen, 2010). In the thermal situation questionnaires the result for the three situations cold, neutral and warm are presented in figure 3. The result gives an indication of the value district heating brings to people.

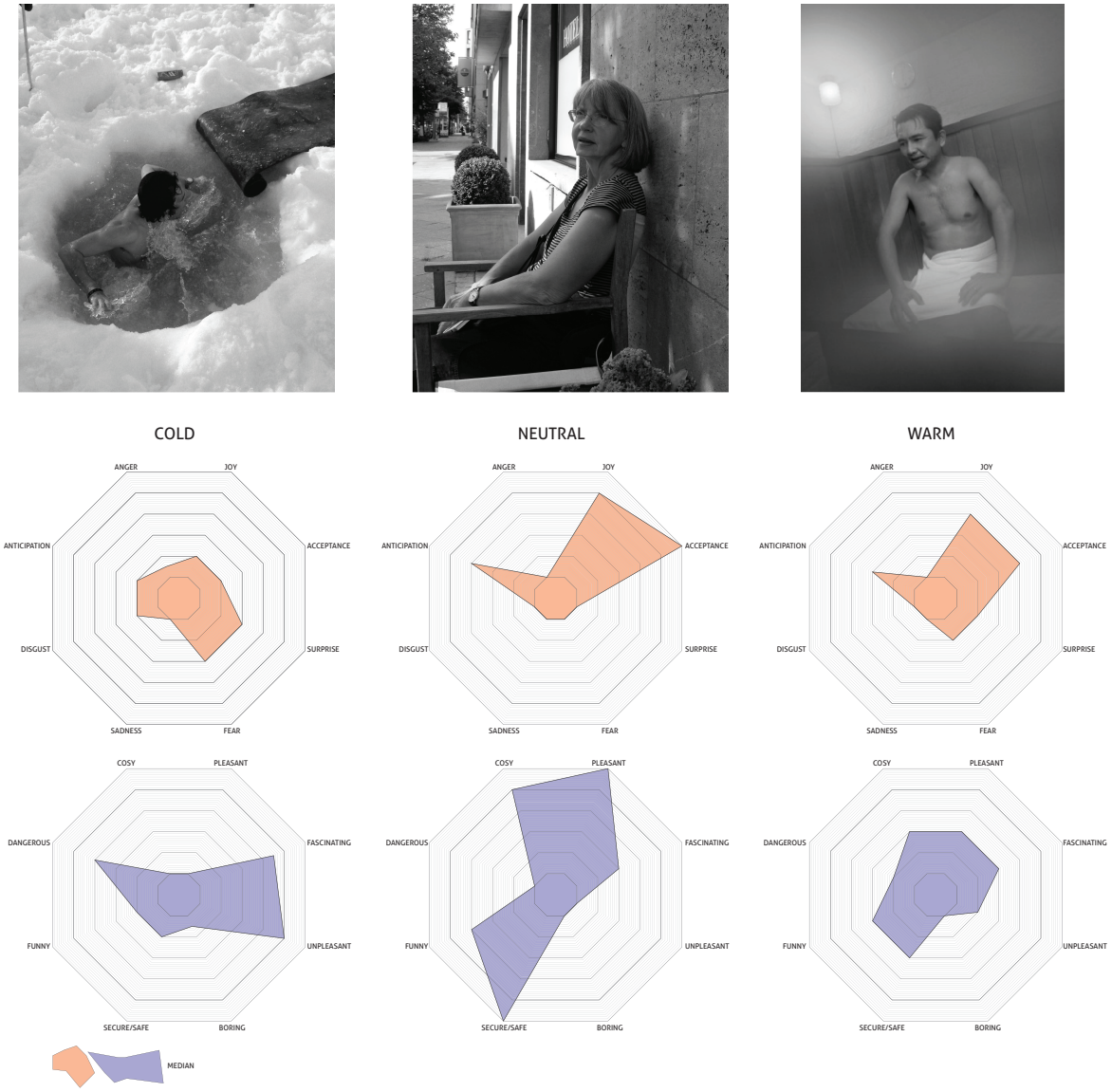


Figure 3: The result for three of the situations in the thermal situation questionnaire.

Too warm

When someone is too warm there is potential to save energy. Of interest is that even in wintertime with a mean outdoor temperature of 1°C the participants recorded that they were too warm in 35% of the reported instances of thermal discomfort. Many of these instances occurred at home (40%) either in an unspecified location in the home (53%), in bed (24 %) or in the kitchen (12%). The activities the diarists were engaged in when too warm were often rather active situations (e.g. exercising, walking) or being indoor with outdoors clothing (shopping, arriving home/to work). Cleaning, dancing, exercising, walking, getting dressed, drinking, hurrying,

playing board games and shopping were activities when the diarist were too warm more often than too cold.

Parts of the body

Often, thermal discomfort did not concern the whole body but one or several body parts, see figure 4.

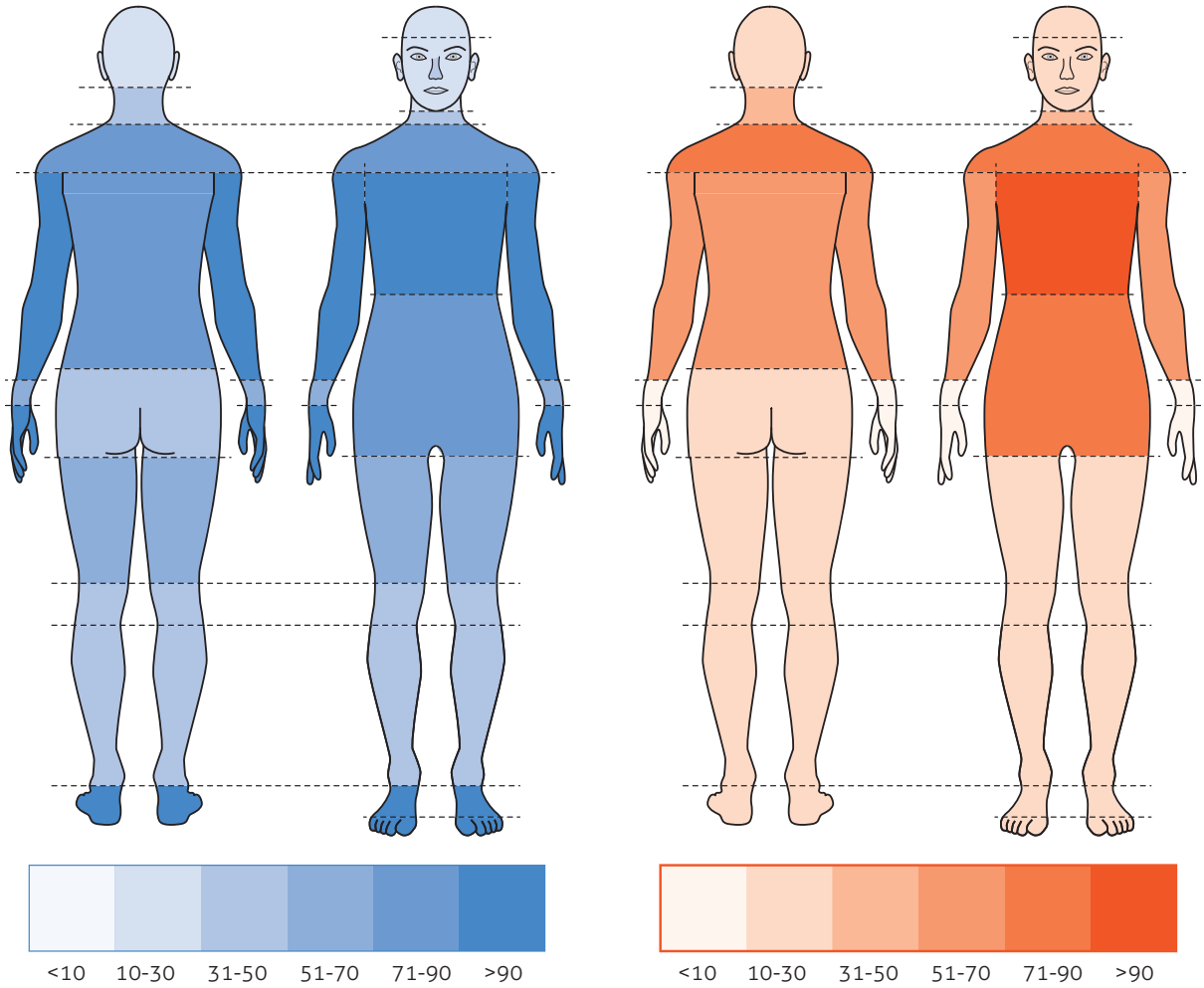


Figure 4: The number of times each body part was cold or warm, as reported in the thermal diaries.

There is more than comfort

Thermal comfort is comfortable, but there are other thermal states that have the potential to be more pleasurable. Actually, "recent research indicates that dynamic thermal environments can potentially deliver higher levels of occupant satisfaction than static, homogenous indoor environments" (Parkinson, de Dear, & Candido, 2012). The same change in temperature in the surroundings is experienced as pleasant and unpleasant depending on which thermal state a person is in.

Experience of consumption

In everyday life, consumption of heating and hot water is experienced in different ways such as in the sensations of hot baths and showers, bare feet on heated ceramic floor tiles on a cold winter day, and in large constantly heated living spaces (Berker, 2013). Nevertheless, we are often unaware of the extent of our consumption and these sensations could be a starting point when trying to increase the general public's awareness of their consumption. As the participants in the

thermal diaries achieved thermal comfort in many different ways than interacting with the radiators or adjusting the setting of the heating systems, it could be argued that the participants do not see those items as their primary provider of thermal comfort, see see figure 5. Extending the concept of heating system to include additional heating and cooling artefacts as well would better fit the user perspective, and could be seen as a personal heating system.

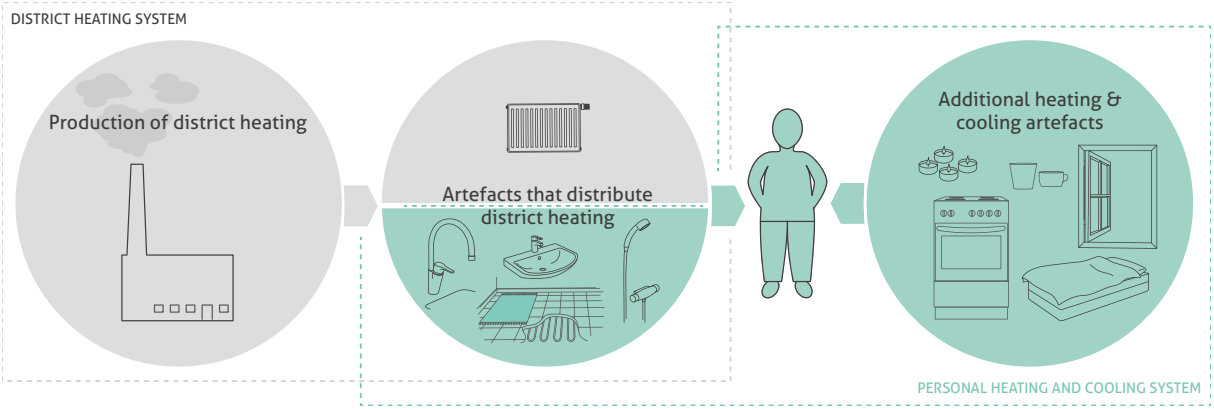


Figure 5: The personal heating and cooling system vis-à-vis the district heating system.

Engagement in low energy activities to achieve positive thermal experiences

In the extensive variety of artefacts and activities the participants used to achieve thermal comfort (see figure 7), both physical and emotional pleasure were present. An interesting aspect was that some participants used artefacts that only gave emotional pleasure to achieve thermal comfort, such as lighting a candle "for the feeling of it" or communicating with others via computers. It was seen that physically and emotionally pleasurable use of the heating system, such as long hot showers, and long-lasting baths consume high amounts of energy, while many of the additional heating artefacts do not use energy at all during the usage phase – such as blankets. In addition, such additional heating artefacts can deliver both warmth and emotional pleasure (see figure 6 and table 1), and the concept Splash, an alternative to conventional showering, is an example of this. With Splash, the water is contained and splashed over the body in a relaxing way that simultaneous save energy compared to conventional showers (Kuijer & de Jong, 2011).

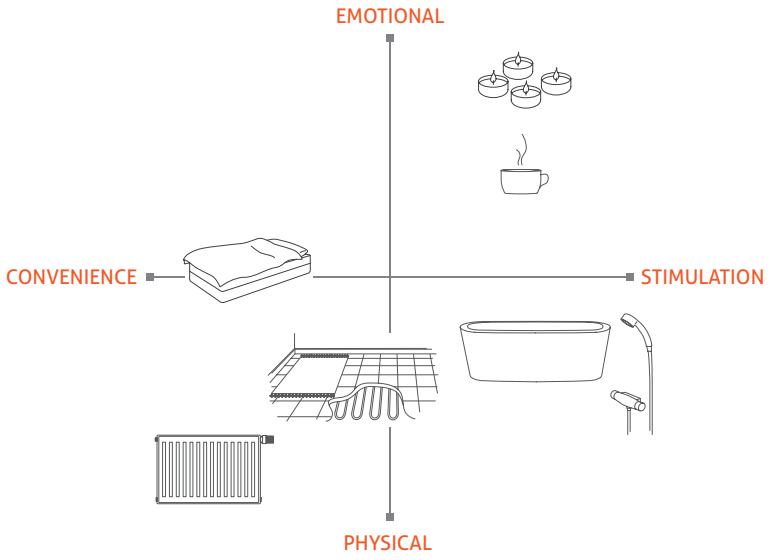


Figure 6: The different kinds of pleasures derived from using different kinds of heating and cooling artefacts.

Artefacts/actions	Mentioned types of pleasures related to use
Shower	Physical pleasure (warmth/cold) and emotional pleasure (e.g. acceptance)
Bathtub	Physical pleasure (warmth/cold) and emotional pleasure (e.g. acceptance)
Family members	Physical pleasure (warmth) and emotional pleasure (contact with others)
Computer	Emotional pleasure (contact with others)
Blankets and duvets	Physical pleasure (warmth) and emotional pleasure (e.g. cosiness)
Wheat pillow	Physical pleasure (warmth) and emotional pleasure (e.g. cosiness)
Candles	Emotional pleasure (cosiness)
Movements	Physical pleasure (warmth) and emotional pleasure (e.g. joy)
Sun	Physical pleasure (warmth) and emotional pleasure (e.g. joy)
Infrared heating (outdoors)	Physical pleasure (warmth in a chilly environment) and emotional pleasure (e.g. fascination)

Table 1. Artefacts and actions in people's personal heating systems and the types of pleasurable aspects of use that were mentioned

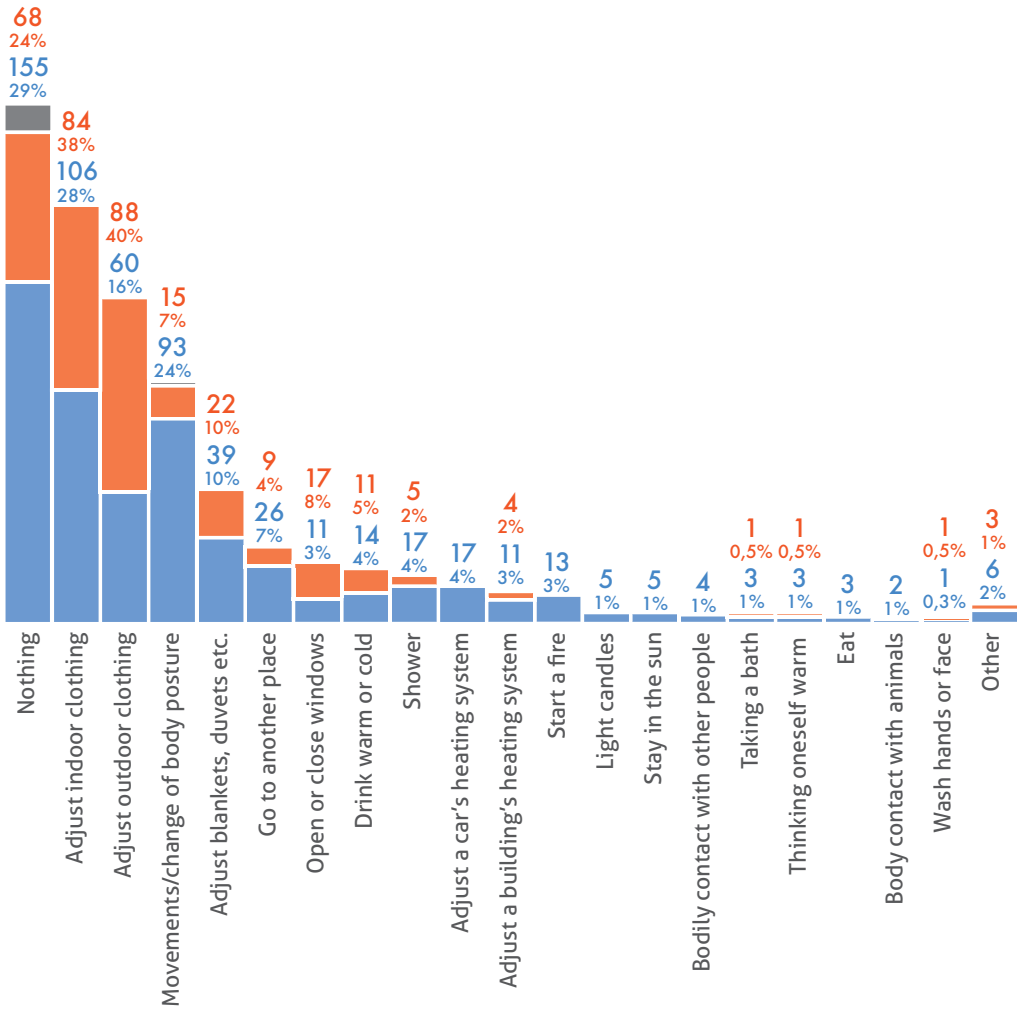


Figure 7: The actions the participants taken when being cold or warm. The blue percentages display the proportion of a particular action to get warmer of all the cases when any action to get warm was taken, and the red percentages show the corresponding proportion when taking action to cool down.

Different kinds of (more) district heating use

District heating can supply more appliances than it does today. One example is white goods made by Asko that partly runs on district heating and another example is towel dryers. However, it is interesting that many people already make use of the district heating in many different ways, such as warming butter to room temperature by placing it on the floor and letting the underfloor heating slowly warm it up, thawing food on radiators (see figure 8), warming themselves up by the towel dryer, warming their feet and drying clothes on radiators, etc.

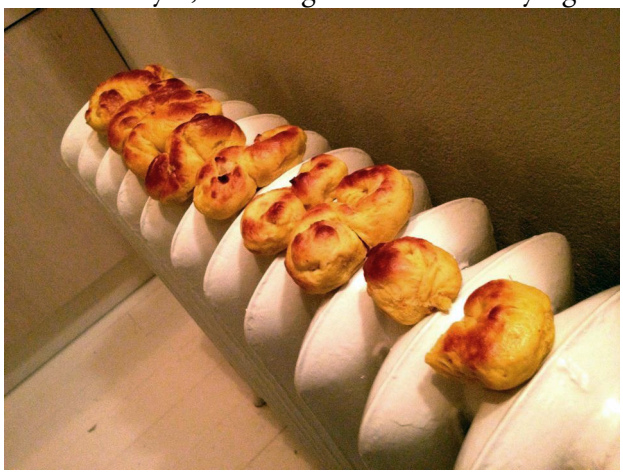


Figure 8: Thawing saffron buns on the radiator (a picture posted on Facebook).

There is more to comfort than thermal comfort

To be comfortable is related to a lot more issues than the thermal conditions, see figure 9 (Burris, Mitchell, & Haines, 2012).

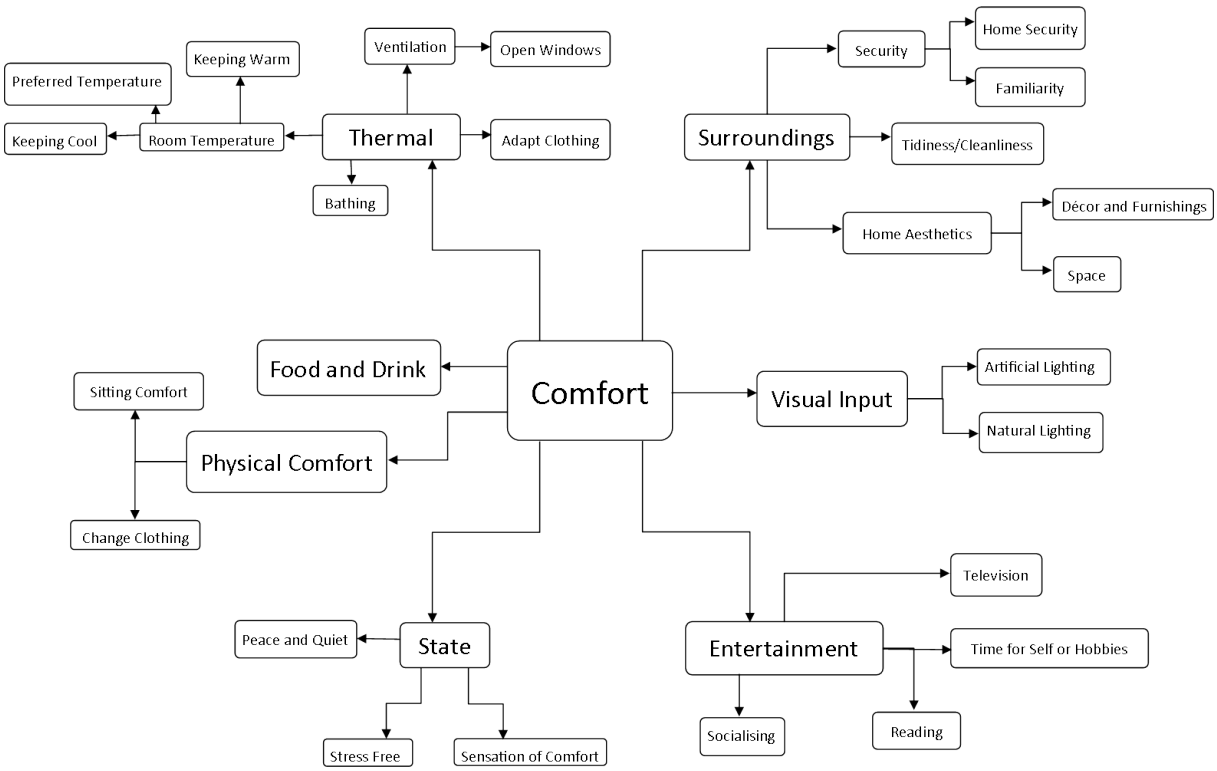


Figure 9: Understanding of and creation of comfort in the home.

References

Aune, M. (2007). Energy comes home. *Energy policy, 35*(11), 5457-5465.

Berker, T. (2013). "In the morning I just need a long, hot shower:" a sociological exploration of energy sensibilities in Norwegian bathrooms. *Sustainability: Science, Practice, & Policy, 9*(1), 1-7.

Burris, A., Mitchell, V., & Haines, V. (2012, 12-15 April 2012). *Exploring Comfort in the Home - Towards an Interdisciplinary Framework for Domestic Comfort.* Paper presented at the 7th Windsor Conference: The changing context of comfort in an unpredictable world, Cumberland Lodge, Windsor, UK.

Carlsson-Kanyama, A., Lindén, A.-L., & Eriksson, B. (2004). *Hushållskunder på elmarknaden.* Department of Sociology, Lund University.

Chappells, H., & Shove, E. (2005). Debating the future of comfort: environmental sustainability, energy consumption and the indoor environment. *Building Research & Information, 33*(1), 32-40. doi:10.1080/0961321042000322762

DEFRA. (2005). *Securing the future.* Department for Environment, Food and Rural Affairs.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy, 31*(8-9), 1257-1274. doi:http://dx.doi.org/10.1016/S0048-7333(02)00062-8

Gram-Hanssen, K. (2010). Residential heat comfort practices: understanding users. *Building research and information, 38*(2), 175-186.

Ho, H.-N., Bergman, P., Koizumi, A., Tajadura-Jiménez, A., & Kitagawa, N. (2012). *The pleasant heat? A study of thermal-emotion associations.* Paper presented at the International Multisensory Research Forum, Oxford, United Kingdom.

Ketola, A. (2001). *Elen är fri.* Thesis for the degree of Licentiate of Engineering, University of Lund, Lund.

Kuijer, L., & de Jong, A. (2011). *Practice Theory and Human Centred Design: A Sustainable Bathing Example.* Paper presented at the Nordic Design Research Conference Helsinki, Finland.

Parkinson, T., de Dear, R., & Candido, C. (2012). *Perception of Transient Thermal Environments: Pleasure and Alliesthesia.* Paper presented at the 7th Windsor Conference: The changing context of comfort in an unpredictable world, Cumberland Lodge, Windsor, UK.

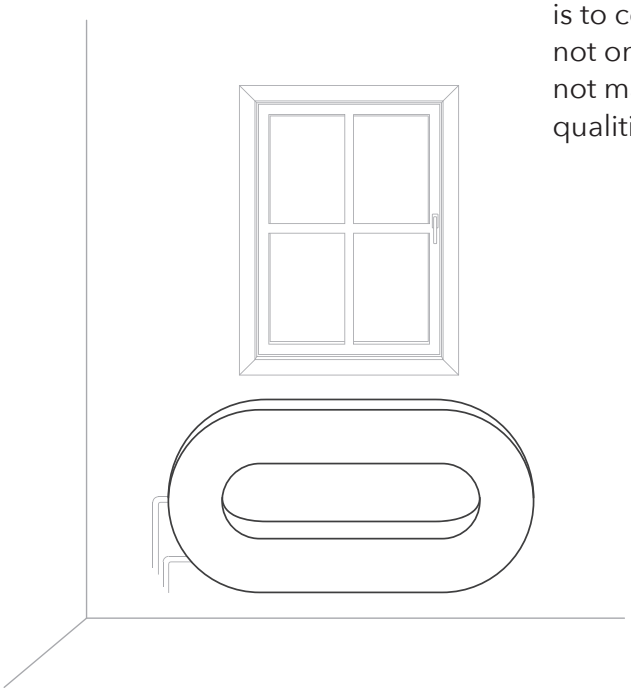
APPENDIX 3

DESIGN CONCEPTS

In the three tables below I present the design concepts within the three design directions defined and presented in section 5.2: **additional ways of making use of district heating**, **informed and in control**, and t**hermal comfort and pleasurable thermal experiences**. For each concept I describe the idea, comment on whether similar solutions are available, and reflect on benefits and drawbacks with each concept.

Table 1. Design concepts and reflection on the design direction described as additional ways of making use of district heating

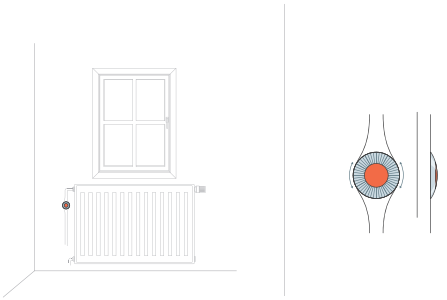
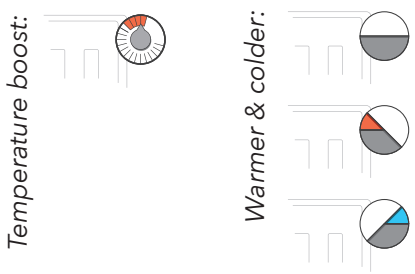
CONCEPTS - ADDITIONAL WAYS OF USE	REFLECTIONS ON THE CONCEPTS
Shared greenhouse A free standing shared green house for apartment blocks heated with reused heat from the building. A similar thing has been done in The District Heating House (Zinko, 2006) but for a detached one-family house and the green house was attached to one of the outer walls of the house.	A shared greenhouse makes use of three unique characteristics of district heating, first heat used for space heating in homes can be reused, here in the greenhouse, and second that it is present in the ground in urban areas. A greenhouse can thus be a symbol for a building's connection to district heating. Thirdly, the green house is shared, just as the district heating system is shared.
Outdoor heaters Outdoor heaters are used both at home and in public places such as pubs, bars, cafés, etc. With some innovative thinking these could be replaced with district heating. For instance, the ground at that spot could be heated and the seats used could be heated or pre-heated, although this might result in extensive piping.	Outdoor heaters are mostly used during late evenings in spring, summer and autumn and thus not during district heating's peaks in demand. In summers, district heating companies can have a difficulty to cool of the returning heat carrier (i.e. the returning water in the pipes). In this way, outdoor heaters could make use of the unique qualities of district heating: that it at times of they year the available heat sources are more than sufficient. There are two major challenges with this concept, firstly it is a technical challenge to make a sensible solution that is easy to use, and secondly if used in public places it is yet another way of communicating district heating as manifestations in the city without showing if someone has district heating at home or not.

CONCEPTS - ADDITIONAL WAYS OF USE	REFLECTIONS ON THE CONCEPTS
Warm surface for kitchens A warm surface can be useful in kitchens, for instance to rise dough, keep food warm, and to thaw frozen food quicker.	Warm surfaces do not make use of any of the unique qualities of district heating and thus it might be difficult to understand it as a *district* heating product, and not just as a heating product.
Multifunctional radiators Designing radiators so that residents more easily can use them to dry and heat up things in the home, but also encourage them to do so. People could be encouraged to hang things on them (e.g. textiles), heat things on top of them (e.g. thawing foodstuff), or put things in/on to them (e.g. wet shoes). Flat horizontal surfaces could sometimes be helpful. If with some type of temperature gauge it would be easier for users to establish when the objects would be dry/heated. There are already radiators on the market in the shape of towel dryers and accessory products that can be mounted on existing radiators (e.g. for shoes and textiles). 	Some people already use radiators in a multifunctional manner, but often with a feeling that it not the 'correct' way of using radiators. Therefore, the design must invite people to do so. There are accessory products, yet, as soon as it is an accessory product it is as if the idea of using the radiators for something beyond space heating is not the standard way of doing it. A problem with towel dryers is that people do not know if they are running on electricity or on district heating. Thus, the energy supply method needs to be clear in the design. A positive aspect of multifunctional radiators is that residents might not put furniture in front of a radiator that is useful also for other things than space heating. The biggest challenge with this concept is to communicate *district* heating and not only heating, as the concept does not make use of any of the unique qualities of district heating.

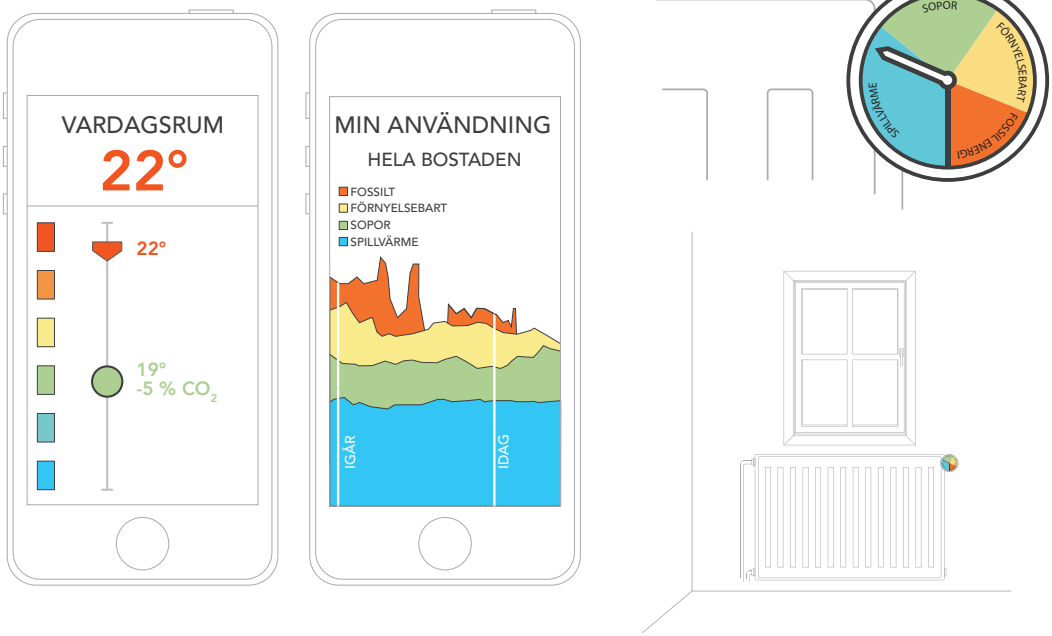
CONCEPTS - ADDITIONAL WAYS OF USE	REFLECTIONS ON THE CONCEPTS
White goods The District Heating House was already equipped with white goods supplied with district heating. Such white goods were later produced and sold by the white goods manufacturer Asko. Yet, for a layperson it is not easily discernible that they are heated with district heating and they do not communicate their benefits, such as electricity savings. One idea is therefore to redesign the interface of white goods with district heating to clearly communicate what is different and what is better than appliances running solely on electricity.	In white goods connected to district heating, electricity is used for processes district heating cannot support (e.g. centrifugation) while district heating is used for what it does better – heating. However, this must be communicated clearly which is a challenging task.
Low temperature oven Dehydrators and sous vide water ovens are different types of low-temperature ovens used to prepare food in lower temperatures than in standard ovens (maximum 99°C). A dehydrator can be used to dry foodstuff and to prepare raw food dishes, for instance. On the market today there are electric dehydrators for raw food and in addition a standard oven can be used yet with less precision. Sous-vide water ovens are filled with water and the food is placed inside and heated a quite long time, usually for several hours.	In dehydrators and sous vide water ovens the temperature span is similar to a washing machine and thus should fit the temperature span of district heating. It is therefore a sensible way of replacing electricity with district heating. Additionally, raw food and sous vide are perceived as innovative ways of preparing food and utilising district heating might increase the chances of district heating being perceived as more innovative than today. As with white goods, the presence of district heating must be communicated through the design. A problem is still that a low temperature oven might be not be perceived as a *district* heating product, just as a heating product.

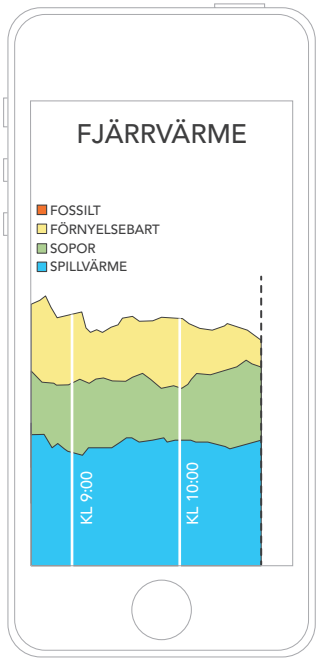
Table 2. Design concepts and reflection on the design direction described as informed and in control

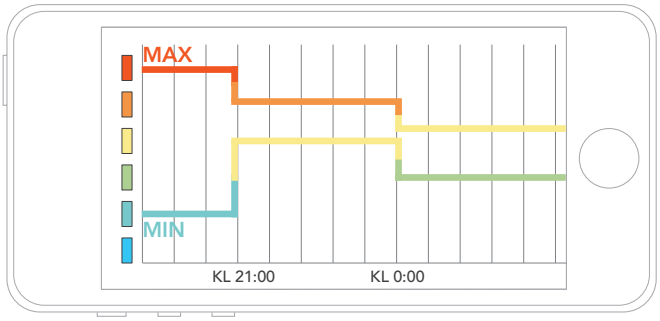
CONCEPTS - INFORMED & IN CONTROL	REFLECTIONS ON THE CONCEPTS
Basic information (Suitable for apartment buildings in which residents are not informed about if they have district heating or not.) Basic information to residents must include if they are connected to district heating or not. The information could be displayed on a map of Gothenburg clearly showing all houses or as an online tool where residents can type their address, but it could also be simple and low-tech by displaying a sign inside the building. Anyhow, it is important that residents easily are made aware of if they are connected to district heating or not. In addition, a clarification of the different roles different district heating operators could be made. What is Göteborg Energi responsible for and when (if anytime) should residents contact them? What are building owners and managers responsible for and when should residents contact them, and how?; To what extent can residents control the heating in the building?; How does the system work?; Who is responsible for bleeding the radiators?, etc.	An accessible answer to the rather basic question of wheather or not a building has district heating is a prerequisite for people to be interested, aware, and informed about the district heating system. As mentioned, there are many efforts to direct information regarding district heating to citizens both at a national and at a regional level. Yet, residents are not informed about if they have district heating or not, which in effect means that they do not know if general information about district heating concerns them personally or not. Basic information is a first step towards communicating to people both as end users of heat and as citizens.
Exploring the indoor climate Different tools for exploring the indoor climate can be used to learn where it is warmer and colder in a space. Thermometers, thermographic cameras, thermochromatic indicators, anemometers (measuring wind speed), and hygrometers could be used, for instance.	Change location was a common way of pursuing thermal comfort in the diaries. Although tools for exploring indoor climates would encourage people to explore their own indoor climate and personal preferences, wind, humidity, and temperature at different activity levels and times of day, they would not facilitate a clear association to district heating.

CONCEPTS - INFORMED & IN CONTROL	REFLECTIONS ON THE CONCEPTS
Feedback on the status of the heating system Giving feedback on the state of the building's heating system, meaning if the system is "on", and processes, meaning if the system is heating up the space, cooling it down, or keeping the current temperature. More in-depth information such as the temperature and flow rate of the circulating water in the hydraulic heating system could also be included 	Giving feedback on the state of the heating system would help residents to understand when the heating is, as some of the participants in study 2 expressed it, "on". Radiators with thermostatic radiator valves are difficult to understand and both the temperature and the speed of the circulating water are of importance. For those that are interested in technology and their heating system, rich feedback on the system's processes could be a way of making how the radiators function less of a black box. Yet, as with tools for exploring indoor climates this concept is more a way of understanding any heating system than specifically understanding the *district* heating system. In addition, it is more a way of being informed than a way of being in control.
Warmer and colder Residents could, in different ways, be allowed to control their heating more without necessarily increasing their energy use significantly. For example a home could have 20°C as a base temperature, and then if a resident would prefer the living room to be warmer, they would have to lower the temperature in different room. Another solution is to allow either short and hot showers or long and slightly colder showers. To relate more to peak consumption the water could get warmer at off peak hours than at peak hours. Yet another solution would be to allow residents to temporary boost the indoor temperature in a room. After a pre-defined time, for instance one hour, the heating level goes back to normal.	To ensure that people do have the level of control over their heating needed for a warmer and colder concept, new types of business models might be needed. This concept could for instance be directed towards residents in leasehold apartments where the leaseholder association as a whole can make decisions regarding new business models, for example. This concept would enable acknowledgement of residents' personal preferences, for instance keeping the living room warm living and the bedroom cold. It would also allow people to make individual changes to suit their needs. 

CONCEPTS - INFORMED & IN CONTROL	REFLECTIONS ON THE CONCEPTS
Feedback and control related to heat sources Feedback and control related to the different heat sources used in the district heating system would increase people's awareness of heat sources. If the feedback is given in real time or relates to the time of consumption, then the residents can see the difference of, showering at peak and off peak hours, for instance, but feedback in itself is not enough. Residents must also be given the option of acting on the feedback and thus a feedback system should be combined with controls that take the complexity of everyday life into account. There are numerous examples of consumption feedback for use of hot water and heating, but fewer made specifically for district heating. Often, feedback and control possibilities (if any) are separate but in this concept they should be combined.	By focusing on the types of heat sources used, feedback and control can present an association to district heating. In study 2, the participants were usually aware of waste incineration while not aware of the use of excess heat from industries. With this concept residents could get a more accurate overview of the different heat sources used. Currently waste incineration and excess heat from industrial processes are often categorised as one heat source, residual heat, covering 50-60% of the heat. Yet, as residents are often only aware of the use of heating from waste incineration it is a risk that they will think that 50-60% is based on waste incineration. As waste incineration is discussed in public (e.g. topics such as import of waste) I think it is important to provide residents with accurate and clear information on the subject.



CONCEPTS - INFORMED & IN CONTROL	REFLECTIONS ON THE CONCEPTS
The state of the district heating system The Göteborg Energi website holds information about the state of the district heating system but it is not easily understood by laypeople. On the webpage and through other communication channels, real-time information about peak hours, currently used heat sources, operating production plants, etc. should be stated. Forecasts should also be available so that residents can understand what is expected to happen. As the production plants are present in residents understanding of district heating it may be favourable to also connect the information to the plants as well as the heat sources, so that in wintertime residents will realise that Rosenlund, for instance, will be to started or that fossil fuels will be used.	To inform people about the state of the district heating system would indicate that Göteborg Energi sees residents as potentially conscious and active players in the district heating system. 
Temperature span Instead of aiming for a set-point temperature residents should be able to set a temperature span which they should also be allowed to vary in width as well as max and min. This is a way for district heating companies to get residents' acceptance of using a building as a short-term thermal energy storage with greater variation than +/- 0.5°C.	Residents' needs for warmth vary and to compensate they make use of a variety of means in their personal heating system. If the temperature varied slightly more than +/- 0.5°C people could instead use other means in their personal heating system. In addition, if residents would be able to control this by setting the spans they could also turn them off at times when variation would not be acceptable.

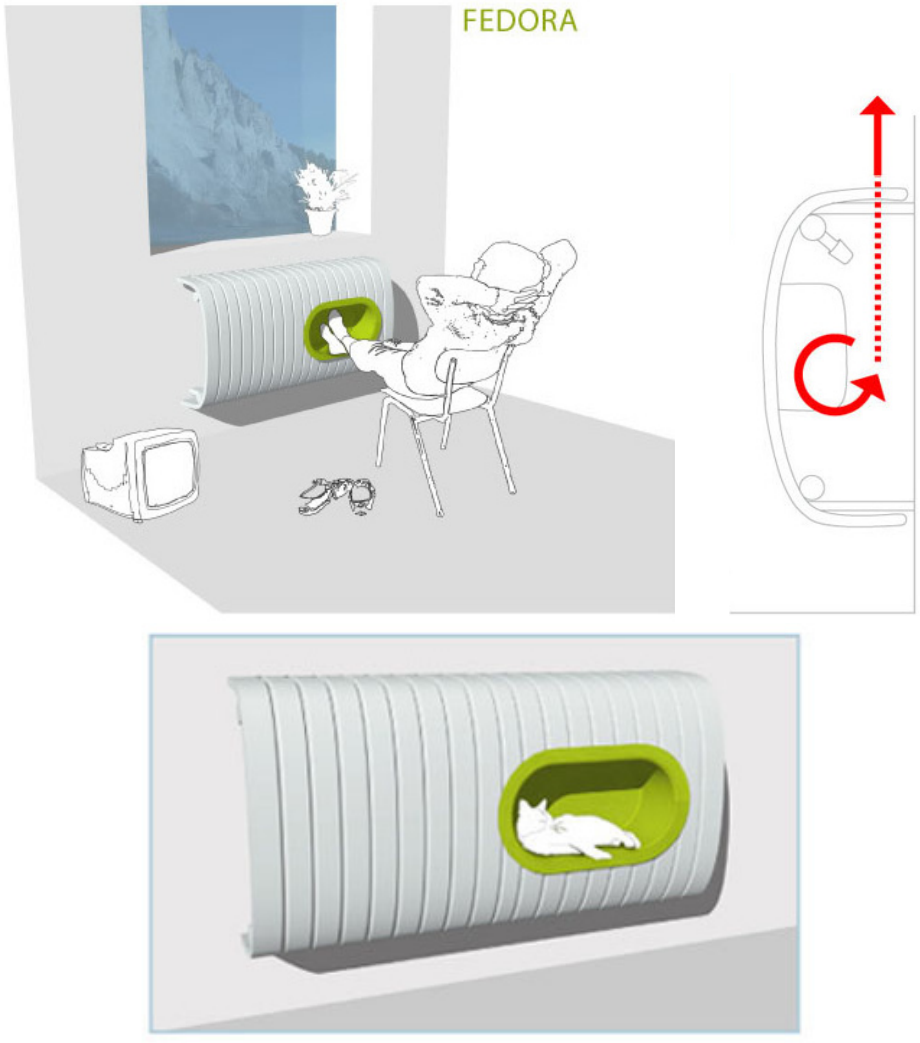


CONCEPTS - INFORMED & IN CONTROL	REFLECTIONS ON THE CONCEPTS
Co-producer Just as with the electricity network ordinary residents could become co-producers, meaning that they could be allowed to transfer their excess heat into the district heating system. A less technically innovative way of achieving the above is to design bins for mixed waste (either for private use inside homes or collective containers for mixed waste in waste sorting rooms) with clear information about what will happen with that waste. This would acknowledge residents' role in waste creation.	The first concept is technically very difficult to achieve and, in addition, the efficiency is highly questionable. Yet, it would send strong signals to residents that they are considered to be able to play a role in the district heating system. The second concept is somewhat of a double-edged sword. Although it would acknowledge residents' role in the district heating system, waste incineration is an end-of-the-pipe solution to the problem of waste and I would not like to contribute to an idea that waste creation is not a problem as it gives us district heating.

Table 3. Design concepts and reflection on the design direction described as thermal comfort and pleasurable thermal experiences

CONCEPTS - THERMAL COMFORT	REFLECTIONS ON THE CONCEPT
Hot spots (floor heating) For underfloor heating residents could direct the warmth more precisely to spots where they usually experience cold, for instance where they stand in the bathroom or where they keep their feet when seated.	Hot spots do not make use of any of the characteristics of district heating, which presents the problem that this concept might not be perceived as a *district* heating product, and just as a heating product.
Heated furniture Heated furniture is one way of heating the body more directly instead of just through the indoor air.	Just as with the concept above, this concept might not be perceived as a *district* heating solution.

CONCEPTS - THERMAL COMFORT	REFLECTIONS ON THE CONCEPT
Sensing the radiators Radiators could be designed for heating oneself on them directly (thermal conduction) and not only through heating the air (thermal convection).	Heating themselves on radiators is something that people already do, but it is not perceived as the 'correct' way of using radiators. Therefore, the design of this concept must invite people to use radiators in this way. This concept also runs the risk of being perceived as any heating product and not specifically as a *district* heating product.



Design: Christine Birkhoven and Eric Falaise, 2007

Christine Birkhoven was born in Santiago de Chile 1979. From 1997 until 2009 she lived with intervals of time in Germany and Spain, now living in Zurich, Switzerland. Since 2004, several works in the fields of Research, Sustainability and Product Design. Christine works as independent designer and had participated in several exhibitions in Milan, Zurich, Lausanne, Cologne, London, Santiago de Chile, among others. www.christine-birkhoven.com

Eric Falaise was born in France by Limoges 1971. Since 1995 he live in Germany, where he worked for several Manufacturer. Actually (2016) he is working for andres GmbH by Cologne to create Retail- and POS-item. www.andres.de

CONCEPTS - THERMAL COMFORT	REFLECTIONS ON THE CONCEPT
Portable district heating devices A solution for person heating is portable heating devices that can be heated on different heat sources in the home, when available, or through the regular heating system (i.e. with distict heating). The heating devices should enable people to rapidly avoid thermal discomfort and should be able to warm up a person who feels cold all over the body, while small enough to conveniently heat parts of the body. For convenience and rapidity, the heating devices should always be ready for use. The devices should further be warm enough so that people directly can sense that the pads are starting to warm them, yet, not dangerously hot. To be identified as district heating product and to better communicate the qualities of district heating the heating devices could be designed so that they represent the different heat sources in the district energy system. There are examples of such design concept from, for instance, online design competitions.	Portable heating devices heated with district heating or other available heat sources in the home could be a way of replacing other pre-heated portable heating devices, such as wheat pillows and hot water bottles. At best, it could also invite more residents to use this type of person heating. If this concept would be seen as an extension of the district heating system or heating system it could serve as a way of extending the idea of district heating. This concept has technical challenges in the way it is intended to be heated and design challenges when it comes to rapidity and flexibility, as well as in representing the mix of heat sources

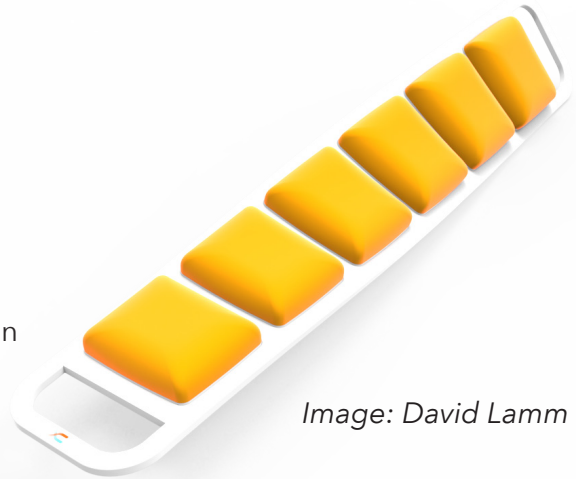
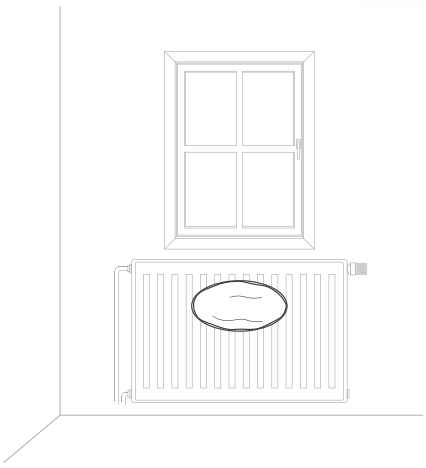
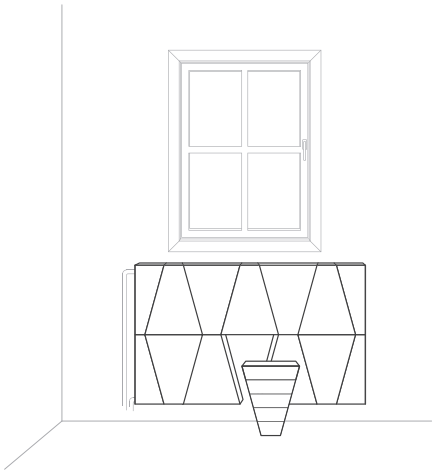


Image: David Lamm



CONCEPTS - THERMAL COMFORT	REFLECTIONS ON THE CONCEPT
Mobile radiators Alternatives to mobile heating devices are to have radiators or parts of radiators mobile. If the whole radiators are mobile their placement could be adapted to, furnishings, for example.	Radiators are usually placed under windows to avoid downdraught from the windows. Yet, in some cases residents might consider this to be impractical and put furniture in front of radiators. To avoid this, mobile radiators would be a solution. This concept would however not be making use of the specific characteristics of district heating.



Design: Anna Gotha

http://www.annagotha.dk

REFERENCES

Zinko, H. (2006). *Demonstrationsprojekt fjärrvärmeanpassade småhus Göteborg - Avancerad fjärrvärmeanvändning i småhus*. Svensk Fjärrvärme.