User experience aspects of radiant floor heating

Considerations for supporting users mental models

Master's thesis in Interaction design and technologies

SAIF HASAN, JOEL SÖRENSSON

Department of Computer Science and Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF GOTHENBURG
Gothenburg, Sweden 2022

Master's thesis 2022

User experience aspects of radiant floor heating

Considerations for supporting users' mental models

SAIF HASAN

JOEL SÖRENSSON

UNIVERSITY OF GOTHENBURG

CHALMERS
UNIVERSITY OF TECHNOLOGY

Department of Computer Science and Engineering
Chalmers University of Technology
University of Gothenburg
Gothenburg, Sweden 2022

User experience aspects of radiant floor heating
Considerations for supporting users mental models
SAIF HASAN, JOEL SÖRENSSON

Supervisor: Sara Ljungblad, Department of Computer Science and Engineering
Examiner: Mikael Wiberg, Department of Computer Science and Engineering

Master's Thesis 2022
Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: The final concept (if applicable)

Typeset in LaTeX
Gothenburg, Sweden 2022

User experience aspects of radiant floor heating
Considerations for supporting users mental models
SAIF HASAN, JOEL SÖRENSSON
Department of Computer Science and Engineering
Chalmers University of Technology and University of Gothenburg

Abstract

To promote energy savings, manufacturers implement system features such as programmes and schedules to their thermostats. Despite these features, the energy saving levels are not sufficient. The main user interface for the heating system is the thermostat itself. These thermostats often lack in creating an user experience that provides enough usability in order to support adequate energy savings.

The thesis is written in collaboration with a company that has the goal to develop a thermostat for their product line. The aim of the thesis has been to explore the domain of residential floor heating thermostats and their users, in order to create a better user experience by supporting users' mental models of floor heating systems. The thesis has resulted in 7 design considerations that aims to support manufacturers during their development of thermostats along with providing research with knowledge on users behaviour within the heating system domain. The design considerations are suggestions on how features and information could be developed and presented for the user in order to improve the user experience. They include considerations such as *Aligning mental models by introducing the user to system functionality*, that through a design concept, Ethermal, is exemplified and aims to show how the design considerations could be implemented in practice.

Keywords: Interface, user experience, interaction design, technology, floor heating, thermostat, mobile application, project, thesis.

Acknowledgements

We would like to express a general appreciation and gratitude towards all of the people that made this thesis possible.

A special thanks to our supervisor Sara Ljungblad, for all expert guidance and feedback throughout the project, including the project proposal, planning, design process and academic formalities. We would like to thank her for showing genuine interest and support for the project from start to finish.

We would also like to thank all of the participants that have taken their time to be a part of the project during questionnaires, interviews and throughout our testing phases while also providing insights and valuable feedback that has stood as the base for the project.

There are also several people that can not be mentioned by name due to privacy considerations. However, we would like to express our gratitude to them. The discussions held, their knowledge of the domain and feedback has made the project progress towards the relevant consideration points. We are thankful for the help and support that we have gotten.

Saif Hasan, Joel Sörensson, Gothenburg, June 2022

Contents

1

Introduction

Home heating represents the majority of the domestic energy consumption in both Europe and the U.S [23, 46]. Increasing the usability and efficiency of home heating is an important goal for saving money and reducing our ecological footprint [49]. Fabricators and manufacturers are constantly adding functions and features to these systems, and one main focus within these functions has been to promote energy savings to these energy costly systems. One way to do this has been through the development of programmable thermostats, which have been promoted as a means for energy saving [46]. Programmable thermostats have the possibility to reduce energy consumption by 5-15% compared to manual systems [45]. The complete infrastructure and functionality for these programmable systems have been found in approximately two thirds of the households that use a central heating system. However, due to poor user experience and a lack of usability when it comes to the interface and interaction of the control devices, programmable heating systems in practice show little to no energy savings to their manual counterparts [34].

Since control of the temperature is dictated by user interaction (e.g., selecting a set-point), the usability of thermostat interfaces is critical [55]. Meier [35, 34] states that the low usability in these complicated systems are partly an effect of users having a low understanding of how their systems operate. The market as it is today offers a wide variety of devices to control heating systems. The common factor between the large majority of the devices is that they use small screens but with different input controllers and interfaces. Although research exists on user behaviour with HVAC thermostats, there is a lack of research related to use of radiant floor heating. Radiant floor heating is a system with high inertia, which means that perceived temperature in the environment changes slowly [1]. Hence, for users to be able to reap the benefits of such a system, it requires anticipation of need and pre-setting temperature changes. However, one of the primary barriers to use proactive settings is the complexity of feature-rich interfaces [15]. Moreover, smart technology research shows that end-user programming accuracy requires routine specificity and rigidity [22]. This is incompatible with ethnographic studies of how people improvise daily behaviour and modify their routines. This type of pervasive technology, services and systems should instead allow for flexibility in control for the user.

The project was conducted in collaboration with a company that aims to enter the market of programmable floor heating systems for homes and businesses. Preliminary hardware had been developed to utilize a digital control interface. Research was needed to get a better understanding of what features should be provided on the device in relation to user needs, and conceptual development of a good experience when it comes to functionality and usability. The heating system will additionally support control through an application, which is something that will be considered in this project to make the user experience coherent.

1.1 Stakeholders

In this project the stakeholders are primarily the end users of the product and application that the company offers. The end users are house or apartment owners that use electric floor heating systems.

The producing company is another stakeholder for this thesis. The company does not have an interaction design department specifically and the design aspects are in the current situation done by other engineers. As an expanding company they have realized the importance of good UX and are in the need of exploring how to provide a good user experience for a possible upcoming product line.

The thesis will be a part of our Masters degree from Chalmers university of technology, which also is a stakeholder for the thesis. Requirements such as certain tasks and deadlines will be present and is something that the project will have to take into consideration. Other aspects are also things such as being able to publicize the thesis along with taking into consideration the parts of the thesis that are required to be present to make a complete master thesis.

1.2 Research Problem

Because temperature control is dictated by user interaction (e.g., selecting a set-point), the usability of residential thermostat interfaces is critical [55]. Programmable heating systems have the added benefit of reducing energy consumption through set-point scheduling [46]. But due to poor interfaces and usability when it comes to the interaction in these systems, the programming features are not widely utilized [51, 12, 34, 46]. The lack of usability is a weakness in the user experience of advanced thermostats because usability is among the most frequent complaints about them [46], these complaints include misconceptions about how the thermostat behaves and energy use. Meier [35, 34] strengthens this by stating that the low usability in these complicated systems are partly an effect of users having a low understanding of how their systems operate. These user misconceptions and missing knowledge are particularly important since they may encourage incorrect usage that cannot easily be overcome by better flow in the interface alone [46]. Hence, supporting users mental models of system behaviour need to be considered a critical part of designing the interface and providing a good user experience of heating system thermostats.

From this problem, the research question was formulated:

What design considerations are important in regards to support users' mental model, when designing the UX of a floor heating system?

1.3 Aim and deliverables

The aim for this project is to answer the research question, by learning about users' understanding, behaviour and preferences regarding floor heating control. The goal is to utilize this information and through the design process, develop a thermostat and application UI prototype with good usability, by providing a conceptual model that aids the user. The objective of this is to help users understand what the system is currently doing, as well as utilizing the device features and schedule heating according to their motivations.

The project should contribute with knowledge that can both benefit the company that the project is being done at, with a better understanding of the domain and pain points. Along with possible solutions in the form of design considerations and exemplifying UI prototypes.

In relation to developing pervasive technology in home environments, another goal is to consider calm technology principles to keep the guidelines for solutions non-intrusive and socially sustainable in regards to well being and attention conservation.

The project should also contribute with research on users' behaviour when it comes to floor heating. But also to contribute with knowledge on how to support users' in forming a suitable mental model of residential floor heating through user interfaces. The deliverables to reach these aims are guidelines to consider when designing a usable heating system UI that aims to form an appropriate mental model for the user.

1.4 Delimitations

The project will focus on radiant floor heating due to the primary considerations of the company. This will be taken into account in a general manner in relation to perceived temperature and thermal comfort. However, the project will not be going in to depth regarding the effect different floor types, installation depth and room volumes have on system performance and perceived comfort due to the complexity of the subject.

The project will also direct the research towards residential heating for thermal comfort in the home where affected environment sensing is possible. There are situations where the device is installed in other locations than the specific area that is regulated by the system. These cases affect the sensory possibilities in the regulated environment. It will not research applications for heating up paths, garages and similar.

The technicians that install the product should be considered stakeholders, as it's not a system that is usually installed by the same people who then use it. However, it was decided to keep this stakeholder out of the scope to make the project more narrow in focus and due to time limitations.

The project exploration is limited by predetermined hardware. A preliminary version of a touch display combined with limited processing power limits the ways of interaction in the interface, swiping interactions will not be used in order to provide a good UX. Furthermore, the processing power and memory in the prototype affects the amounts of animations and colors possible to implement.

1.5 Ethical considerations

A consideration about ethical issues that may arise in the project: One of the potential ethical issues regarding the user studies that will be conducted is the collection of personal data. The study will have to ask for consent for the collection of the data along with assuring that the data itself is stored in a secure place.

The study will have to take into consideration the representation of users, as the product might skew the representation as it's something that not every home has and that it is a costly procedure to implement. Within representation, it's also of importance to consider age, housing conditions and gender besides socio-economic factors.

An ethical sustainability issue more related to the actual contribution of the research is the support for developing a product that drives out old products that might still be functional. Although the product is seen as one that owners can keep for years or even decades, the risk of it replacing current functional devices still remains, since thermostat replacement is seen as one of the least invasive and inexpensive measures for improving building performance [55].

Having a home with smart devices also increases the vulnerability for malicious actors that can pose a threat to home users' privacy, security and safety [48]. Depending on the devices in a smart home, the systems might collect data about residents' lifestyles, such as movement, energy use, and purchase preferences, in order to support them effectively. Furthermore, another aspect would be context based automation. If you provide settings for home, away and sleep context for example. The user provides information about their occupancy and activities during the days or even when they are on vacation. Consequently, this can translate into a feeling of being monitored, a fear that their personal data can be leaked and ultimately a distrust which prevents people from using an application [48].

However, vulnerability in such systems does not only have to regard external actors, it could also be found within home or the system users. Occupancy based smart devices have the ability to locate your position and perform actions accordingly. Having functions that react to your behavior or the anticipation of your behavior can easily be identified by users within the same system or home. Examples of this could be smart light fixtures that turn on the lights to your driveway when you are headed home or a thermostat that turns up the heat as a result of your doings. These types of functions are reliant on information about you that in many cases can be identified by other users in your system or surrounding, without you necessarily actively noticing.

Another ethical aspect in general with designing for usability by providing conceptual models is creating an image of a system that is less than completely true to how the system works. This can be seen as manipulating the user to believe something that doesn't represent the true nature of a system.

2
Background

This chapter aims to highlight the thesis background within smart home technology and residential heating, more specifically radiant floor heating and its controls. The chapter then brings up related work that has been done within the domain of thermostats and their usability along with how control is perceived within smart technology and research on modern solutions.

2.1 Smart home technology

Appliances in a traditional home are operated separately and locally, each device is controlled by pushing buttons or flipping switches. However, through *ubiquitous computing*; pervasive computing technology that is integrated into our everyday environment, the "smart home" concept has received considerable attention the last decade [60]. Aldrich [3] describes a smart home as a residence that is equipped with computing and information technology that responds to the user and its needs, with the goal of providing comfort, convenience, security and entertainment. The technology in a smart home facilitates interoperability between household devices and the automation of tasks, in a built "entity" [60]. The type of smart home technology on the market is big and offers a wide variety of products, everything from smart speakers to heating systems that are connected to the internet. Thus, a smart home is a place where the appliances not only conduct isolated tasks; but an ecosystem of interconnected devices that can function together.

In 2020, 12.5% of homes in Europe could be categorized as smart homes – for 2025, already 26.8% are expected [48]. Through the development of ubiquitous computing and its pervasive nature, we are now outnumbered by devices [10]. Most people in developed countries have multiple devices, from laptops and smartphones to smart heating systems and internet-connected speakers. We face information and calls for attention from technology in every aspect of our lives, which makes it vital to consider how smart home technology can be designed to integrate into people's lives. Most work in the smart technology area has focused on developing the utility and usefulness of products that enter the smart home market [29]. However, Weiser and Brown [58] promotes to also considering how ubiquitous technology can work to conserve and respect human attention, a vision coined "calm technology".

2.1.1 Perceived control in smart technology

The smart home vision continuously evolves as peoples' expectations of the smart home keep changing [36]. The adoption rate of smart technologies in both residential and commercial buildings is growing. The goal of this type of integrated technology is to provide more control and improve the lives of users [22]. However, smart system functionalities can easily cross invisible boundaries, and users feel that they are at the mercy of this technology rather than controlling it. An important goal of smart home research will be how to properly extend system functionality to create more control both perceptually and practically. Researchers often refer to control issues as one of end-user programming [22]. However, end-user programming, as is commonly believed, requires routine specificity and rigidity. This is incompatible with numerous ethnographic studies of organic, opportunistic, and improvised ways in which people build, maintain, and modify routines. Currently what can be observed is a discontinuity between the subtle lifestyles revealed by research and the smart homes that many engineers envision [22]. This suggests that relying on end-user programming of smart home systems ought to be readjusted to better reflect this complexity and allow people to keep control of their lives. What needs to be considered is peoples improvisation and spontaneity, and allow for flexibility in smart home technology [22].

Research has been done on perceived control and user preferences in applications that provide different levels of automatic contextual behaviour [5]. The study defined three levels of interaction between mobile devices and their users: personalization, passive context-awareness, and active context-awareness. Six services with the three defined variations of interactivity were investigated. According to the study, participants feel a lack of control when using a more autonomous interactivity approach, and context-aware computing comes with a degree of perceived monitoring. However, the conclusion was that users are willing to accept a large degree of autonomy from applications as long as the application‘s usefulness is greater than the cost of limited control [5]. However, in these types of situations a certain level of trust is needed. Symonds [54] suggests that access and intervention options should be considered for building trust.

2.1.2 Intelligent energy services

Intelligent energy systems that leverage machine learning techniques are becoming more prevalent and integrated in all aspects of our lives [2]. These systems sense information about their users, learn from this information, and exploit what they have learned to make decisions on their users' behalf. Occupancy based heating and smart metering to lower energy consumption are two examples of features that can be perceived limiting the control and affecting the privacy concern.

A study that utilized the research through design-approach aimed to more efficiently heat homes by using occupancy sensing and occupancy prediction to automatically control home heating [49]. The idea revolved around eliminating the need for manual user programming of a thermostat schedule, to improve the efficiency of home heating (i.e., improving the tradeoff achieved between energy use and time in which occupants are cold). The result, a service called PreHeat, senses current occupancy and utilizes historical data to estimate the probability of future occupancy. This allows the home to be heated only when necessary, without needing to program the thermostat, which raises the efficiency of heating and a more accurate use of energy in relation to thermal comfort.

2.2 Residential heating

A heating system is a mechanism that utilizes thermal energy to affect the temperature in an environment. The main function of residential heating systems is to maintain the temperature at an acceptable level in the house for the user, especially intended to provide thermal comfort. The majority of energy usage by households in the EU in 2019 was for heating their homes, 64% of final energy consumption in the residential sector [23].

2.2.1 Radiant floor heating

The principle of heating by radiant energy can be observed every day, the effect you feel from an active stovetop or the warming shine of the sun, being the most commonly observed examples. Radiant heating as a technology depends on utilizing the principles of heat radiation to transfer energy directly from a heat source to people or an object via infrared radiation [56]. Radiant heating systems generate heat that is transferred to the floor or to panels in the wall or ceiling of a house. When radiant heating is located in the floor, the heating elements are embedded under the floor surface, it is often called radiant floor heating or simply floor heating. The temperature change of floor heating is slow, since it is a high inertia system, meaning that it adjusts itself slowly to temperature changes [1]. There are three types of radiant floor heat; radiant air floors (air is the heat-carrying medium), hot water (hydronic) radiant floors, and electric radiant floors [56, 1].

The project mainly revolves around electric radiant floors, which have electric coils embedded under the flooring, this is usually an addition to other types of heating in a residence [1]. It is generally known as comfort underfloor heating, because of the more distinct warm feeling electrically heated floor gives. When underfloor heating is installed as comfort heating, it is likely to be left on in order to avoid cold floors, which results in higher energy consumption [1]. According to the Swedish Energy Agency, to achieve a comfortable room temperature of 20 degrees, the floor temperature need to be only 22 – 24 degrees C. But when the floor temperature is at 22 degrees C, it does not feel particularly warm to the soles of the feet [1].

2.2.2 Thermostats

Residential thermostats have played a key role in providing thermal comfort in homes since the late 1920s [55]. A thermostat allows users to regulate and set their desired temperature in a heating system. Hence, the usability of the thermostat interface is an important aspect to consider. Peffer et. al [46] explains the basic thermostat with four technical components; a temperature sensor in the desired environment, a switch or actuator to the physical target of heating equipment, a feedback loop between the two and some means of displaying the relevant temperatures. This combined provides the means for the user to control the temperature in an area that has a heating system installed.

Thermostats were originally simple manual electromechanical devices, from a user perspective they showed the current temperature, held a temperature setting dial and a power switch (fig. 2.1). The thermal comfort and energy consumption of households were heavily dependent on diligent adjustments of the occupants [55].

Figure 2.1: Manual thermostat - Honeywell Classic round [CC0]

Programmable and smart thermostats

Programmable thermostats (fig. 2.2, 2.3) succeeded the simple mechanical counterparts with a more modern feature - setpoint scheduling, which allows for more convenience and, in theory, greater energy savings without sacrificing comfort [46]. The setpoint scheduling of programmable thermostats allows the system to adjust the temperatures according to a pre-set time schedule. The users define the temperatures and schedule according to their personal preferences. The energy savings possibility implies that users set low temperatures at the times when not occupying a space, then raising it to comfort temperatures again at times they would use the space. This would result in the benefit of lower energy consumption without any discomfort [56]. Among the recent and modern devices, a large portion of programmable thermostats have built in network capabilities and use mobile applications that enable remote control. This would categorize them as smart devices. Some of these devices, such as the Nest learning thermostat 2.3 utilize machine learning for adapting the temperature based on the user's previous changes. Additionally it holds features for smart metering and geo-fencing, this enables them to automatically adjust the temperature in relation to current energy pricing and/or user location.

Figure 2.2: Touchscreen programmable thermostat [CC0]

Figure 2.3: Nest learning thermostat [CC0]

2.2.3 Thermostat usability

Smart functionality permeates modern home technology and one focus within the thermostat and heating systems domain has been to provide energy saving features to this energy costly system. A solution for this has been through the development of programmable thermostats, which theoretically can help to reduce energy consumption [45]. In contrast to traditional energy saving methods, such as temperature isolation in a fridge, programmable heating systems are dependent on the user to actively and correctly program the system themselves [46]. The users in this case have to both understand what settings result in a more efficient usage of the system, along with understanding how to conduct the tasks in the system and what effects it has.
Meier et. al. [34] found that the majority of occupants operate their thermostats manually rather than relying on the programming functions that are implemented. The study discusses that the reasoning for it is that many of the users are intimidated by the thermostats and have a fear of not being able to restore the original settings if done wrong [34]. The study suggests anecdotal evidence that thermostats are overly complex and that such complexity may exclude people from being able to use their controls effectively, therefore reducing the potential energy savings achievable [34]. Peffer et. al. argues that the reasoning for not utilizing the features of thermostats is that the users find it difficult to understand the heating systems and lack confidence and motivation to overcome the difficulties [46].

Research has pointed out that occupants feel frustrated when they interact with building interfaces and do not experience a change in their environment [15]. This is especially common in heating system controls, which is a complex system with a slow thermal response. The result is occupants perceiving that they have low control of the system. The research also points out that there is a lack of understanding how the heating system works, since a correlation was found between perceived control and an understanding of the system. The slow response of thermal systems can be countered with appropriate feedback and by proactively setting system behavior with programming features. But one of the primary barriers to use proactive settings is the complexity of feature-rich interfaces on thermostats [15]. According to

Combe and Harrison [12], manufacturers focus is to provide functionalities, rather than engaging with their users to create more usable systems and interfaces. It has been stated that there is a lack of design guidance within these types of systems [46] and users complaints has been related to the thermostats complexity, small buttons and text, having confusing terminology and symbols along with the number of steps needed to program the thermostat.

Peffer et. al. [45] looks further into how energy saving can be facilitated through the use of programmable thermostats, where the main focus lies within the user interface. The study compared and conducted usability studies on several different programmable interfaces, all used for heating, ventilation and air conditioning (HVAC) systems. Several of the analyzed interfaces were seen to be complicated and difficult for the user to understand leading to frustration and hardships for the user when trying to complete tasks [45]. The study suggests a list of relevant recommendations when designing interfaces for these systems:

- To include all important and often used actions at the home level; consider no covers or clearly provide affordances.
- Use a graphic tabular form to view the temperature setpoints for the time of day and day of week.
- When possible, include confirmation prompts (e.g. do you want to save?), or some other means of confirming when something is edited or changed.
- Use plain English wherever possible, no abbreviations and standard icons.
- Use clear affordances
- For touchscreens, buttons should look like and act like buttons

Manual thermostats provide a relatively simple and intuitive interface, but are limited by a reliance on consistent user adjustments. Programmable and smart thermostats allow users to automate setbacks, but they are often complex, overwhelming, hindering involvement, and ultimately sacrificing potential energy savings. In a study comparing manual, programmable and smart thermostats by Tamas et. al. [55], they found that the interfaces do not provide adequate support for users. However, smart thermostats performed better than regular programmable devices in usability testing. An overall highlight was that users desire more feedback from the interfaces and want to be able to remote control their thermostats.

Newer studies show that some implementations of programmable thermostat interfaces have shown to be more successful in setting up schedules. The modern smart thermostats have in particular been connected to interfaces that have remote or cloud-based options for scheduling setups and therefore offer various interfaces that allow users to set schedules via computer interfaces and apps instead [47, 28]. These connected systems are able to provide flexible interface designs, offer a higher degree of usability and more aesthetically pleasing interfaces.

3

Theory

This chapter in the report covers the relevant theories used in this project. The chapter starts with a short introduction of user interfaces, then continues with usability and dives deeper into theories within usability forms the baseline theory when designing a usable interface. It continues with a description on calm technology and its principles. The chapter ends with its focus on conceptual models and relevant elements along with mental models which are central for interaction between users and technical systems.

3.1 User Experience

User Experience design could be seen as a process that enables design teams to create products and services that provide a meaningful and useful experience to the user [17]. User Experience is an approach that is centered around the users and aims to design for humans [17]. A User experience process includes various important subsets such as user interfaces and usability among others. Products and designs that provide good user experience are not only concerned with being usable, but rather the product being efficient, fun and pleasurable as well [17].

3.1.1 User-Interface

A user interface can be defined as the connection in a cyclical feed of information between human and computer [7]. Figure 3.1 shows an illustration of what interaction between human and technology looks like, when a user interface allows for an exchange of information. It enables a contextual interplay in which users perform actions and reach a predefined goal. The sensor in figure 3.1 can for example be thought of as a touch screen and the actuator a display, the user interface allows for the communication.

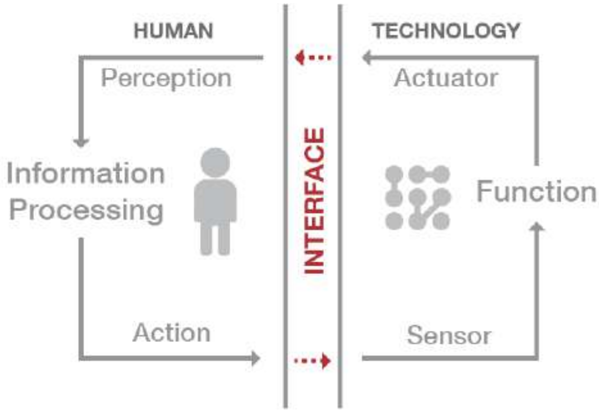

Figure 3.1: Feedback loop of interaction between human and technology through an interface

3.1.2 Usability

Creating a product that possesses features and functionality that can not be utilized by its users is a scenario that neither the manufacturer or the user strives towards. The development and design of a product can through usability approaches prevent such a scenario. The international standard on ergonomics of human-system interaction, ISO 9241-210 has defined usability as "Extent to which a system, product or service can be used by specified users to achieve specific goals with effectiveness, efficiency and satisfaction in a specified context of use" [24].

Usability is described by Nielsen [38] as a quality attribute that determines how easy an interface is for a user to use. The attribute of usability further be divided into five sub-attributes that more specifically describe different quality components: learnability, efficiency, memorability, errors and satisfaction. These attributes in combination with utility, that describes a product's function, can together create a product that is useful for the user [38].

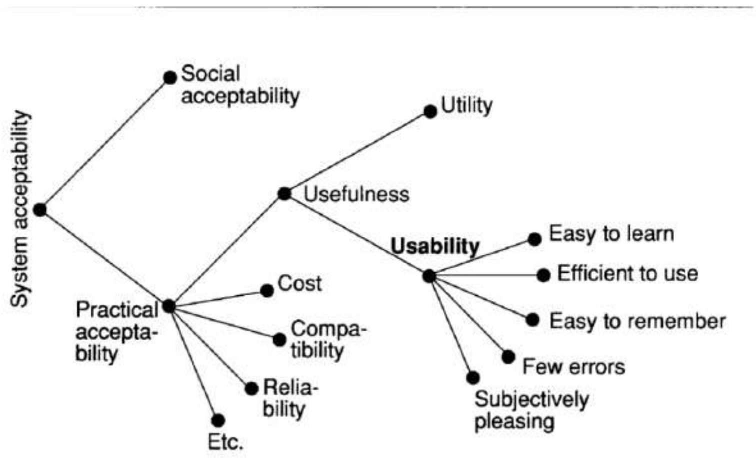

Figure 3.2: Attributes of systems acceptability
[39]

The five quality components of usability can be summarized to be:

- The *Learnability* of a product refers to how easy the user can learn to accomplish basic tasks when encountering a system or design for the first time.

- *Efficiency* refers to how quickly users can perform tasks once they have gotten familiarized with a design

- *Memorability* allude to how easily a user can reestablish proficiency after returning to a design after a longer period of not using it.

- *Errors* as a quality looks at three aspects, the amount of errors a user makes, how severe they are and how easily they can recover from those errors.

- *Satisfaction* is a subjective view on how pleasant the design is to use.

3.2 Usability heuristics

Nielsen describes 10 general principles that can be used as usability heuristics when designing an user interface [40]. The heuristics can be used as a tool for measurement when evaluating user interfaces and also contribute to a fast and practical way to solve problems or make decisions during the design process. The 10 heuristics that Nielsen describe are:

1. Visibility of system status: The design should give the correct feedback and have the users informed of what is going on.
2. Match between system and the real world: The design should not use complicated and internal jargon but instead use the language that the user knows and speaks.
3. User control and freedom: Users should be able to move freely in the design even when having a mistake done. Support functions such as Undo and Redo.
4. Consistency and standards: The design itself should follow the platform consistency such with wording and icons.
5. Error prevention: Minimize the possibility for errors in the system by removing error-prone conditions or confirmation options before committing to the action.
6. Recognition rather than recall: Minimize the need for users to have to remember and instead make actions, objects, and options visible.
7. Flexibility and efficiency of use: Allow users to tailor the design for their own needs, taking into account the needs for novice respective expert users.
8. Aesthetic and minimalist design: Do not overload users with information in dialogues as it competes with the information that is relevant.
9. Help users recognize, diagnose, and recover from errors: Precisely define problems and describe errors in the users language and constructively suggest a possible solution.
10. Help and documentation: The best system is the one that does not need documentation, but it may be needed to provide the user with help and doc-

umentation. In this case, the documentation should focus on the tasks done by the users and list specific steps that can be carried out.

3.2.1 Affordance & Signifiers

Having clear affordances in a design are vital to its usability. Donald Norman in his book *The design of everyday things* describes the term affordance, [44] which he defines as "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used.". In other words, the affordance of a thing or a product could be seen as what the object invites the user to do with it. A typical example of affordance can be seen in our everyday life, a door that needs to be pushed open with a metal bar for a handle. The metal bar has such a correct shape and placement to be grasped by a hand. The door in this case affords for the user to pull it, and no matter how often someone uses such a door, the person will find itself pulling the door from time to time as the affordance can be a stronger influence than the signs that says Push [13].

Affordances are a way to determine what actions are possible while signifiers communicate where the action should take place [44]. A good interaction design is needed for both. Interaction when working with graphical designs on electronic displays can sometimes be done through several ways. How do you know where to touch, tap, slide upwards, downwards or sideways? Are the actions done through a mouse, your fingers or something else? Users are in some way in need of understanding the product or service that is being used. They need some kind of sign of how to do an action and the results that will follow, this is where signifiers can be a solution [44]. A common use of signifiers that you probably have in front of you is the scroll bar on the right side of the screen, indicating that the page is vertically scrollable. The existing signifiers have to be perceivable for the user, else they fail to function its purpose [44].

3.2.2 Feedback

Feedback is a system's way of communicating the results of an action done by the user [44]. The feedback of a system is of importance for the user to have a good understanding of what the user is doing, what the user has done and what it has resulted in. It is something that should be planned and prioritized, so that unimportant information is presented in an unobtrusive way, while important information captures your attention [13]. Feedback can take shape in several ways and can be found in everything from a confirmation text when sending an email to the whistling of a boiling kettle.

A type of feedback that requires no special action or mode shift on the user's part to view is described by Cooper in his book *About face* as modeless feedback[13]. Modeless feedback is a way for designers to give subtle unobtrusive status information, which enables the users to get constant feedback which good design is in the need of [13].

Within the category of modeless feedback there is a more specific type of feedback, Rich visual modeless feedback. This type of feedback aims at providing the users with in-depth information (rich) about the status or attributes of a process in a system through idiomatic use of pixels on a screen (visual) [13]. This type of feedback can be seen in most popular applications today. It can for example be seen in the word counter in Microsoft Word which gives discrete feedback of the word count status of the document, without any user action.

3.2.3 Mapping

Mapping is a term that is borrowed from mathematics, meaning the relationship between two or more objects and their elements [44]. A way of describing what mapping is in practice could be done by supposing that you have several ceiling lights in a room with a long row of buttons that control each light. The mapping would in this case specify which switch that is connected to which light. Without a good mapping of it, the task of switching on or off the correct light becomes much harder. Norman shows a solution that utilizes a good mapping for this issue in *The design of everyday things*, which he calls floor plan light switch [44]. The mapping for the switches are placed on a miniature floor plan, where the lights placement in the room is represented with a switch on the miniature floor plan, which can be seen in figure 3.3.

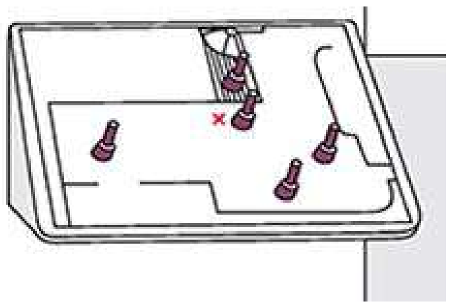

Figure 3.3: Don Norman's mapping example of a floor plan light switch [44]

3.3 Calm technology

Weiser and Brown [58] define the development of Human Computer Interaction (HCI) in three major waves: First, the era of mainframe computing, where one terminal is used by many people. The second wave is known as the era of the personal computer. One person uses one computer. Third wave is what we are going through right now. With the development of ubiquitous computing, the need for a more unobtrusive way to compute arouse as well.

Amber Case [10] suggests that pervasive technology for homes, a place for calm and comfort, should be considerate to not interrupt and agitate. Designers and developers should rather work towards creating time and space for people to reflect and breathe. Residential floor heating systems are a part of the home technology that involves constant peripheral information, it augments the temperature in a room which can be sensed through one's feet and body, as well as visual information through a thermostat interface. Case [10] describes that ideally, technology allows people to shift their attention for a second, get the information we need, and shift back, letting us attend to more things in our environment without being overwhelmed. Designing for calm technology can be a solution for that need. Amber Case [10] describes calm technology as a type of non-intrusive design. She describes it through a range of principles that should be taken in to consideration when designing pervasive technology, with a calm and peripheral aim in mind.

The principles for designing Calm technology are the following:

- Technology should require the smallest possible amount of attention.
- Technology should inform and create calm.
- Technology should make use of the periphery.
- Technology should amplify the best of technology and the best of humanity.
- Technology can communicate, but doesn't need to speak.
- Technology should work even when it fails.
- The right amount of technology is the minimum needed to solve the problem.
- Technology should respect social norms.

The principles revolve around three key considerations: attention, reliability, and context. It is a set of values that, when considered properly, inform decision making. The principles together aim for the design of devices that do not take us out of our environment, but rather minimizes the technological friction in our lives. Furthermore, they help us consider what is absolutely necessary to communicate and what is not [8]. While good design gets users to reach their goal with the fewest steps, the principles of calm technology allows us to reach it with the lowest mental cost [10].

Calm communication patterns:

- Visual status indicators
- Ambient awareness
- Contextual notifications
- Persuasive technology

An example of *visual status indicators* are status lights and status bars, it is one of the calmest ways of conveying a piece of information [10]. It's also the lowest resolution of all status indicators—at its simplest - on/off or working/done. They are ideal for communicating low-importance and persistent information.

Ambient awareness means making use of peripheral information, we receive queues from the environment that allows you to know something without needing to actively investigate [10]. For example, it can be a visual indicator outside of the center field of view, a subtle sound or feeling the cold or heat in a room.

3.4 Cognitive processes

Humans pay attention, process, make decisions and respond to the environment that is taken in via the senses. Because our cognitive capacity is limited, simplifications are used to reduce the mental strain [7, 59]. Our information processing and the mutual relationship of the content can be explained with a model by Wickens [59] (fig. 3.4). The parts represent, among other things, sensory intake, perception, different types of memory and response. By separating these parts gives a schematic picture of human abilities and limitations in the interaction with an interface.

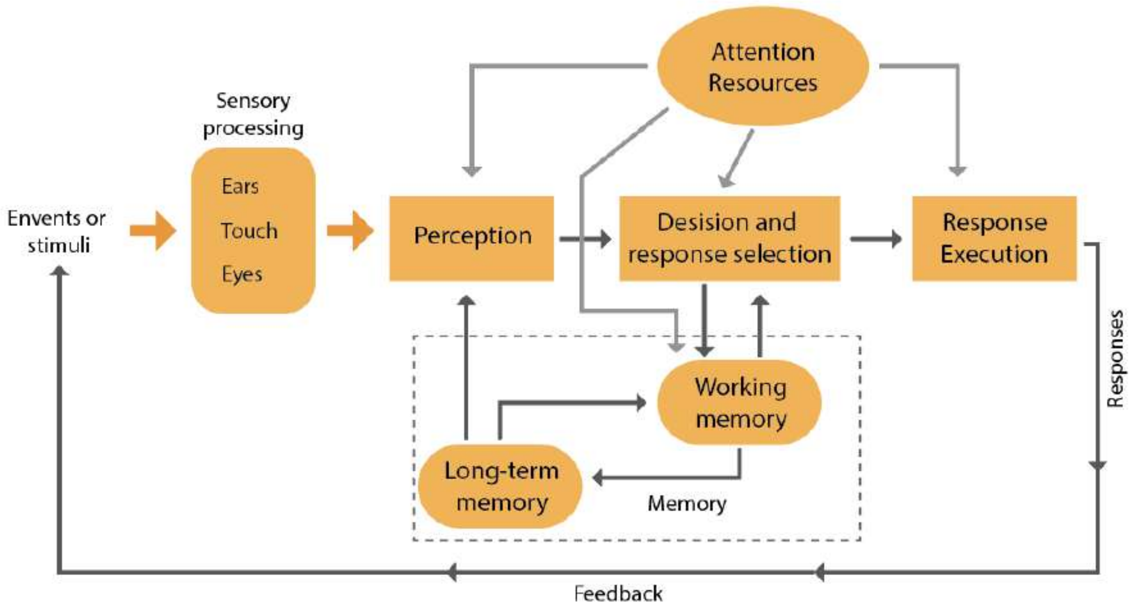

Figure 3.4: Wickens model of cognitive processing [authors own image] (Original illustration found in [7] p.358)

The process takes place in parallel and in series as new information is picked up while processing previous data [59]. Because human experiences and deduction skill plays a major role in decision making, we have an ability to make correct decisions even in cases where the information is of low quality [7].

Data-driven processing (bottom-up) depends on what physical stimuli are available, its quality and the senses status [59, 7]. This is an automated and unconscious process. An analysis is made of stimuli without adding additional information. In this type of process, disability can occur create a deterioration of the processing.

What is detected by the senses is also greatly affected by context-driven processing (top-down), which is about what knowledge and experience man has from before, as well as expectation of the current situation [7, 59]. The process begins at a higher level of consciousness and touches towards a more unconscious level. This process is active. Using context-driven processing, man can fill in incomplete information with meaningful data in context, based on prior knowledge [7].

3.5 Mental model

Mental models are a way to get an understanding of people's motivations and thought processes [61]. Understanding what mental models are can in some cases also help to clarify certain usability problems found in products [41]. Nielsen defines mental models as *what the user believes about the system at hand* [41]. It is a model of what users know or what they think they know and is based on beliefs rather than facts [41]. Each individual's mental model of a product or an interface is different and can in some cases create a gap between designers and the end users. The designers can not rely on their own mental model due to experience or knowledge gaps but rather have to look more deeply into the mental models of their users[41].

The actions and interactions users have with a product can rely on their mental model [41]. When mistakes are made by the user interacting with the product, it is often dependent on their mental model not being aligned with the designers. In these cases, Nielsen describes two options, the first one being to design the system and product to conform to the users mental model and the second one being to improve the users mental model to be aligned with the system [41].

3.6 Conceptual model

Norman describes conceptual models to be an explanation that usually highly simplifies how something works [44]. The explanation does not have to be accurate or complete as long it is useful [44]. A good conceptual model can in some instances create a better mental model for the user of the used product or service. A way for designers to leverage this is by introducing the user to functionality by effectively using signifiers, interactive tours or onboarding to align the mental model to the system [6]. A conceptual model that Norman depicts is the one of files and folders icons on your computer. It can help to create the conceptual model of files and folders in your computer when in fact there are no folders inside but rather more technical and complex than that.

3.6.1 Semantics

Semiotics is the study of signs while Semantics is the study of their meaning [53]. Applied to design, Sunde describes the product to be the sign, and it concerns how designers encode meaning into their products that communicates with the user [53].

Mönö [37] further defines the functions of product semantics to be:

- To describe its purpose and mode of operation.

- To express its properties and characteristics.
- To exhort reactions from the user.

All products or objects are designed to have a purpose or some kind of meaning, that has the goal to be communicated to its user [53]. Product semantics are a way to describe this type of communication and for designers it can be used as a tool in order to provide a better understanding of its utility.

3.6.2 Metaphors

Metaphors are considered to be a central component of a conceptual model [50]. Metaphors rely on real world connections that users make between the visual cues that can be found in an interface and the function that it has [13]. Metaphors in the context of user interface and interaction design are meant as visual metaphors that have the goal of signaling a specific function or feature [13]. In practice, metaphors could be exemplified as a pair of scissors on an icon, indicating a cut function.

3.6.3 Microcopy

Microcopy in an interface are short sentences or naming that tell users what to do and addresses user concerns and can provide context to a situation [32]. The microcopy can in turn lead to powerful hints that help users to map the action and to anticipate the future outcome.

4
Methodology

This chapter provides a description of the relevant frameworks and methods that will be used during the project. The chapter starts with describing the concept of design thinking, to then narrow down on the specifics. The overarching structure of the methodology will follow Jones' design process, which will further be described. The chapter continues with a section on what individual methods will be used within the different design phases.

4.1 Design process

This study will primarily address the design problems by using Jones model of design as a base for the iterative work. Jones describes his design process through the phases *divergence, transform and convergence* [30]. Similarities to this process can be found in various other design processes. The design process in general can be described as an iterative process that contains different phases or activities [13, 44, 50]. Preece et. al. [50] describes their design process with a Double Diamond structure of diverging and converging, with four different phases consisting of *discover, define, develop and deliver*. Hartson and Pyla [27] describes an iterative four phase design process as well, where the phases are *analyze, design, prototype and evaluate.*

4.2 Divergence

In Divergence the divergence phase the goals are to broaden the knowledge base and understanding of the domain and problem that the researcher faces. This phase is research heavy and in practice has the goal to gather new data for the upcoming phases [30].

4.2.1 Literature review

Conducting a literature review is a research method that is an essential part when writing academic papers within all research disciplines and research projects [52]. A literature review is intended to filter information from different published sources, with the goal of capturing the essence from the previous research to inform the current project [26]. The method is a useful approach for researchers to get a better understanding of a domain and an overview of the research area and the possible gaps in the research [52]. This makes the method appropriate to conduct early on in the design process, as it can lay a strong foundation for the background and the theory of the project.

The challenge with literature reviews is finding the right keywords for searching, as a sufficient amount of relevant research might be hard to find. Furthermore, identifying a research gap also suggests that enough literature needs to be reviewed, therefore the keywords used in the search are particularly important in the method.

4.2.2 Competitive analysis

Performing a competitive analysis is one of the earliest research steps in the UX design process [14]. This purpose of the analysis is to gain knowledge on; Who is currently trying to solve this problem, how they are doing it and what the main differentiators in the products are. Using this in the start of the design process can help inform the design process and to learn strengths and weaknesses of current solutions and understand where your solution would stand in the market [21].

Douglas [21] describes that the competitive analysis includes:

- Understanding your goal - Create a short list of main comparison criteria before starting. This will keep the research guided [14].
- Really know your competition - This is when the method starts to form a table of information, Douglas [21] suggests that a good number at the beginning stage is around 5-10 direct and indirect competitors, so that it is easy to maintain and track what the competition is doing.
- Look for commonalities among competitors - In the process of looking at commonalities, it is a good idea to write down the actions users can perform.
- Analyze - When analyzing the UX research, a summary should be created of what was found as well as what impact the information will have. This stage helps identifying design opportunities because of a gained knowledge of flaws in other solutions [21].

There are considerations that should be kept in mind during the analysis. A common error when conducting a UX competitor analysis is producing a never-ending list of market solutions [14]. This can result in you drowning in information without any insights. The goal definitions from the start can help prevent this. Lucas highlights a limitation of the analysis; you might be able to surpass your competitors by copying the findings, but it does not give you information to really innovate [31]. The design findings in the research should serve as an inspiration and adapted to fit your product and users. One should not assume that the competitor solutions have come from the best practices.

4.2.3 Site-mapping

Sitemaps are a structured representation of content in a system and the primary goal of creating sitemaps is to create better information architecture [4]. Developers use sitemaps to define the taxonomy through the grouping of related content. There are two types of sitemaps - visual ones representing the content organization and coded ones by creating a list in XML (fig. 4.1). The visual sitemap often shows a hierarchical view of the relations between pages to help identify where content sits and show the relationship between different pages. Creating a sitemap consists of connecting blocks or images of content with lines [4]. The sitemap should include a main view and subviews. Although a site-map in many cases can simplify and give the reader a quick overview of the system, when done in larger or several systems it is a time consuming method and requires the researchers to have access to an entire system.

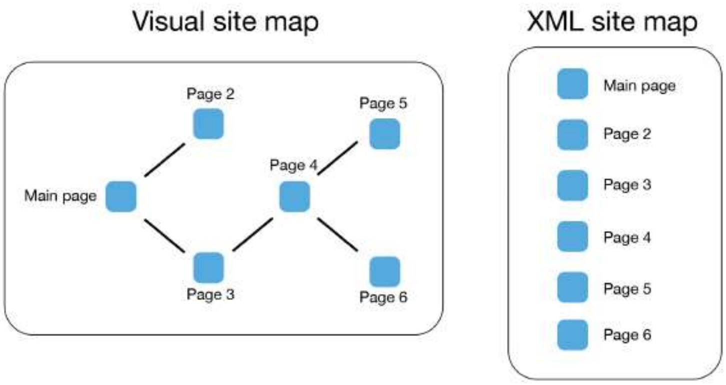

Figure 4.1: Illustrating example of visual sitemap and XML sitemap. [Authors own image.]

4.2.4 Cognitive walkthrough

The cognitive walkthrough method is used to inspect and evaluate the usability of a system [26]. It is used in situations where a person has to actively engage with a system interface to know what actions to do without preexisting experience or knowledge, to assess each step of the interaction to move the user closer to the goal [26]. The method can provide a systematic way to find specific pain points in the interaction sequence [26]. The result of resolving these potential pain points is an interface that is considered more usable and more learnable.

This method is well suited for evaluating systems in various phases of the design process as it for example can be applied to competitors in an early phase and it can be a way to evaluate low and high fidelity prototypes. The method can in practice be done by having a usability expert perform the cognitive walkthrough by looking at it from a user's point of view, while conducting specific tasks in a system. The evaluator then asks the same four learning theory-based questions for each step in the action done.

- Will users want to produce whatever effect the action has?
- Will users see the control for the action?
- Once users find the control, will they recognize that it will produce the effect that they want?
- After the action is taken, will users understand the feedback they get, so they

can confidently continue on to the next action?

Although the method is good for investigating and finding general usability problems, it is also one of the disadvantages with the method. It is not well suited for more complex and in depth issues in an interface, to analyze those factors, other methods such as usability testing are more appropriate.

4.2.5 Questionnaire

Questionnaires is a quantitative method that relies on self-report information from about their thoughts, feelings, perceptions, behaviors, or attitudes, which is typically in written or numerical form [26]. The method is good and simple to produce and administer but has drawbacks that the result is easily affected by factors such as question wording along with response options of various kinds, which makes these factors that should be paid attention too [26]. Questionnaires are also a great way of reaching participants that are not local. By creating digital questionnaires that can be spread online, the reach and participants gathering can be efficiently conducted, saving both time and resources for the researchers.

4.2.6 Interviews

Interviews is a qualitative data gathering method that can be used to gather data on motivations, thoughts, feelings and attitudes [26]. Interviews can in some cases be structured in a way that the interviewer does not deviate from the script of questions [26]. This approach makes it easier to compare results with each other. The interviews can also be more or less unstructured, but researchers typically have a guiding set of topics or questions that they follow [26]. This method approach has the advantage of being more comfortable for the participant and more like a conversation [26]. It is of importance to be reminded that the less structured approach can lead to data that is harder to analyze. A challenge with interviewing is asking the right questions in order to gain the most valuable insights, this is where preparation and semi-structured interviews form a strong base.

4.3 Transformation

The Transformation phase shifts the effort from collecting data and information to synthesizing it, revealing patterns and other findings that further define the problem space and potential solutions. Jones' describe the operative words for this phase to be eliminate, combine, simplify, transform and modify [30].

4.3.1 Affinity diagramming

Affinity diagramming is a method used to externalize observations and insights that are found in research while also meaningfully cluster them [26]. It can be used to categorize and sort qualitative data resulting from an interview or other types of user studies. It can be done by writing down observations or quotes from the studies on post it notes, that are color coded by each participant in the study [26]. The post it notes can then be grouped and clustered based on affinity to give the researchers a good overview of the data and forms into research based themes [33]. The method results in a bottom up approach where the data itself is the basis for the themes rather than having set themes that the data is categorized into [33]. A challenge in affinity diagramming is keeping the objectivity, as the data is interpreted and sorted through subjective perception. Affinity diagrams are a fitting method to use in the middle and later parts of a design process as a prerequisite to conduct the method is that the researchers have data to analyze.

4.3.2 Behavioral archetypes

Behavioral archetypes are a type of structured models of customers and users' response to a brand [20]. The method, as the name might suggest, taps into the behavior level of users cognitive processing. The focus is on who does what, how and why they do it [20]. Compared to the method persona that represents an individual person which can carry quite a lot of subjectivity, behavior archetypes instead represent a typical user and its behavior and motivations.

When conducting the method, the archetypes fall into two categories[20]: Mindsets, that are the existing mindsets prior to engagement with a brand. These are usually linked to users' interests and drive their decision to buy from a certain brand [20]. States are developed throughout an experience with a brand or product and can change depending on the quality of interaction they have, which through time will determine the users loyalty for the brand or product [20].

4.3.3 How might we

How might we (HMW) is a method that enables researchers to think outside their own pet solutions which in some instances have little resemblance to the actual problem that is trying to be solved [42]. HMW is used as an ideation method by researchers through questioning the problem through how might we questions. This can lead to being able to frame and define the problem while also generating lots of creative ideas [42]. This makes the method very suitable in the end of a discovery phase, in order to gather and set the design problems that the team faces.

It can seem quite straightforward to write HMW questions, but there is more than meets the eye and it can be challenging to formulate the question for them to be useful. Nielsen describes 5 different tips when creating the questions [42]:

1. Start with the problems uncovered.
2. Avoid suggesting solutions.
3. Keep the HMW Broad.
4. Focus the HMW on the desired outcome.
5. Phrase the HMW questions positively.

These tips are a good way to ensure that your questions are of correct scope and formulation. An example of a poor HMW question would be *"HMW make the return process less difficult?"*. A better formulated version would be *"HMW make the return process quick and intuitive?"*.

4.3.4 Brainstorm

Brainstorming is a method that is primarily used in the ideation phase of a project. It is a method used by design teams in order to generate ideas in order to solve specific and defined design problems [16]. The method enables researchers to approach the problem in a free thinking environment with controlled conditions [25]. When conducting a brainstorm it is of importance to be open minded and not challenge ideas too much as it can hinder comfort and creativity within the team [25]. The ideas generated can be out of reach in practice but can in turn spark possible solutions within the team. The brainstorming session should approximately be around one hour, where the interesting ideas are noted and saved for the upcoming phases [25].

4.3.5 Crazy 8

Crazy 8's is a design sprint method that has the goal of generating multiple outside the box ideas in a short manner of time in order to push beyond the first idea you have [19]. The method is used through initiating the session by setting a design problem or a defined question that the ideas are supposed to revolve around. When done, each participant folds a sheet of paper three times in order to create eight squares. Each participant then has 8 minutes to draw 8 different ideas on the topic, one idea in each square. The ideas themselves do not have to be practical or even feasible and can be "crazy" as the name suggests. When the eight minutes have passed, each participant presents their generated ideas. The team now has several ideas that are then discussed. As the ideas can vary in feasibility and practicality, the discussions afterwards should consider what takeaways that are usable for the project moving forward.

4.3.6 Flow chart

Flow charts are a graphic means of documenting how operations and functions in a system are connected [11]. Flow charts are a way for designers to understand the structure and overarching architecture of a part of a system. When producing a flow chart a start and a finish is often predefined to clarify the procedure. Its pictorial means also serve as a way to communicate the architecture in between project members or stakeholders with other domain backgrounds. The flow charts can also be used to study a process for potential improvements or documenting a process [11].

Flow charts can be done in several different languages or syntax's depending on the purpose of the flow chart and the area it is set to model. Many modeling languages have parts of their syntax in common but are differentiated by certain functions specific to the language. Some of the common modeling languages that can be found today are BPMN (business process modeling notation) [9], Swim lane diagrams and Use case diagrams, which are all languages in order to model processes of different sorts.

4.4 Convergence

At this stage in the process the problem has been defined, the variables have been identified and the right objectives have been agreed [30]. The Convergence phase now aims to focus on reaching the goals and to narrow down the possible solutions that are implemented into one final design.

4.4.1 Wireframing

Wireframes is a process that can help entire teams and the stakeholders to ideate towards an effective and user centered prototype or product [18]. It is a process where researchers and designers draw overviews of interactive products and interfaces to establish how the flow and structure can look through different design solutions [18]. These drawings can be done both on paper or digitally and is a way of marking out the bare boned solution that includes navigation and more detail than regular sketches does. By creating lean interface layouts, the designers and its stakeholders are able to cost and time effectively determine if concepts are worth further development [18].

4.4.2 Parallel prototyping

Parallel prototyping is a method that considers a range of potential design solutions and ideas that are designed in parallel before selecting and refining one specific design [33]. This method enables researchers to broaden their approach and encourages them to experiment and investigate a wider range or possible opportunity within the design space [33]. The method is conducted by having the designers create a range of low fidelity prototypes that can then be evaluated and tested by end users or through a heuristic evaluation by experts. The goal with these tests is to find what attributes are most preferred and not to pick the "best" prototype [33]. The evaluations should contribute to the designers reflection on individual elements in the design and their intended goal through the reaction of the users evaluations [33].

4.4.3 Heuristic Evaluation

A heuristic evaluation is a usability inspection method that is conducted by an expert with an agreed-upon set of best practices for usability. A good start of heuristics The method can help identifying problems before actual users are used to evaluate the design, which can be time and in some cases cost effective [33]. Heuristic evaluation can contribute to detecting the baseline usability issues that should be done before user tests [33]. The method is well suited for the early and middle phases of the design process when evaluating early prototypes are relevant and can bring a lot of value [33]. It can also be done in later stages although user evaluations might be of more value then.

4.4.4 Usability testing

Usability testing is a way to seek empirical evidence regarding how the usability of an interface design can be improved [33]. It is a method that allows designers to observe a user's experience with a digital interface as the person walks through a set of steps for a given task [33]. The test should be designed revolving around specific tasks and scenarios that are more commonly done and represent the end user's main goals. The scenarios main goal is to contextualize the task and provide any extra information needed to conduct and complete the given task [33]. And as the test shows the pain points and issues with the design, the researcher will get an understanding on how their internal evaluations differ compared to their typical end users [33]. The method is a good way to evaluate prototypes of various fidelity and can be a way to catch minor usability issues that can be individual.

Nielsen and Landauer [43] researched and concluded the saturation point in regards to the amount of users that effectively can help find new usability problems. The conclusion is presented in figure 4.2 which illustrates the amount of participants that corresponds with the percentage of identified unique usability problems. The analysis concludes that, in order to capture 85 percent of the issues, five participants are enough to recruit. Furthermore, it is acknowledged that involving more participants might risk finding the same problems and becoming more costly than productive.

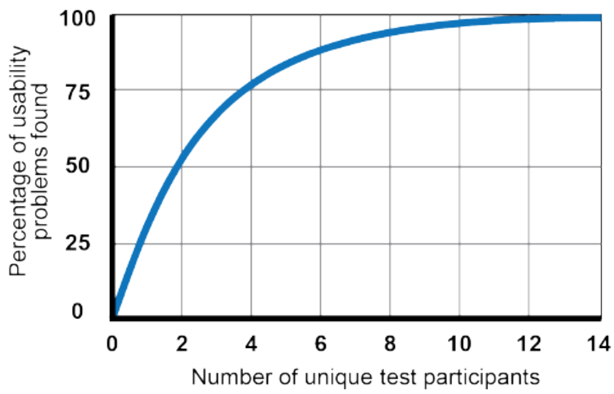

Figure 4.2: Graph illustrating corresponding test participants to percentage of identified usability problems. Author's own image. (Original graph and data found in [43] p. 209)

4.4.5 A/B testing

A/B testing is a method that allows you to compare two different versions of the same product or a design. The method is done in order to get an understanding of which one gets you closer to your goals by comparing the testing results from the different versions [33]. The method will not help you understand why a certain design is more preferred over the other and is a replacement method for other qualitative methods that are able to assess users' attitudes and needs. A/B testing is done by randomly assigning different people along two paths of designs, an A-test and a B-test [33]. The two test results are then compared to each other resulting in one being more preferable when aiming towards reaching the design goals.

4.4.6 Think-aloud

Think-aloud is a method used to reveal aspects and elements of an interface that delight, confuse or frustrate the users [33]. The method is one of the most common evaluation methods and has a straightforward procedure [33]. The method is done by giving participants a set of tasks that should be done. The set of tasks should be common day to day tasks or tasks done to achieve a common goal. The participants are then encouraged to verbalize what they are doing, feeling and the thoughts they are having when completing the tasks in a system [33]. The focus during the test should lie on what is happening instead of why it is happening. The goal of the method should also be to evaluate certain aspects of the system that can be tested individually rather than the entire system [33].

5

Planning

The chapter gives a description on how the process during the project will look like and what the main aspects of it are. This chapter also contains a time plan on how the thesis will achieve the goals formulated in section 1 and 3.

5.1 Project initiation

Week 1-2 involves a project initiation phase, which consists of onboarding at the company, project planning, as well as a pre-study in order to refine the research question, problem area and scope. The weeks also include receiving relevant resources for the project.

5.2 The design process

Weeks 3-17 includes the design process consisting of three phases; Divergence, Transformation and Convergence. Each phase has an aim and a purpose that the plan takes into consideration that will be executed through different activities and design methods.

5.2.1 Divergence

The project will start off with gathering information from a **literature research** and a **competitive analysis** including performing **cognitive walkthroughs** of the current market solutions, then continue with **interviews** with floor heating users and technicians that install heating systems and thermostats. These are seen as key methods to get an *understanding of the domain* of floor heating and thermostats, as well as *acquiring a picture of the different users* understanding, usage and interactions with their heating systems and possibly connected mobile applications.

5.2.2 Transformation

The project will continue by *synthesizing the gathered information* through **affinity diagrams** and **behavioral archetypes** in order to understand motivations behind preferences, decisions and activities. This will result in initial **design requirements** to narrow down and focus the work in the **ideation** sessions for a thermostat and application user interface.

5.2.3 Convergence

Next stage is to *transform* the ideas from abstract concepts to actual **flow charts**, **wireframes** and multiple initial **prototypes** of interactive user interfaces that can be evaluated with **heuristic evaluations** and **usability tested** with users. The key aspect in the process of prototyping and user testing is the *iterations* within this stage. This aims to narrow down the spread of possible solutions, including shaping the hierarchy of the system and specific attributes of the interface. Furthermore, this stage aims to make it centered around the **design requirements**, which change along the prototypes throughout the iterative process.

Lastly, after iterating the **prototyping**, **evaluation**, **usability tests** and **A/B tests** to a stage where the considerations can be deemed *validated*, the final prototype and the design considerations will be as conforming as possible to support the aim and research question of the project. This will then shape the *final discussion and conclusions* from the entire process.

5.3 Report Writing

The report writing would be continuously executed during the whole project, with an initial plan of at least one day a week. In the beginning most writing will be to refine the background, theory and methods. Closer to the final weeks (ca 17-20) execution, result, conclusion and discussion will be written more intensely. Notes are taken after each method is completed in a Miro board, making sure that no details are lost during the process. The weeks around 20-22 will prepare and conduct the presentation of the thesis, as well as revising the report to its final version.

6
Process

The process chapter is structured around the design phases that the project has based its planning on. The first part of the chapter will diverge (6.1-6.7) and get a better understanding of the domain of heating systems and their users. It will then continue by transforming (6.8-6.14) the data and information collected into knowledge and concepts that are then converged (6.15-6.20) towards building and testing different solutions.

6.1 Literature review

The literature reviews (4.2.1) were conducted with the purpose of providing a well grounded theory for the project to be based on, and were carried out as an initiation of the project. The literature that has been gathered covered methods and theory within interaction design along with literature more related to the specific domain of smart homes, calm technology and heating system usability.

The result was 24 papers, which was deemed sufficient to shape the theory and sources needed to carry out the project. The literature for the review was obtained from various sources accessed through Google scholar, Chalmers library and ResearchGate. Other web based sources (interactiondesign.org and nngroup.com) along with books have also been used as resources for the literature review. In some cases the authors have also been searching for keywords related to the domain through the use of Google scholar in order to find related research and work. Some of the keywords that have been used to find related works have been *smart home technology, pervasive technology, ubiquitous computing, calm technology, floor heating, thermostat usability, programmable thermostats, heating system interface, heating system human computer interaction and domestic heating systems.*

Among other things, the research pointed out users perception of control in automated smart home systems, how the slow response of thermal systems affects the perception of control, evaluations of different thermostats usability and the rarity of programming the heating in relation to a lack of usability in thermostat interfaces.

What couldn't be found in the research, e.g. a gap of information was: research about usability of devices in underfloor heating specific context, as well as how users mental models of the system related to the usability, which is why this domain is researched in this study. The findings of the literature review resulted in the introduction, chapter 2 including related work, and frameworks in chapter 3. The literature review stood as the base of information to be able to formulate a relevant research question.

6.2 Analysis of current solutions

This section analyzed current thermostat solutions that are out on the market, some of the thermostat have been bought while some were only analyzed through digital means. The analysis was done through a competitive analysis, site mapping and cognitive walkthrough.

6.2.1 Competitive analysis

To get an overview of current programmable thermostats on the market, a competitive analysis (4.2.2) was conducted, which started by creating a list of comparison criteria. This list contained:

- Device name
- Type of interaction
- App compatibility
- Features available on device
- Features available in app
- Providing onboarding/guided installation
- Who can install it
- Program schedule via app and/or thermostat
- Type of heating

From this, a Google search session was conducted to find a mix of 10 direct and indirect competitors to be put into a comparison table. The user manual was added to the table of comparison criteria in order to easily look at and understand what different features and options were available to users. Short notes/summaries, screenshots and overviews of interesting details were created to help identify differences between the devices.

Takeaways from competitive analysis

The resulting list of competitors contained 11 devices, which were either direct competitors (electrical floor heating thermostats) or indirect competitors (boiler floor heating- or AC/air heating thermostats). The figure 6.1 contains a reduced table of the analysis and only holds the differences that were deemed most relevant in terms of findings. A full table can be found in appendix A.1.

Competitor	App compability	Onboarding/ guided user installation	Installation via	Program schedule via	Heating
Device 1	Their own	N/A	Licensed electrician	App	Floor
Device 2	Their own, HK, GH	Yes, intro to settings through app during setup	Technician or user	App and thermostat	A/C
Device 3	Their own, GH	Yes, intro to settings through app during setup	Technician or user	App	A/C
Device 4	Their own	No	Licensed electrician	App and thermostat	Floor
Device 5	Their own	No.	Licensed electrician	App and thermostat	Floor
Device 6	Their own, alexa, GH	No	Licensed electrician	App and thermostat	Floor
Device 7	Their own, HK, GH, 3rd party	Limited, options mentioned in app onboarding	Technician or user	App	Boiler Radiator/ floor
Device 8	Their own	No	Licensed electrician	App and thermostat	Floor
Device 9	Their own	No	Licensed electrician	App	Floor
Device 10	Their own, GH, Alexa, HK, 3rd party.	Yes, intro to settings through app during setup	Technician or user	App	Boiler Radiator/ floor
Device 11	Their own, GH, Alexa.	No	Licensed electrician	App and thermostat	Floor

Figure 6.1: Reduced competitive analysis table

The most common type of interaction on the thermostat devices was capacitive touch buttons, while a couple had touch displays. All had the option of being controlled by mobile applications. Furthermore, some had the possibility to be connected to third party services like Google home (GH), Apple HomeKit (HK), Amazon Alexa, which extended the control to voice based interactions. The devices were either programmable on thermostat device and in application or only in application.

The market solutions contain a lot of functionality listed in the manuals, among other things for floor heating devices: Manual mode, program/schedule mode, home, away, comfort, eco, power regulation, timer, boost, anti-frost. The impression was that the features are sometimes named in an ambiguous way, which made it hard to understand what practical differences there are between them. The air heating devices had slightly different functionality: comfort mode(temp. span), eco mode (longer temp. span), sleep (lower setpoint span). The scheduling works by putting these modes into times of day, which are setpoint spans, since they can both heat and cool to keep a temperature compared to floor heating devices. In scheduling the floor heating, one temperature setpoint is put into the times of day.

Electrical floor heating thermostats are required to be installed by licensed electricians because of the high current handling. The devices that don't require licensed electricians to install them, involves users to a higher degree by guiding them through the app during the installation (if they do it themselves), and has a personalization process which introduces features. All of these particular devices are compatible with more than their own application, since they have the possibility to extend their operability in an ecosystem of other products and appliances than just heating. This puts them more definitively in the "smart device" category. The finding from Tamas [55] showed that the "smart devices" had a higher level of usability, as well as the suggestion from Benson; that gaps in mental models can be aligned through onboarding [6]. By considering this, it could be seen as an opportunity to provide an understanding of the feature set, by designing inclusion of users to some degree in a setup process.

Five devices (device 4, 5, 6, 9, 11) that were considered to be direct competitors, in regards to electrical floor heating and requires a licensed electrician to install them, were purchased to be analyzed on a more detailed level.

Key takeaways:

- The impression is that the competitors provide a lot of features in the thermostat interfaces
- There are practical differences which limit the possibility of comparing features between A/C and floor heating thermostats.
- There is in many of the products a lack of consistency between app interface and thermostat interface
- Involvement of the user in some version of a setup could be an opportunity to introduce the device functionality to users

6.2.2 Site-mapping

The site-mapping (4.2.3) was done through a visual map of device 4, 5, 6 and 11 individually to get a detailed understanding of the competitor products. Device 9 was ordered but did not arrive until later, which was why it was excluded from the site-mapping. The aim of the method was to get familiar with the functionality and information between the devices, as well as create an overview of how some programmable/smart floor heating thermostat interfaces are structured today. The method was done on thermostats that were seen to be direct competitors (specific to electrical floor heating) and was considered by the company to be the top selling programmable and smart thermostats in Scandinavia. Two of the four thermostats analyzed had touch displays while the other two based the main interaction through capacitive touch buttons on the frame of the device.

The mapping was done by setting up the thermostats in a testing rig that was modeled to the dimensions of the thermostat and 3D printed (fig. 6.2, 6.3. The rig was used to simulate the safety of a wall mounting point and enabled the authors to connect the thermostats to 230V current while staying away from any exposed high voltage cables. The authors then documented the installation process from the initial start through pictures taken at every interaction done with the thermostat. This documentation was then done throughout the entire interface to document the possible interactions, states and activities. The documented photos were then imported into the collaboration tool Miro, where the interfaces were structured to mimic the architecture of the thermostat interface.

Figure 6.2: A competitor thermostat in the 3D printed testing rig. [Authors own image]

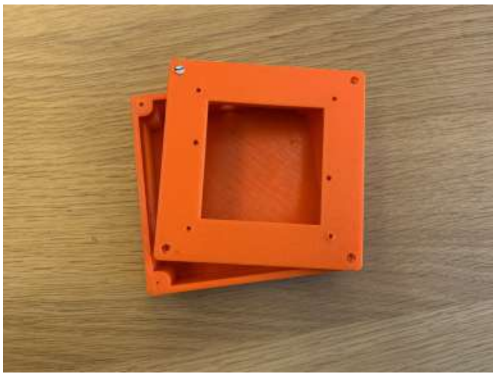

Figure 6.3: The 3D printed testing rig without a thermostat installed. [Authors own image]

Takeaways from Site-mapping

The site-mapping resulted in a color coded mapping where the observer gets a good overview, the map presents the functionality of the system by the vertical length, along with the depth of the menu hierarchies by the horizontal length. Figure 6.4 shows the result from device 5. All sitemaps can be seen in figures A.4 and A.5 in the appendix. Viewed from a distance the site-mapping clearly shows that many of the systems analyzed use a deep menu hierarchy where some functionality is found deep into the system, resulting in more interactions to be able to reach certain goals or activities. The site-mapping also showed what functions and features that other manufacturers have decided to place directly into the thermostat. What was initially hard to understand, was what the different options meant in terms of functionality, the microcopy is not very straight forward in regards to expected outcome. The manuals attained in the competitive analysis helped in understanding the functionality in those cases. The different devices provide the same functionality and more or less the same features, however, they are called different things or work slightly differently. For example the features boost, comfort and eco were found in device 4, which were all temporary temperature functions. In device 6, boost was also a temporary temperature function, however it did not have the same outcome as in device 4. The devices were concluded to be feature rich and non-descriptive in regards to anticipated feature naming. This was confusing as the system is described through different functions to be more advanced than what it is. It also leads to redundant functions and naming that does not conform with users' understanding of the name in relation to the function.

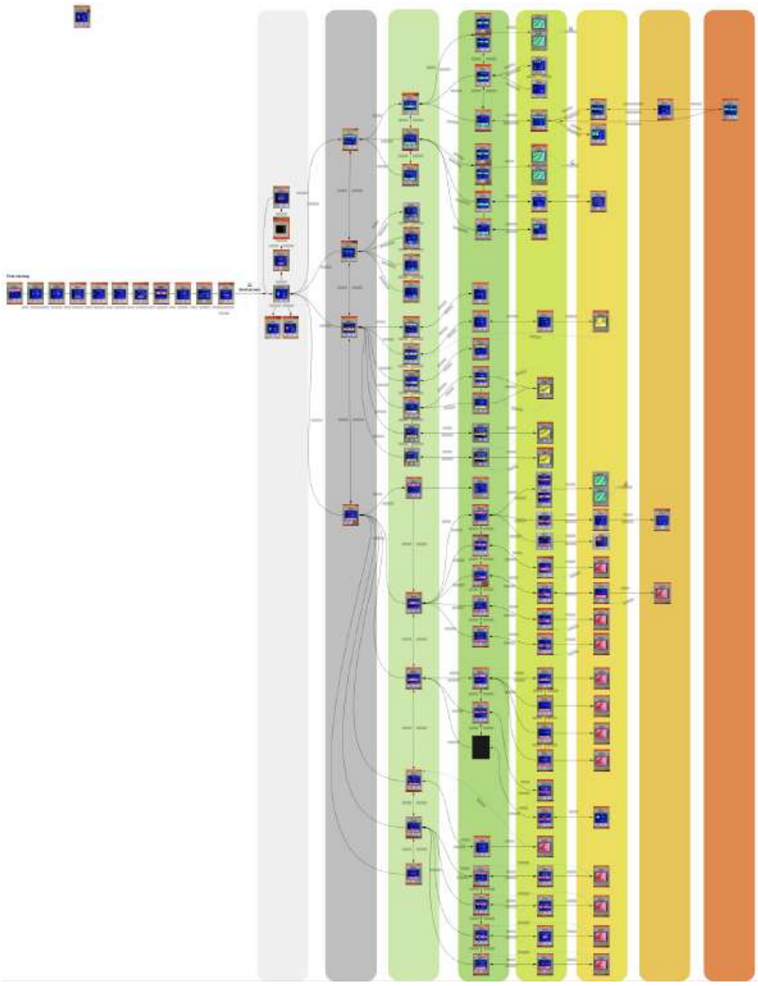

Figure 6.4: Sitemap of device 5. The feature richness is shown by the vertical length while the depth of the architecture represented by the horizontal bars. The deepest vertical length in the image shows that functions such as programming require the highest amount of interactions.

Out of the thermostats tested, they all had the programming of schedules feature located in the thermostat. This can through the mapping be seen as interaction intensive activity by having the deepest reach in the map in all sitemaps, due to the complexity of the task through the medium of a small display. This also sparks the question of what features that are really needed and which features that are redundant. The mapping of the thermostats also revealed the users ability to navigate through the interface. Due to the nature of smaller displays, the thermostats are dependent on using long vertical and horizontal lists to cater the many functions that the thermostats offer.

Key takeaways:

- It provided the researchers with a mental model of the system features that is provided.
- It seems to be common to use non-descriptive microcopy regarding features.
- Some microcopy are shared between devices, however do not have the same

outcome.
- They boast a lot of features and advanced settings.
- The programming of a schedule is a tedious process in the small format.
- It sparked a question about what features truly are needed directly on the thermostat.

6.2.3 Cognitive walkthrough

The 5 thermostats acquired were analyzed more in depth on a task based level through cognitive walkthroughs (4.2.4) by the authors, to evaluate the usability of the current products on the market.

Eight common tasks were performed on each one:

- Increase/decrease temperature by 5 degrees
- Set for away/vacation
- Start a temperature timer
- Adjust temperature timer length
- Adjust temperature timer temperature
- Start a schedule
- Change schedule temperature
- Override temperature in schedule mode

The steps needed to perform the tasks were listed and notes were written down regarding:

- Will the user try and achieve the right outcome?
- Will the user notice that the correct action is available to them?
- Will the user associate the correct action with the outcome they expect to achieve?
- If the correct action is performed will the user see that progress is being made towards their intended outcome?
- Other thoughts the researchers had on performing the task

6.2.4 Takeaways from cognitive walkthrough

The cognitive walkthrough provided an overview, comparison and good understanding of how common tasks are supported and used in the acquired thermostats. The cognitive walkthrough was done on 5 different thermostats of various brands and models. Not all of the thermostats had the features to be able to conduct the tasks set out to do, because of lack of implemented features. The amount of interactions done to conduct tasks varied a lot in between both the thermostats and within the same thermostat with different tasks.

Key takeaways:

- Not all of the thermostats offer the tasks set out to analyze, such as device 11 that neither had a timer or a boost feature.
- Many of the thermostats provide an extensive amount of other functionalities such as being able to program schedules directly through the thermostat.
- Some interfaces require the user to navigate to a "go back" option which was seen in Device 9, where the back button simply was another menu item put in a long list. This is a design choice that introduces a lot of excise in the interface.
- The thermostats had many different states which can be confusing and sometimes override each other without informing the user on future states. The behavior or features and naming of them are not consistent resulting in having to learn the specific thermostat's behavior from experience and recall rather than to recognize.
- The thermostats contain redundant features, resulting in displaying a more complex system to the user with the goal to make it easier by creating shortcuts and functions for specific instances. Such as seen in device 4, where the *comfort* feature is simply a timer. This instead results in confusion as different naming suggests that different functionality exists as well, despite that not being the case.

6.3 User research

The user research section aims to collect data on the usage of heating systems and user behaviors around such systems along with analyzing the results and defining them further. This has been done through questionnaires, interviews, affinity diagramming, behavioral archetypes and an experiment.

6.3.1 Questionnaire about floor heating usage

A part of the early user study aimed to create and send out a questionnaire (4.2.5) to get quantitative insights on users' floor heating systems, their behavior and mental model. The questionnaire was created in Google forms and was divided into general questions regarding the thermostats that the users have today and their behavior interacting with it. Depending on the user's answers they were divided and slotted into answering different questions. The factors that affected which questions the users would further get was if they has heated floors in more than one room and if the thermostats they has were programmable or not.

The questions that were formulated in the questionnaire are primarily based on the gaps in the previous literature research along with general information that can stand as a part of the base for upcoming interviews.

To gather participants for the questionnaire, the first step was to find users with floor heating installed in their residence as this was a requirement to participate. Through company communication channels, employees at the company were asked if they had floor heating and were willing to participate in the study. Based on the answers in the channel, the questionnaire was sent out to the people that fulfilled the requirement.

Takeaways from questionnaire

In total 21 participants answered the questionnaire. Out of the 21 participants, 10 had either worked with installing or selling thermostats at some point during their working career. The results from the questions showed that a majority of 61.8 percent of the users interact with their thermostat every few months or less and while 28.6 percent interacts with it a few times a month and less than 10 percent or two participants interact with their thermostat several times a week can be seen in figure 6.5. This further points towards a low interest of interaction of the thermostats in domestic residences.

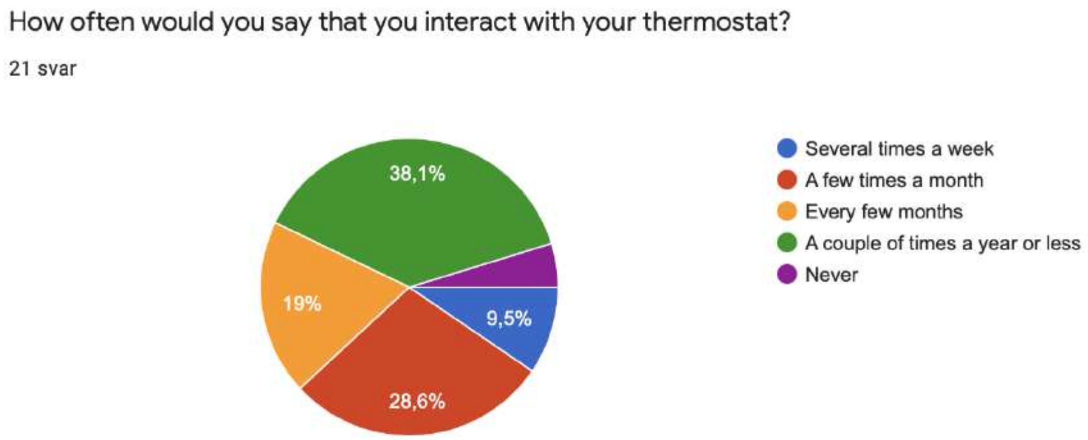

Figure 6.5: How often users interact with their floor heating thermostats, results from the questionnaire. [Authors own image]

When the 21 participants was asked how they use their heating system today (fig. 6.6), the most common answer with 33.3% was that they primarily keep the system on and keep the same temperature. Keeping the system on and changing the temperature manually was the second most common way of using the heating system with 28.6% and then utilizing an automatic schedule for heating with 23.8%. Other answers were "I configure a personal week schedule for each room" (1 participant), "Because hydronic floor heating is so slow-acting, I rarely adjust the temperature settings " (1 participant) and "I would set a schedule if the interface was more intuitive. I currently always have a fixed temperature" (1 participant).

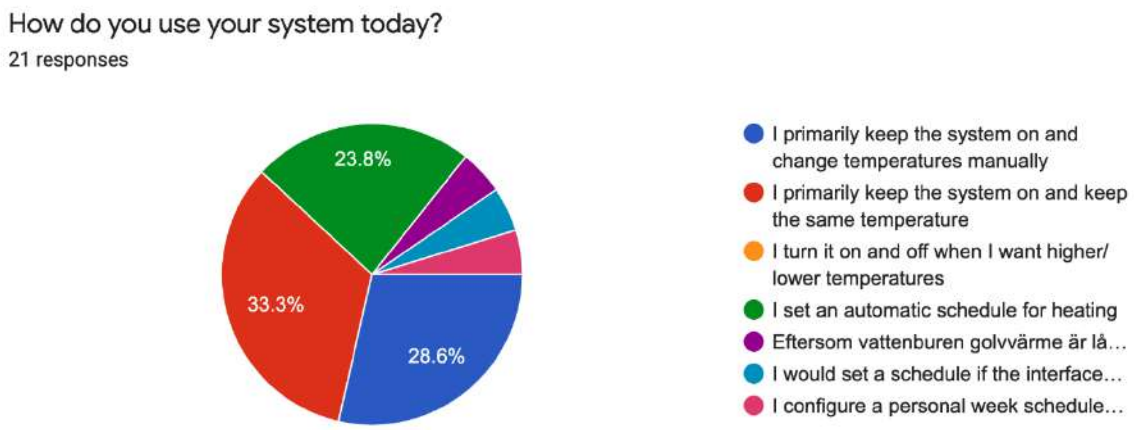

Figure 6.6: Result of how they use their thermostat today from the questionnaire. [Authors own image]

When asked what the most relevant temperature shown on the thermostat is, all of the predefined answers got chosen close to equal. The predefined answers were the target and set temperature for both room and floor. The result can be seen in figure 6.7.

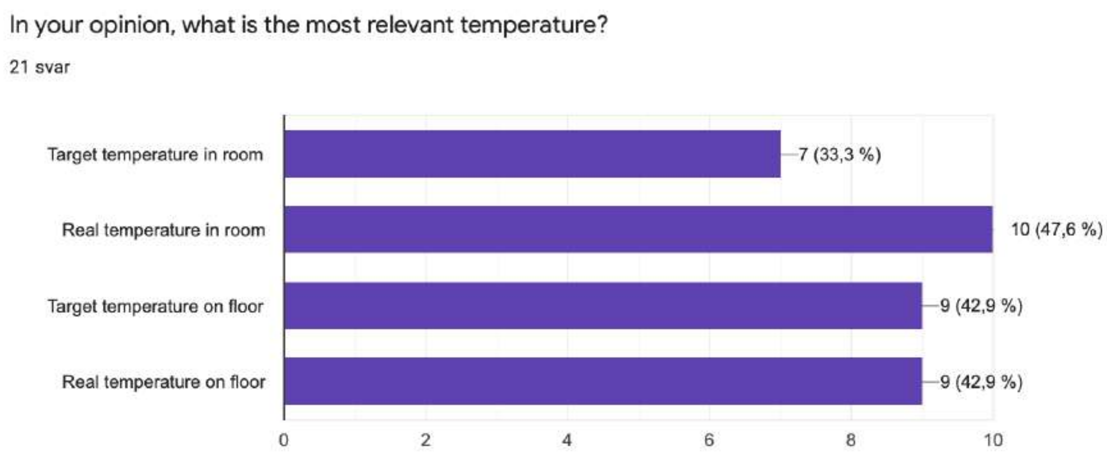

Figure 6.7: Result of the most relevant temperatures from the questionnaire. [Authors own image]

Two of the questions revolved around what the users perception of different modes and microcopy commonly used in today's thermostats. This open question aimed to understand the difference between the terms comfort and eco settings along with schedule and timer. The results show that the participants equally interpreted the difference between a comfort and eco setting to be a difference in temperature or a difference in behavior of the schedule. The difference between schedule and timer was seen to be that a schedule is something reoccurring while a timer is one single time period.

Out of all of the participants 61.9 percent had floor heating in several rooms, and out of these participants 69.2 percent control each room with a room specific thermostat.

The result also shows that 9 of the users who answered have programmable thermostats, 14 had manual thermostats and one did not know. The functions that participants with programmable thermostats state that they use are schedule, timer and a boost feature.

6.3.2 Interviews about floor heating use

People that had floor heating in their homes were recruited for semi-structured interviews (4.2.6) through a convenience selection. The purpose of this was to get qualitative data of how people use their floor heating, their understanding of their system, as well as their preferences, settings and thoughts about the functionality. The questions from the interviews were divided into three categories; Questions related to their general usage and settings, questions related to their understanding of their system, and questions related to interface/control of floor heating. The interviews started with informing the participants about the purpose of the interviews and was followed by receiving a consent form regarding the data collection. Each researcher performed three interviews, half were audio recorded with consent for later transcription and in the other half notes were taken during the interviewing process.

In total six interviews were performed, five interviews were conducted through online video calls and one in person. The interviews took between 19-30 minutes (average: 26 min). All the participants were male (Age: 23, 26, 29, 30, 40, 60) and all had electrical floor heating. The participants were divided equally between living in a house or in an apartment, three had programmable thermostats and three had manual thermostats. The interviews resulted in qualitative data that was later analyzed through Affinity diagramming.

6.3.3 Data analysis of the interviews

Affinity diagramming (4.3.1) was used to categorize and sort the qualitative data from the floor heating user interviews into relevant groups based on commonality. The answers and descriptions from the interviews were put onto post-it notes on an unsorted board in the online tool Miro. The post-it notes relating to the interview categories were color coded to get an overview of their origin when they would get resorted into specific affinity groups. The researchers then sorted them into different groups by affinity, discussed the content and assigned relevant group names. This process was repeated until groups were formed that could be further sorted into large categories by group affinity (figure 6.8).

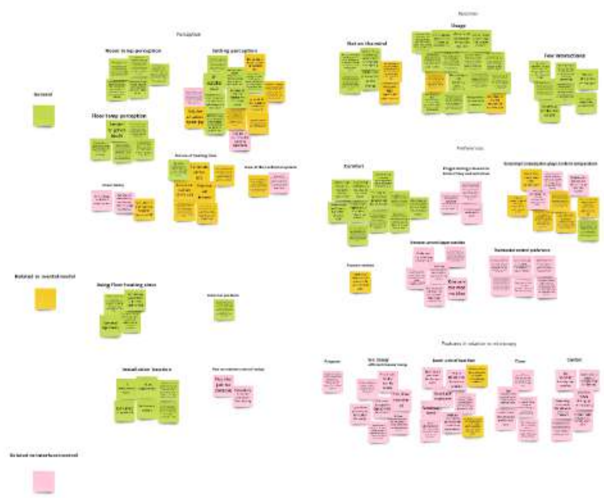

Figure 6.8: Result from affinity diagramming. [Authors own image]

Takeaways from data analysis

The affinity diagramming resulted in three major categories: routines, preferences and perception. Each category contains subcategories to further describe and define the results from the data collection (figure 6.8).

Routines

The routines category contained users' descriptions on how they use and interact with their floor heating system. Within the overarching category of routines, two sub categories have been found, usage and few interactions. These two sub categories will further be summarized and explained through citations from the data collection.

- Usage

The usage of thermostats varied throughout the households. Most users describe comfort primarily as the warmth of the floors rather than actually heating up the air around it. However, this can not be said to be the only reasoning that the floor heating is used for, for some users the secondary usage of heating up the air in the room also plays a role in its usage. This can lead to a different usage depending on the season, such as turning the heating off during the summer due to already having a warm environment indoors without any extra heating element.

"In the summer we don't keep it on, when the air is warm. It's actually in autumn, winter and spring when it is cold that we use it. Then the summer is quite short here, so overall it is on more than off."

"I turn it on and off almost daily. If I'm not home for a whole day, I turn on the floor heat when I get home, keep it overnight, then turn it off in the morning before I leave."

"It's always on except for when I'm traveling."

- Sparse interaction frequency over time

Users generally do not interact with their thermostat often. It is often seen as a product that works in the background and that most people do not think about, which results in them not interacting with the system. The interactions that are done are primarily in specific scenarios where the user acts out of the ordinary, such as leaving the home for a longer period of time during a vacation. Out of the 6 participants, 3 kept the system on the same setting regardless of the season while the rest did not use the floor heating during the summer months because of already high temperatures. These 3 users were also the ones that stated that they experienced the floor to heat up the room.

"I pretty much never touch it really, when I'm going away I turn it off and that's it"

"Basically never look at it on a weekday basis"

"I don't really change the settings, is too cumbersome, maybe done it twice in the last 6 years."

Preferences

All users have preferences and this category summarizes three of the more protruding preferences that have been found in the collected data. The three different sub-categories that the data fits in to within preferences are comfort, programming consumption and control.

- Comfort

When talking about the value of floor heating for the users, it was described to be the comfort it brings. However, comfort was described differently between the participants. The thermal comfort temperature differs a lot between users, while some are happy with a floor that is not cold, some users want it to feel hot and do not have a maximum temperature when it comes to comfort, only a minimum. For a smaller number of users the thermal comfort is also related to the air temperature and it being warm, but where the focus still is on the floor. But these users have an upper limit when it comes to the temperature of the room, which is directly affected by the floor.

"It's really for the feeling on the floor. But we know that when the floor gets hot, it gets hot in the air as well"

"Comfort for me is a pleasant room temperature and that the tiles don't feel cold."

- Programming and consumption

Users see a value in being able to control the thermostat through programs in order to cater the temperatures to their own preferences while also saving energy that benefits both their economy and the environment. The factors that affect how users program or would like to program their thermostats are mainly to balance thermal comfort and consumption. Users want to have thermal comfort when they are at home while also saving energy and money when the home is unoccupied.

"We would base a schedule on finances in that case, then it would have been that it turns off/on during times when we are not home."

"Want it warmer, but don't want to raise the temperature due to more energy use"

- Control preferences

Users control preferences for the thermostat differed throughout the data and was an aspect that did not have one straight consensus. Some of the users saw an opportunity in being able to remotely control the thermostat through an app, in cases such as having a big house or before arriving home. 4 users saw the control through an application remotely as something that would not be necessary due to the lack of interaction and interest in the system. A pain point spotted from one user was that the person had a hard time setting their specific scheduling times, due to the lack of knowing when the system would reach that set temperature.

"Feels better to change directly in the thermostat if I'm home"

"Probably would not use my mobile phone. Barely touch it as it works today, think it will only be more work."

"Think it would have been more interesting with app control if you live bigger for example. I always have it available around the corner right now."

"Would be nice to be able to control it when you are not home, kind of had it on during Christmas when it shouldn't have been heating."

A problem that was expressed regarding control was that one participant had a problem with scheduling, the thermostat did not reach the temperature at the time it was scheduled. Instead, the thermostat started heating towards the temperature at the scheduled time. This required the participant to reschedule multiple times in order to learn how long it took the system to reach the desired temperature.

Perception

The perception of temperature is one of the important aspects that can affect the thermal comfort that a user feels. In the data collection, perception had been divided into two primary categories, floor temperature perception and room temperature perception.

- Floor temp perception

Users often perceive the floor to be cold when the heating system is turned off or too low, which is also the opposite to what they see as thermal comfort. The perception of the floor temperature can for some also be a reason to interact with the system in order to change or get informed of the system's state.

"When it feels cold (not hot) I want to see how many degrees it is set to, if it is right or if it does not feel right with the temperature on the floor"

"If I experience the floor as cold, I might take an extra look at it"

- Room temp perception

For some users the perception of the room temperature can be the factor that initiates their thoughts on the heating system. These participants use the floor heating as a medium to heat up the air in the room and therefore correlates the room temperature to the floor. Three out of the six participants stated that the room temperature is what affects them the most.

"I think it's the room temperature that affects me the most. If it is very hot on the floor, then it I don't get affected so much."

"If I feel that it's cold inside, that's when I think about it and turn it on."

"When I feel that it is hot in the house or outside, I usually actively go and lower it and vice versa if it is cold outside."

- Settings perception

There is a pain point that the temperature shown on the thermostat does not appear to correlate correctly with the real temperature in cases where the thermostat shows a specific temperature. The reason for this could be how different a surface temperature feels compared to the same air temperature. From the interviews users with a manual thermostat that uses a scale (such as 1-5) did not consider the perceived temperature and heat level a problem. Heating scales are seen to be separate enough to not be considered non-conforming, but require a learning curve to find comfort as well as a perceived limited control over their temperature. When perceived temperature is non-conforming with the temperature scale, the temperature scale just becomes another scale to learn what settings feels good.

"Guess it's the floor temperature it shows, never thought it might be anything else"

"The temperature feels less than it shows"

"Represents nothing, it is at 24 but is definitely not, if I really need heat I run it at 27 degrees"

- Picture of heating time

All interview participants had from previous experiences created a mental model that the floor heating takes a while to reach temperature. The time that it takes for the floor to heat up was more diverse and is also a question that is hard to answer as it is dependent on the temperature difference between the current and set temperature. The answers that the user gave ranged from more abstract timelines such as:

"It is the fact that it takes some time to get it started, which means that I do not turn it off."

"Oh, I have no great idea of that. I would guess it takes ... It's pretty slow."

to more concrete time definitions such as:

"It might take 3-4h to get it warm"

From my perception it takes a little over a day, from being turned off until I have proper heat."

When it comes to users' understanding and mental model of different functions and modes of thermostats the result was less accurate. In many cases thermostats have the ability to be turned on either 0 or 100 percent of its maximum power, nothing in between. This makes certain functions such as boost or eco functions on the thermostats non-conforming with what the users mental model is. Most users saw boost-functions as a way to heat up the floor faster, which is not the case since it can only heat at one pace. Users also interpret eco modes as something that is more power efficient when in fact often is a way for manufacturers to describe a lower temperature (which may or may not be more power efficient).

Key takeaways:
- Users rarely interact with the thermostat
- The temperature setting is not perceived to be conforming with what the floor feels like
- Users that have thermostats without temperature scale do not mention that the setting is non-conforming with perception
- Both the feeling of the floor and room plays a role in the interacting decision
- Slow system response is a problem when scheduling temperatures, heating should reach temperature at set time as default
- Users are well aware that the system is slow
- Remote control would be seen most beneficial in cases where the home is large or to save energy when aways for a longer period of time

6.3.4 Behavior archetypes

The behavioral archetypes (4.3.2) were created based on the results from the questionnaire and the interviews. There was a need to understand and define the motivations and underlying thoughts of the users. This was done by analyzing the data through affinity diagrams, underlying patterns about behaviour and motivation arose, which stood as the primary base for the behavioral archetypes. The questionnaire also supported in understanding the motivations through prominent behaviors, for example what features they use, in relation to how often they interact with their thermostat, as well as how they utilize their heating system today.

Based on goals, thoughts, needs, actions and pain points different categories emerged that described four types of behavior and attitudes found in the user research. The attributes were in some cases also strengthened with quotes from the user studies, visualized through post it notes. It resulted in four behavior archetypes: The low effort archetype, the comfort dependent archetype, the consumption concerned archetype and the optimizer archetype. Along with this, each archetype got a narrative to contextualize the previous attributes. The final behavior archetypes can be found in the Result chapter.

6.3.5 Experimentation with perception of floor temperatures

The result from the research on people's usage and perception of their floor heating system showed a majority of the participants experiencing that the floor temperature is lower than what the thermostat shows. This could partly be due to differences in material properties which have been shown to have an effect on the perceived temperature, despite being the same temperature.

To investigate this further, one of the researchers tested his subjective experience of different temperature settings on wood and tile flooring, while measuring the actual surface temperature of the floor with an infrared thermometer. The test was done on two tiled floors and one wood parquet flooring, where one of the tiled flooring had floor heating installed and turned on. The temperatures that were tested were 23,5 and 21 degrees on wood flooring and 23,1 and 31,2 degrees on tile flooring.

Takeaways subjective floor temperature perception experiment

The subjective result from the researcher was that the perceived temperature was lower than what the thermostat showed, even though the thermometer correlated with the temperature that the thermostat was set to. Furthermore, the perceived temperature on the wood floor was warmer than the tile floor when they had approximately the same temperature. This correlates back to studies done by the Swedish Energy Agency, stating that the feeling of temperature can differ depending on the conducting material [1]. Colder wood flooring of 21 degrees which was achieved through opening a window in the room to cool down the floor was perceived as being equivalent in temperature to a slightly warmer tile floor. The result of having the same perceived temperature despite there being a difference in the actual surface temperature can be dependent on the conduction and convection of the materials that were tested but also the relative skin temperature on extremities.

Figure 6.9: One of the heated floors during the experiment. [Authors own image]

6.4 Ideation

This section has had focus on synthesizing the information and knowledge gained in the previous section in order to ideate on possible issues and solutions. This has been done through the methods: How might we, brainstorming, Crazy 8, Flowcharts and Wireframes.

6.4.1 How might we

The How might we questions (4.3.3) were done in order to gather and define the present design problems that are faced in the project, in order to ideate in relevant areas. The method was initiated by looking at the general pain points and the bigger picture obtained from the previous user studies. This view stood as the base for creating HMW questions, the questions focused on more specific problem areas and aspects of the system that needed more clear definitions before continuing the project. The questions were written down on digital post it notes in the collaboration tool Miro.

Takeaways from the How might we

The result from the method was 10 HMW questions that specified problem areas or pain points. These 10 questions stood as the base for the upcoming brainstorm and Crazy 8.

How might we..

- Provide meaningful information without being too much on the home screen?

- Communicate heat levels?
- Create a conceptual model that helps users understand surface temperature?
- Create an interface that is easy to navigate?
- Help the user find the temperature they want to keep faster?
- Provide options to deviate from scheduled temperatures?
- Communicate that the system is holding, working higher or recessing to something lower?
- Support users to easily set up a schedule?
- Define potential presets that are suggesting schedule context?
- Provide an easy way to edit temperature presets?

6.4.2 Brainstorm

The researchers had multiple brainstorming (4.3.4) sessions based on the How might we ask questions. These brainstorming sessions were done with the aim to explore potential solutions along with the system features as well. Potential solutions and thoughts were listed or sketched on in order to communicate the ideas properly.

Takeaways from the Brainstorm

Conceptual models and mental models relationship were extensively discussed in the how might we questions. Communicating a system conforming conceptual model was the target. The use of related metaphors was seen to be a good way to help understand what the users might want to change.

A brainstorming session included how the project can take inspiration to similar systems that people know and how to relate to their mental model. Metaphors were for thermal comfort was brainstormed, one example is: bare feet, socks, slippers in relation to temperature to describe what comfort level can be anticipated.

Key takeaways:

- Reduce the main screen information.
- Minimal viable information needed to support decision making: Target temperature, Environmental awareness, Temporal awareness, Heating or holding or "dropping" currently, Affected area.
- Use physical button for going back and forwards from main screen and menu options
- Put additional options in menu
- Minimize redundant temporary temperature options
- Utilize mapping and metaphors in order to communicate thermal perception.
- Introduce users to scheduling early in their adoption of the system, through onboarding or involving the user in part of the installation process.

6.4.3 Crazy 8 method to ideate visualizations

Communicating the system behavior and state has the potential to prevent users from overshooting temperatures when thermal comfort is not achieved. Seen in acquired thermostats was that the feedback in the best cases are visual feedback if the system is heating up or not. By giving feedback on how far in the heating or cooling process the system has gotten the user has more information to base a potential system change on.

Two different Crazy 8´s (4.3.5) have been conducted in order to ideate the visualization of when the heating system is heating up the floor and when the system is not in order to lower the temperature. For each Crazy 8, a time cap of 8 minutes were given, where the ideas were sketched within the time cap. The goal was to find ways to communicate the system's behavior in a way that it is compact, informative and easy to read. Here, different ways of showing progress, and metaphors for high and low were ideated on, in order to convey an intuitive conceptual model.

Takeaways from the Crazy 8's

The first Crazy 8 was done by one of the authors and was meant to ideate on how to visualize the systems direction. The result was 8 different fast sketches on potential visualizations for when the system is heating up as can be seen in 6.10.
The two Crazy 8´s that were done in order to visualize when the system is cooling down to a lower temperature resulted in 16 frames constructed by two of the authors. The different visualizations and frames can be seen in 6.10.

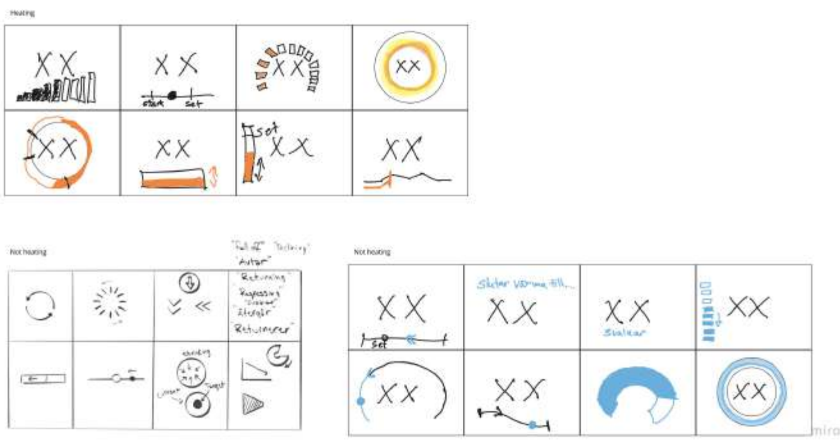

Figure 6.10: The three Crazy 8 visualizations that were done, showing both heating and not heating ideas. [Authors own image]

6.4.4 Development of flowcharts

Flowcharts (4.3.6)were made to get an understanding of how the on boarding process of the users of the thermostat could be structured in the supported mobile application. It provided a fast and efficient way of visualizing the flow and how operations and functions in the system are connected. By modeling the flow of the onboarding process, potential logical inconsistencies could be found and resolved iteratively in order to save time in upcoming phases.

The Flowcharts took inspiration from other modeling languages such as Business process model and notation as well as Swimlane diagrams. The inspiration taken from the BPMN syntax (4.3.6), which are notations such as And-or and X-or elements and from Swimlane diagrams the swimlanes have been adopted and adjusted to fit the needs for this project [9].

Takeaways from the flowcharts

Three main iterations of the flowcharts were done throughout the project based on the continuous development of prototypes, with smaller adjustments in between the two first iterations with a bigger change for the final iteration. The first two iterations, which can be seen in A.6, A.7 in the appendix, contained suggestions on the flow for the user from the first setup until the thermostat is personalized to the users preferences, what was iterated in between was giving the user the option to skip the process of adjusting the schedule by using a default schedule. The third and final flowchart, which can be seen in A.8, provided a more streamlined onboarding process for the user. Features such as presets got scaled down and simplified, resulting in an user flow that is informative and only asks for the most important information.

6.4.5 Wireframing

In order to in a time and resource effective way ideate and test different interface ideas, wireframes (4.4.1) were created. The wireframes acted as a medium to ideate various layouts of the interface, taking into account factors such as the size of hit boxes and texts or other information and control elements. The wireframes were created in both the online UI design and collaboration tool Figma as well as drawn by hand. The initial development was based on the brainstorming and crazy 8's sessions.

Takeaways from wireframing

Sketched wireframes of the application setup and thermostat UI were created initially, which focused more on the entire interface as a whole and can be seen in A.9 and A.10 in the appendix. For the thermostat UI layout, 30 different digital screens were created in Figma. An overview of them can be seen in 6.11. The frames were made on various aspects of the system but primarily the main screen of the thermostat. Out of the 30 frames, 25 of them were made to represent the layout of the main screen while the other 5 frames represented different menu and setting layouts. The main screen frames were in total 5 different concepts that were developed with different system states in mind, resulting in the 25 frames and accompanying sketches.

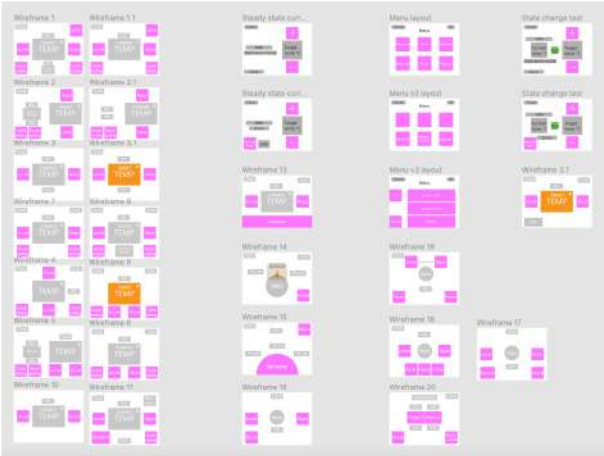

Figure 6.11: A reduced example of the resulting wireframes. [Authors own image]

6.5 Prototyping and evaluation

This section will present the different prototypes that throughout the process have been developed along with the evaluation methods that have been used to assess them.

6.5.1 Parallel prototyping iteration 1

Parallel prototyping (4.4.2) has been a way of utilizing resources and time effectively, by evaluating different combinations and variations of information in the interfaces. This method has been used and relevant in all prototyping stages except the final prototype development. The execution of the parallel prototyping has followed similar structure throughout the prototype phases. The researchers have from previous methods and phases synthesized data along with ideated on possible solutions based on the obtained information. With this information in mind, attributes and elements with specific prototypes were set, these attributes could for example be that the thermostat does not display any temperature grades or is controlled in a certain way.

Takeaways from the parallel prototyping iteration 1

The first iteration contained three different prototypes.

The first prototype 6.12 in this iteration used a combination of both preset names and temperature, whilst also putting the controls for the temperature one step further in to the system hierarchy with the rational that users simply do not make adjustments so often making it less important to visualize on the main screen.

In the second prototype 6.13, the main focus lay in showing the target temperature and easy access to the controls from the homescreen, much like many of the previous competitors. the interface in parallel also displays what part of the schedule that is active in order to provide feedback of the system status and the upcoming state.

The third prototype 6.14 has a primary focus on not presenting the temperature in degrees for the users. it instead uses defined preset temperatures, comfort, cool and night. The prototype connects back to the finding that users who use manual thermostats without a centigrade scale tend to be less frustrated. The naming of the presets aims to provide towards a good mapping of the temperature, making them more situational.

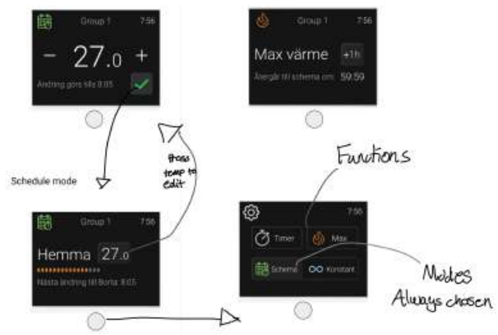

Figure 6.12: Prototype 1.1 iteration 1. [Authors own image]

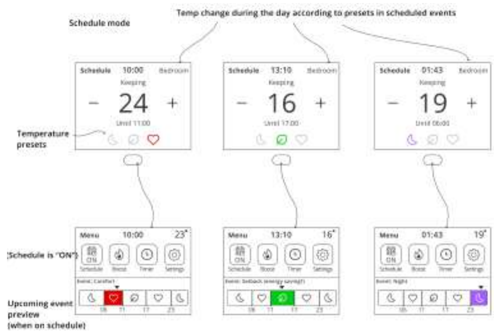

Figure 6.13: Prototype 1.2 iteration 1. [Authors own image]

Figure 6.14: Prototype 1.3. [Authors own image]

6.5.2 Heuristic evaluation

By conducting a heuristic evaluation (4.4.3) on the initial prototypes done in the first iteration, general usability problems and improvements could be found. The heuristic evaluation was individually done on all of the three prototypes in order to get a less skewed and personal result. To evaluate the interfaces Jacob Nielsen's 10 usability heuristics for graphical interfaces were used. The heuristics were then evaluated throughout the entire prototype rather than individual screens.

Takeaways from the heuristic evaluation

The heuristic evaluations gave a good understanding of the general usability improvement areas of the prototypes done in the initial prototyping phase. The most crucial findings from the evaluation was within the heuristic *Visibility of system* *status*. The target temperature, system temperature direction along with the user's environmental perception of the local temperature should be considered to be the MVP to achieve the heuristic. Without this information the user simply can not make an informed decision. The environmental perception is not always available, such as in cases where the temperature is controlled remotely, these instances might be dependent on the current temperature to make informed decisions.

Besides this, various vital adjustments had to be made to have the prototypes evaluated with users in the upcoming method. Adjustments such as not having the ability navigate back in certain situations, undo actions such as removing amount of time in timer and inconsistent system behaviour.

Key takeaways:

- Clarify visibility of system status, use hierarchies and placement to signify connections between information in a smarter way
- Some icons are quite ambiguous in relation to the options we are trying to provide
- Option to lower time should be added to timer, so that they do not need to start over if they add more than desired time
- Fix the issues with buttons that signify navigation, hint outcome of interaction through mapping and microcopy, try return to schedule button

6.5.3 Parallel prototyping iteration 2

With the problems found in the heuristic evaluation, an iteration of the first prototypes were done in order to solve general usability issues. This was seen to be an important task before proceeding to the next stage of the project and testing with real users to be able to find more specific problems. Similarly to the previous prototypes, this iteration was created in the digital prototyping tool Figma.

Takeaways from parallel prototyping iteration 2

The second iteration resulted in 4 prototypes that were heavily inspired by the ones in the first iterations with adjustments and modifications done in order to fix the issues found in the result from the heuristic evaluation. The modifications that were done focused on increasing the visibility of the system status, such as showing the direction the temperature is heading towards and taking environmental perception into account in order to create a MVP solution. Other vital issues were also resolved, such as not creating dead ends in the system along with simplifying navigation by reducing excise and options to undo within system functions. The full prototypes can be viewed in appendix A.11, A.12, A.13, A.14 and an overview of the prototypes from this iteration can be seen in the figures below.

Figure 6.15: Prototype 2.1. [Authors own image]

Figure 6.16: Prototype 2.2. [Authors own image]

Figure 6.17: Prototype 2.3. [Authors own image]

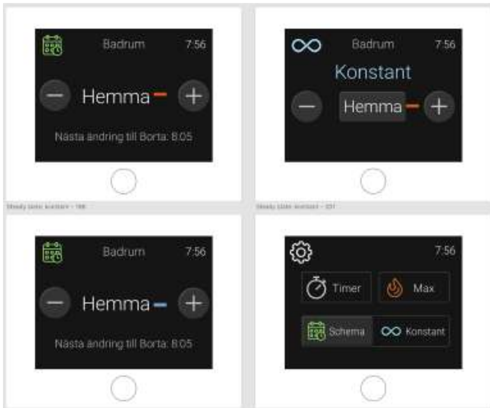

Figure 6.18: Prototype 2.4. [Authors own image]

6.5.4 Prototype evaluation with users

The evaluation took inspiration from usability tests (4.4.4), which then were adjusted to fit the goal of the evaluation. The goal was to get an understanding of how users interpret the variations of information e.g. if they could anticipate an upcoming schedule change and if they would change the current settings based on the information. Four participants were recruited for the evaluation and they were asked by convenience internally at the company, on the basis of not being involved in the development or sales of a similar product.

The participants were introduced to the purpose of the project and were encouraged to think aloud, since it was of interest to understand their thought process and if the information they felt they needed was available. They were allowed to navigate around the interface for around 30s to get acquainted with the navigation before the evaluation started. The user was asked to interpret what the system was currently doing, as well as carry out tasks. In order to take environmental perception into account the presented scenarios to the prototype screens.

An example of the scenarios that the user were presented with was: "You are on your way out, the floor feels cold, but you won't be home again until 18."

And would then get related questions, for example: What can you determine from the information? Based on what you see, is there any setting you would change?

Takeaways from prototype evaluation with users

The evaluations took 10-15 min per prototype, in total between 40-50 min per session. The findings in the evaluation was used for iterating and converging into two more refined prototypes

Key takeaways:

- Only switching between presets was not easy to understand. People understand the temperature scales better and are able to understand what changes they want to make through seeing the temperature.
- Schedule preview helpful to understand what is going to happen during the day. Works as “recall” for previous settings since they might not interact for a long time.
- Target temperature and relative direction is enough information to provide to support informed decisions. Environmental perception makes current temperature less important information.
- Direction of system heating/decreasing benefits from being a moving element.
- Icons need to be labeled if used, however labeling microcopy needs to be clear, comfort/eco/boost too ambiguous. Using text presets provides freedom for personalization. If using icons, they should be generic or else will constrain the context for the preset.
- Back button preferred over return to schedule button, a dialog might be more helpful than having an icon that describes outcome.
- Change mode should be available in the thermostat if people don't have the application. But the current mode should be clear when changing mode.

6.5.5 Parallel prototyping iteration 3

The prototypes took into account several important learnings from the prototype evaluations with users and were central during the development of the prototypes. Both of the prototypes focused on using the temperature scale, temperature presets in schedule mode were more contextualized to day activities, the schedule preview was redesigned to be more scalable, dialogues and texts were implemented in a few cases to clarify settings or turning a setting off.

Takeaways from parallel prototyping iteration 3

This development resulted in two different prototypes. The first prototype (fig. 6.19) focused on creating an experience tailored for the user in the initial phase of usage, where the user has easy access to permanent schedule changes from the home screen. This prototype did not use any confirmation or warning screens when features such as timers were activated, in order to test the difference of having it or not.

The second prototype (fig. 6.20) used temporary changes as its main control from the main screen in order to support users in setting a preference temperature without it having a permanent effect. This prototype, contrary to the first one, did include confirmation and information screens.

Figure 6.19: Prototype 3.1 with permanent schedule overrides. [Authors own image]

Figure 6.20: Prototype 3.2 with temporary schedule overrides. [Authors own image]

6.5.6 A/B usability testing

To evaluate if the information and UI supports users' understanding and mental model of system behavior, usability tests (4.4.4) on the two prototypes were conducted. The aim of the prototypes was to provide an ability to make informed decisions. The refined prototypes (fig. 6.19, 6.20 was usability tested with 5 users, which is described to be enough to find 85% of the usability problems [43]. The 5 participants were selected through convenience selection with the requirement that they not work with thermostats professionally. This biggest difference between the prototypes, except for information layout, was having permanent temperature changes or temporary temperature changes from the main screen in schedule mode. The users were asked to carry out tasks and interpret the information in the prototype variations, while also utilizing the think aloud method (4.4.6) to provide insight for the authors and note their thought process.

The starting prototype (either 6.19 or 6.20) was interchanged between participants, to combine the usability test with A/B tests (4.4.5), to see if starting in a scheduled mode or constant mode would greatly affect the understanding of the device.

The aim with the tests were to determine if the UI supports:

- Interpretation of the target temperature
- What direction the temperature is going
- Temporary temperature changes (Preset overrides and timers)
- Permanent temperature changes (Editing presets)
- Anticipating upcoming events in constant mode, schedule mode and timer mode.
- If the temporal aspect of the modes are clear, regardless of starting in schedule or constant.
- Effectiveness of dialogues and descriptive text

Takeaways from A/B usability testing

The usability tests took 30-35 min per session and resulted in several valuable insights. One of the more prominent findings when testing the prototypes was that the learnability of the systems were very high, despite the prototypes being quite different. The tasks that required similar actions were easily found in the second test compared to in test one.

The findings were used for a fourth and final iteration of the thermostat user interface along with the application onboarding of comfort temperatures and introduction to setpoint scheduling.

Initially the authors believed that the conceptual model should describe the systems behavior exactly, to support the user in understanding the devices. However, it was found that describing that the system is doing nothing to reach a lower temperature did not help users decide if they needed to adjust the settings or not.

Key takeaways:

- Reading dialog texts are not very common, users click depending on button color (in other words, dialogues and texts should be considered an ineffective way of communicating)
- Learnability between prototypes in test 2 are high, when an action has been found in the menu or settings, the task is very easy to complete in the second test - they can be considered fairly simple from this.
- Timers need a confirm/start button. It is not clear enough with the time just starts ticking when clicking the feature (fewer interactions is not always beneficial).
- The presets are understandable. However, the authors thought it is ethically questionable to contextualize them to a degree that clearly describes occupancy.
- Current temp and moving element helped understand what direction the temp is going. More so than static bars for feedback, however in relation to each other it was clear what all of them meant.

- Hard to say what if permanent changes or temporary changes were preferred. However, it was expressed that permanent changes is what they anticipate when changing the temperature in both prototypes. Timers become more important if deciding to use permanent changes to schedule in the main view.
- The feedback appeared to be enough for users to understand that you are on a schedule and that it will change temperatures automatically, this provides positive results that the person scheduling will not be the only one understanding the thermostat information.

7
Result

In order to present the result, the chapter will start with a description of the behavior archetypes that were created from the user research. The final concept - Ethermal, is then presented through its setup and thereafter the features that it possesses. In the next section it will continue to present the design considerations, by exemplifying how they are apparent in the final concept.

The research question that the result seeks to answer is:

What design considerations are important in regards to supporting users' mental model, when designing the UX of a floor heating system?

7.1 Final behavior archetypes

Four different behavioral archetypes could be deduced from the user research, they aim to explain the motivations and goals of users, but should be seen as behaviors users can move between depending on changes in priority.

7.1.1 The low effort archetype

The first archetype is the *low effort behavior* (fig. 7.1). This behavior has the goal of achieving some sort of comfort through minimal effort. This archetype has a low interest in interacting or actively checking the system to keep thermal comfort, and just wants the system to work without any heavy effort. If this behavior is apparent in the beginning of the usage, there is a low change of exploring the device features. This results in needs such as having a system that does not require attention to work and can in best case just be plugged in and used straight away without any adjustments or changes. This behavior can be considered to be more apparent in the secondary user in a household.

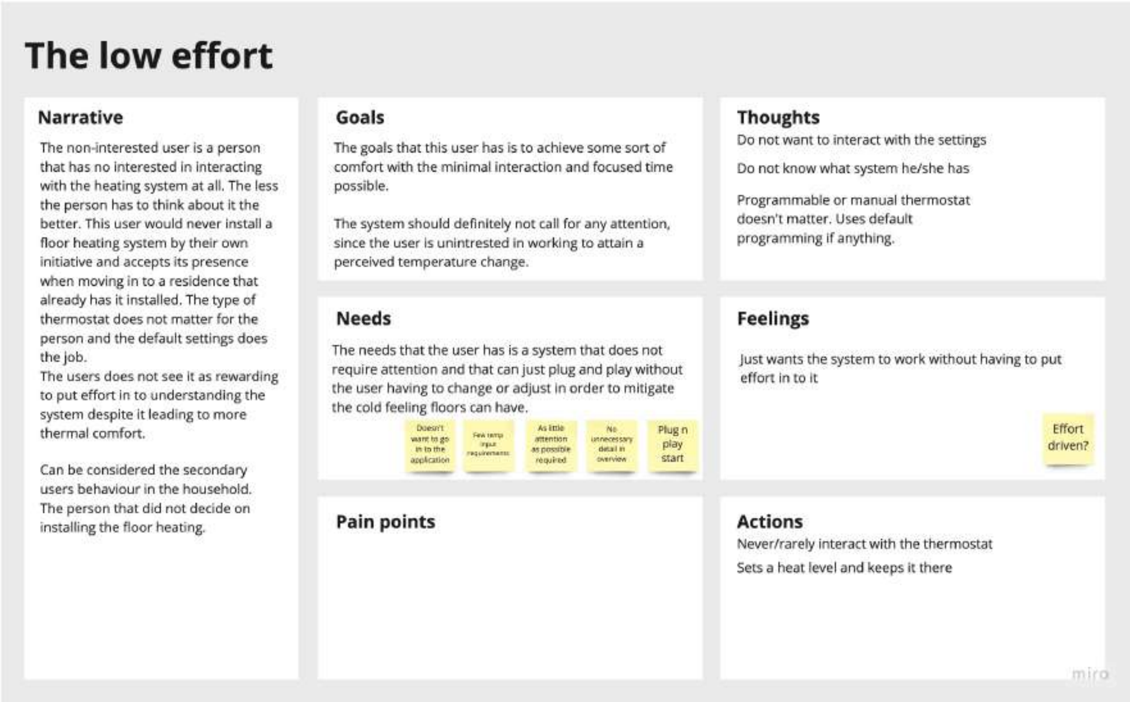

Figure 7.1: The low effort/non-interested archetype, with the goal of achieving a degree of thermal comfort through minimal effort. [Authors own image]

7.1.2 The comfort dependent archetype

The second archetype is the *comfort dependent* (fig. 7.2). This archetype has the goal of always having thermal comfort at the cost of sometimes having to interact with the thermostat and disregards the energy cost to a large degree. This could easily lead to a behavior where the users thermostat is simply on constantly day and night. As the archetype values thermal comfort above anything else, there is also a high chance that there is floor heating in more than one room.

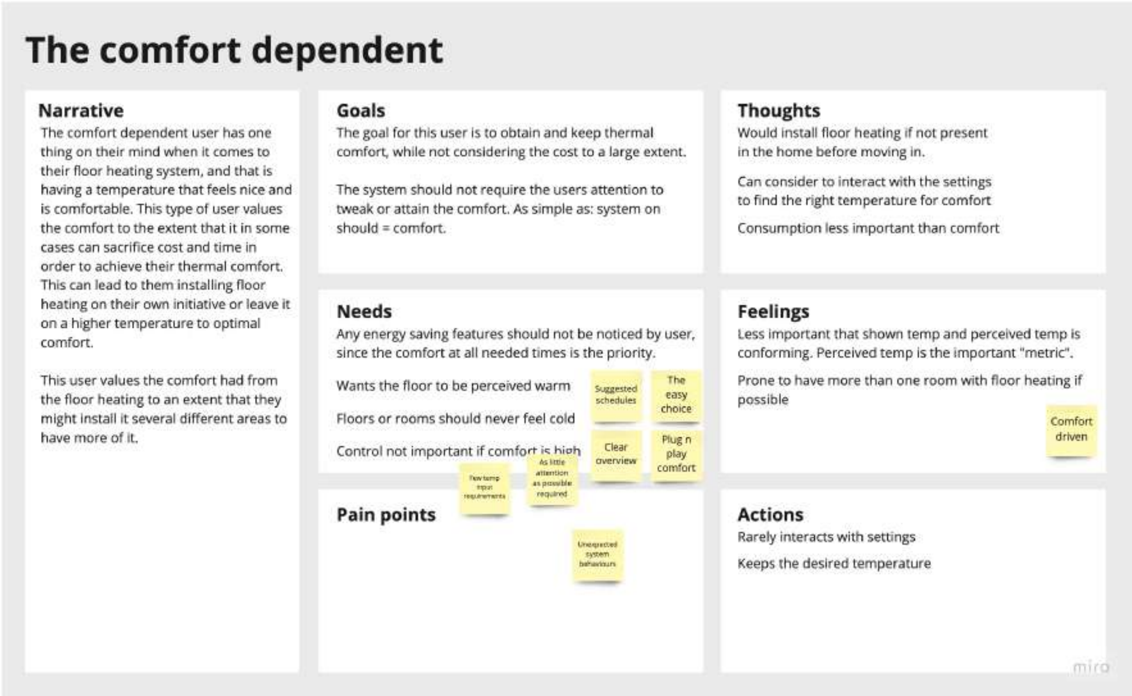

Figure 7.2: The comfort dependent archetype, with the overarching goal of always having thermal comfort at any cost. [Authors own image]

7.1.3 The optimizer archetype

The third archetype is *the optimizer* (fig. 7.3), whose goal is to optimize the system to cater the most amount of thermal comfort to the lowest cost. This archetype does not mind interacting with the system and can in some instances even like it. He/she is aware of how the system works and is always aware of the state, such as what the temperature and mode it is set on. The needs that the optimizer has is to be able to control the system to a high degree along with having a shown temperature that is conforming with the perceived temperature. This can in some cases be a pain point for the user along with having unexpected system changes. To fit the needs that the optimizer has, a user with this behavior tends to schedule their heating throughout the day and base it on their occupancy to not heat it up unnecessarily.

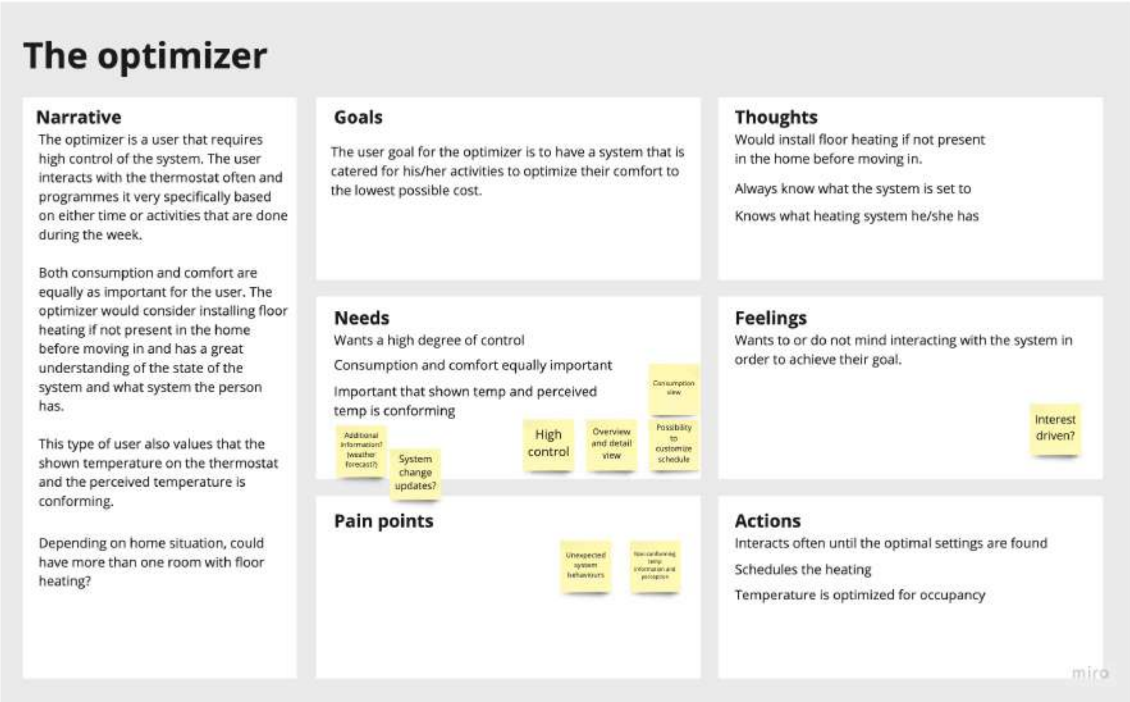

Figure 7.3: The optimizer archetype, with the goal of optimizing the system to cater thermal comfort through efficient and personal system settings. [Authors own image]

7.1.4 The consumption concerned archetype

The last of the behavioral archetypes is *the consumption concerned archetype*(fig. 7.4). This archetype primarily aims to achieve an effective way to heat and minimize unnecessary energy consumption in the process. This user can often endure a lower degree of thermal comfort in order to save energy. Unlike the comfort driven behavior, this archetype does not want to heat up the residence without really finding the need. The consumption concerned user has the floor heating on to achieve a floor temperature that does not feel cold to the touch rather than to have it hot. This archetype, similarly to the optimizer, is aware of the current system state and also wants a high degree of control in the system to tune it towards its goals.

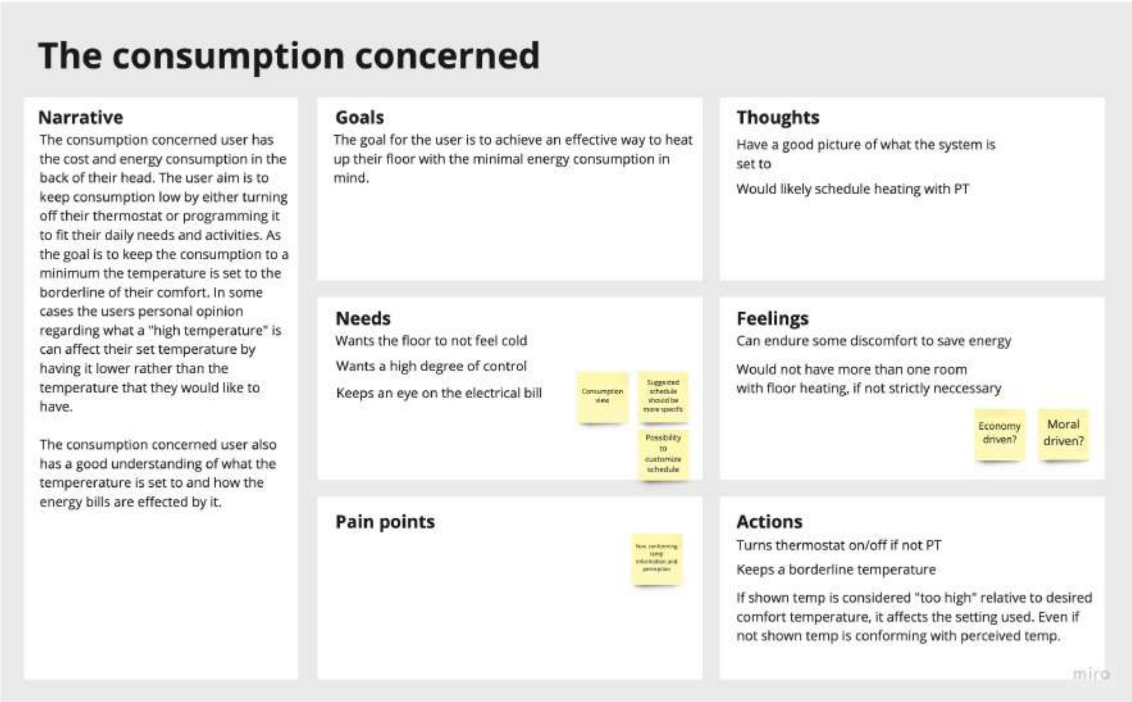

Figure 7.4: The consumption concerned archetype, who can endure a lower degree of thermal comfort in order to reduce energy consumption. [Authors own image]

7.2 The concept - Ethermal

Ethermal is the product of two user interface concepts that were created to exemplify part of an experience of using smart home floor heating. The user interfaces in this case should be viewed as examples of parts in a potentially larger system in a real solution. The first part of the concept, the mobile application, represents how the user could be involved in the setup process and gets introduced to the personalization and automation aspects available in using a smart home floor heating thermostat. The second part is the interface of the accompanying wall mounted floor heating thermostat. This section will present and focus on how the UI and flow works, and in a later section explain how each design consideration is present in Ethermal.

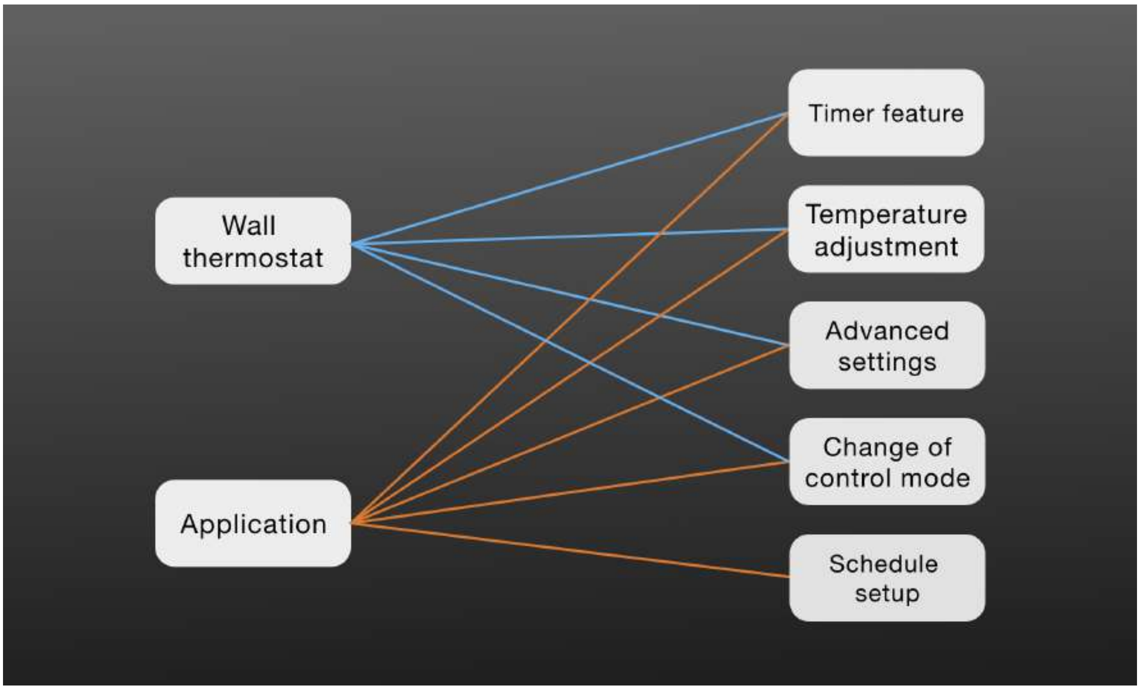

Figure 7.5: Overview of section 7.2, the thermostat and the application.

7.2.1 Onboarding

When the product is installed by a certified technician, the device will guide the final user through the rest of the setup. This starts with asking the user to open the "Heating app" and scan the QR code to connect the thermostat to the application and local network (fig. 7.6).

Figure 7.6: Thermostat setup - Scan to connect. [Authors own image]

After the user has connected the thermostat to the application, conforming feedback is shown both on the thermostat display and on the initial screen in the application to convey that the setup is active, as shown in figure 7.7.

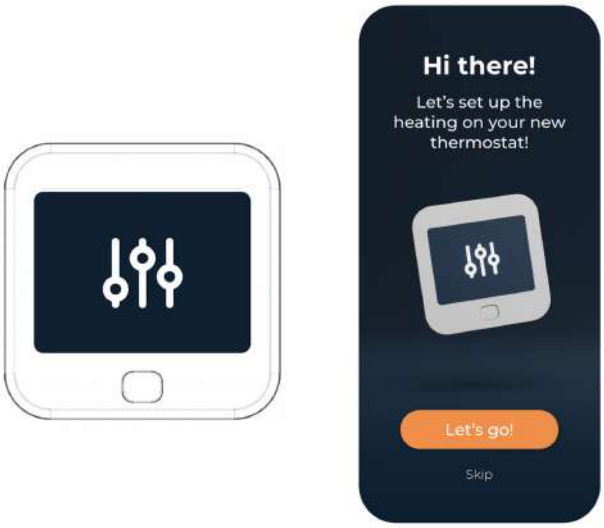

Figure 7.7: Feedback on both devices that the setup process is active. [Authors own image]

The onboarding contains options and information that aims to introduce the user to what can be anticipated through the use of the heating features, what preferences are available and the concept of automation in the form of a weekly heating/energy saving schedule. The flow can be seen in figure 7.8, which starts at the upper left image and ends at the lower right image. The setup, excluding the start screen and overview screen, will take the user through either three or five settings depending on their preferences.

Selecting room or floor regulation

The first stage is choosing if they prefer primarily adjusting the floor or room temperature with the heating system (image 2 in 7.8). Since floor heating is radiant heating in principle, the floor works as the heating element for the room. Typically, users control either the floor or the room as the primary target. The user research showed that people have varying preferences to which one they primarily consider when adjusting settings. Ethermal therefore takes this into consideration by making the options clear in the setup process in the application and communicates what the choice implies. Furthermore, the chosen medium is also communicated on the thermostat main screen (fig. 7.97.10) and allows later changes through advanced settings on the thermostat.

Selecting thermostat control mode

The next stage in the setup is choosing the control mode of the thermostat, if they want to keep a constant temperature or to have an automated heating schedule (image 3 in 7.8). If the user chooses a constant temperature, the application continues to ask what temperature it should keep and the setup is finished. But if the user chooses to schedule the heating, the user will choose what temperature it should target for times when comfort is desired (image 5 in 7.8) and will continue to ask what days and times comfort is not needed, in order to save energy (image 6 in 7.8). To convey how the system will behave, a visualized graph of the energy use/heating is used for this activity. This flow of scheduling was chosen to primarily keep the automation simple and not require the user to think about multiple temperatures for multiple occasions, which other devices do. The user research also showed that the primary use pattern of floor heating is keeping one temperature and, if anything else, turning it off when not needed. This holds a familiar aspect to the automation process.

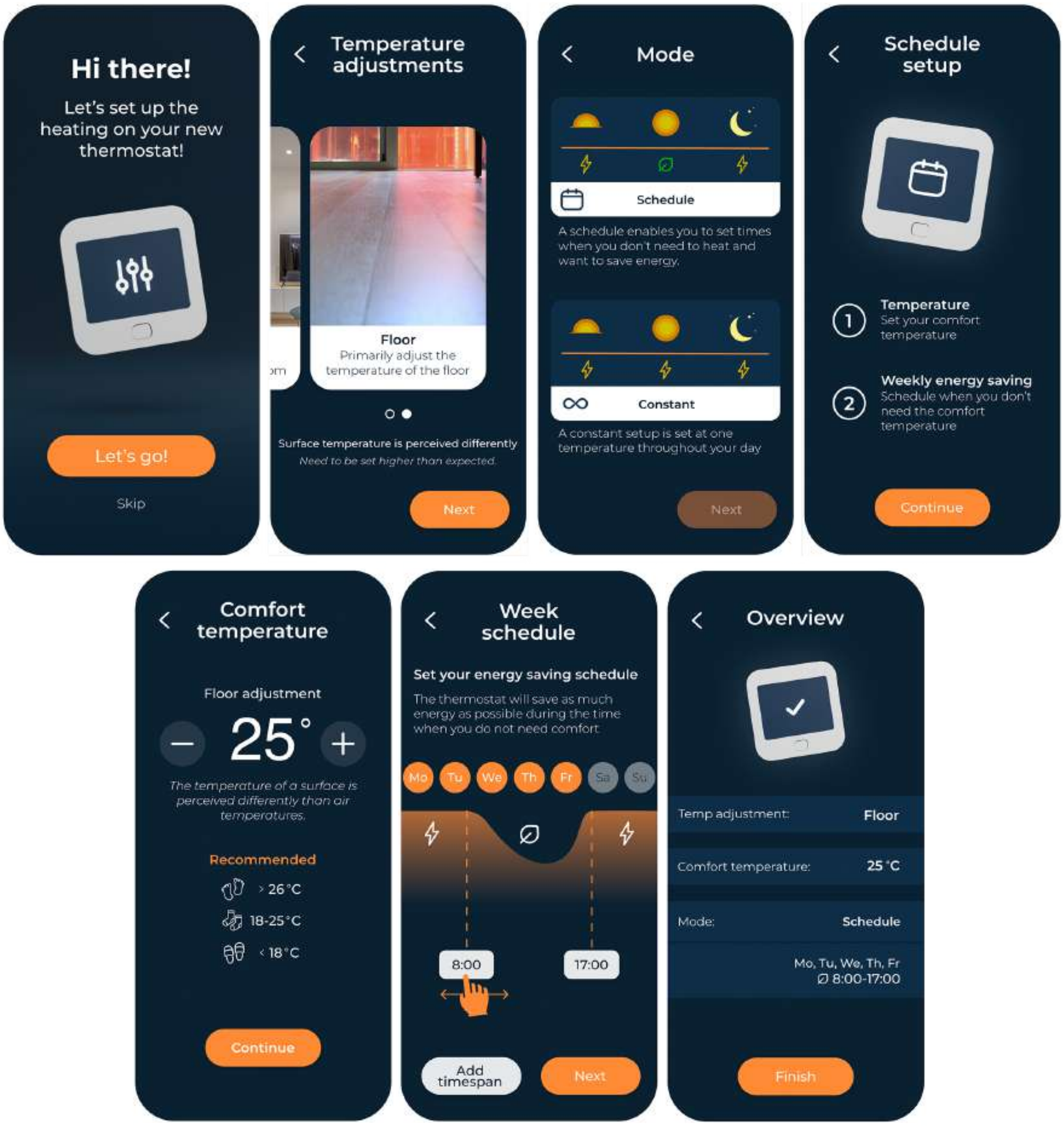

Figure 7.8: Introduction to floor heating options through personalization onboarding. [Authors own image]

7.2.2 Thermostat control modes

The system contains three modes that constitute the overarching control the user has of the heating; Constant, Schedule and temporary (Timer). These differentiate by their temporal aspects. The goal of integrated smart home technology is to provide more control and improve the lives of users [22]. But smart systems automation functionalities have a tendency of crossing invisible boundaries, and users feel that they are at the mercy of this technology rather than controlling it[22]. The reason Ethermal has three distinctly different temporal modes is to allow freedom of control to different types of situations or use behaviors.

Constant mode

The constant mode is as the name suggests, a mode to keep one constant temperature. This mode does not make any automated changes during the day or week. The user has the ability to set a temperature that does not fluctuate. It is a mode fitting for users who have a hard time scheduling their days due to irregular routines or conflicting schedules in the household. The mode is also fitting for the *low interest* user as it allows for a low threshold for users who do not have the interest to personalize a schedule. Similarly the *comfort dependent* user, who does not want to risk the floor to be uncomfortable during irregular days can benefit from having a constant comfortable temperature.

Figure 7.9: Thermostat main screen in constant mode. [Authors own image]

Schedule mode

The schedule mode allows users to tailor their schedule for a balance between thermal comfort and energy consumption by programming recurring setpoints. The mode enables users to set the times where they do not need a comfortable temperature, which sets all other times during the week to be at a comfortable level. Cases where the user is not in need of a comfortable temperature is such as a person leaving the house for work everyday for 8 hours. The schedule would enable you to lower your energy consumption during those hours to then heat it up in time for you to come home. This is a mode that fits a variety of users, the *consumption concerned* and *the optimizer* are behavioral archetypes that have goals that can be fulfilled with this mode. A schedule might not fit the primary goals of the *low effort* and *comfort dependent* archetypes, but this does not exclude that they would be able to see benefits of using this type of mode.

Figure 7.10: Thermostat main screen in schedule mode. [Authors own image]

Timer mode

Timers are a feature that is commonly seen in various thermostats, which was concluded in section 6.2. The timer in Ethermal is the primary and only way for the user to make temporary changes. The mode can be used both when having a system that is set in a constant mode as well as a schedule. The system simply returns to the previous mode when the time runs out. This mode is good for when users want to make temporary changes when user routines and preferences are broken temporarily. This could for example be to compensate for temporary environmental changes that are not in need of a permanent change. Timers enable users to adjust and tailor the temperature for their situational preference, to raise the perceived and practical control of the system, which suits *the optimizer* well.

Figure 7.11: Thermostat menu, timer setup and main screen during timer. [Authors own image]

7.3 Design considerations for floor heating

The resulting design considerations will be presented in this section. They should be thought of in relation to each other in order to get a holistic view of some of the complexity in floor heating systems. The design considerations aim to create an User experience that is usable, efficient and pleasant to use. Each consideration will then be presented together with the background problems leading to the considerations development and examples of how the project implemented them in Ethermal. An overview of the design considerations can be seen in the list below.

- Aligning mental models by introducing the user to system functionality
- Considering the significance of thermal perception
- Choosing the thermal scale
- Providing complimentary information to ambient awareness
- Using preheating behavior for automation in high-inertia systems
- Providing easy access to permanent changes of recurring setpoints
- Slimming the feature set down and using appropriate microcopy

7.3.1 Aligning users mental models by introducing the user to system functionality

Developers of systems that require expert technicians to install them should consider designing the setup process to involve the user to some degree; it can be seen as an opportunity to support the formation of users' mental models and introducing system functionality. Benson [6] explains that gaps between mental models can be improved by utilizing interactive tours or careful onboarding to aid in understanding a new product, an introduction to it. By carefully designing the initial part of the use, the user gets acquainted with heating concepts while also getting an understanding on how to tailor the system for their individual needs and preferences [6].

Current electrical floor heating thermostats are lacking in an introduction to the product, which can be seen in section 6.2.1. Ethermal utilizes the design consideration by having a personalization onboarding (fig. 7.8, 7.12). It introduces the floor heating options to users through a step by step option process. The process aims to be short and informative by guiding the user through what can be anticipated from the options. With this information, the formation of a mental model would be supported, which would help the user become familiar with how to edit settings if their preferences change.
The scheduling procedure in Ethermal aims to be as simple as possible to reduce the complexity of the feature. The user sets their comfort temperature to their preference, and then the days and times that they are not in need of the comfort temperature. This aims to save energy while also achieving thermal comfort during the periods the user wants it. An example of this is shown in figure 7.12 and 7.13.

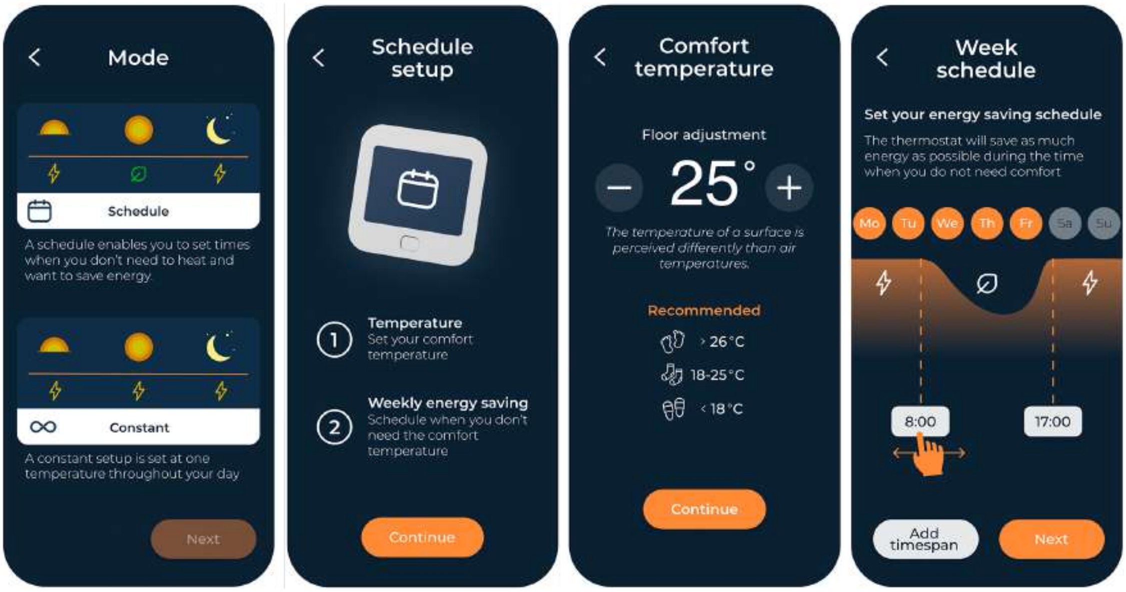

Figure 7.12: Part of the introduction process - scheduling energy saving setpoints

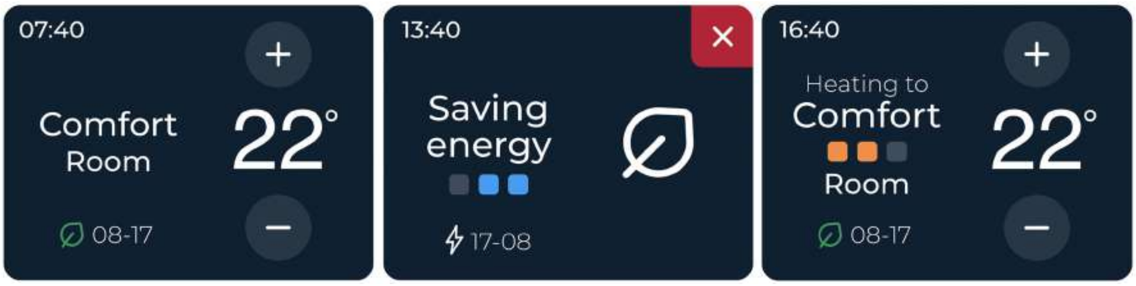

Figure 7.13: Thermostat UI showing behavior based on schedule

7.3.2 Considering the significance of thermal perception

When designing the UX of a radiant floor heating system that uses a temperature scale, the designer needs to be aware that the perception of air temperatures cannot be directly translated to how users will perceive the temperature of floor surfaces. Cognitively users picks up information from surroundings in parallel with processing data from memory [7], where the stimuli (Bottom-up processing by touching the floor) tells the user if the surface feels cold or warm, while the memory of the temperature shown (Top-down processing from previous experience) is processed in relation to the perception. It was expressed in the interviews that no user, that had a temperature scale, perceived the floor temperature to be the temperature that was set. Energimyndigheten [1] explains this by describing that a surface set to a temperature of 22°C doesn't feel particularly warm. This was also tested by one of the authors in section 6.3.5, where it could be subjectively confirmed.

The onboarding process is a way that Ethermal introduces the users to the two temperature adjustment options that are available (fig. 7.14 7.15). It provides descriptions of each option, with the goal of supporting a mental model that can be used in order to control the system to fit their needs. For floor heating, the user is informed that the surface temperature on the floor is perceived differently and suggests what can be anticipated from choosing different options. The UI provides recommendations on temperatures, and maps out what the anticipated temperature range might feel like through icons, as can be seen in 7.16.

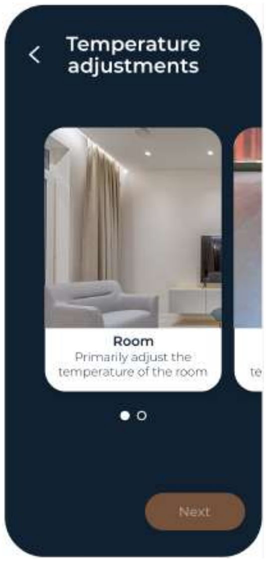

Figure 7.14: Set up choice of primarily regulating air

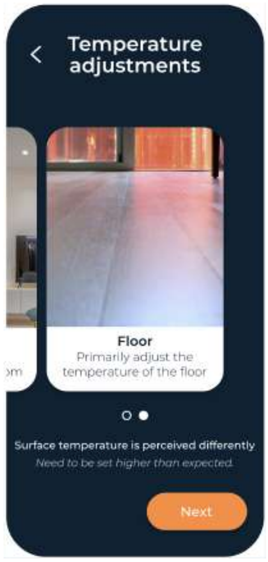

Figure 7.15: Set up choice of primarily regulating floor

Figure 7.16: Set up suggestions for picking comfortable floor temperatures

7.3.3 Choosing the thermal scale

It was deduced from the interviews that abstract heating scales, such as ones ranging from 1-5, requires a learning curve in order to relate the scale to a thermal level through experiencing the range. In relation to the high inertia of radiant floor heating, this can take days or weeks to become familiar depending on how actively the user interacts with the settings. The temperature scale however, communicates in familiar thermal terms, since users are aware of it from previous experience and is conforming to most mental models. However, in relation to the medium it describes (air or surface), the thermal perception and temperature can appear less conforming. This means that the design choice comes with problems either way, but having this design consideration in mind early can help the development of the overall system. So the consideration can be described through Nielsen's [41] two options when designing for mental models; the first one being to design the system and product to conform to the users mental model (utilizing a familiar thermal scale), and the second one being to try and improve the users mental model to be aligned with the system (utilizing a different thermal scale that the design needs to help users understand).

The prototypes through the project have used and tested different variations of scales, they can be seen in A.15 and the prototype iteration process 1-2. The different scales that have been used ranged from Celsius scale to more abstract scales of various levels. In 7.17 and 7.18, two of the early prototypes can be seen. For participants in the prototype evaluation, these versions were hard to understand and anticipate the thermal outcome when adjusting.

Figure 7.17: Early prototype that only uses 3 thermal presets, max, comfort and cold

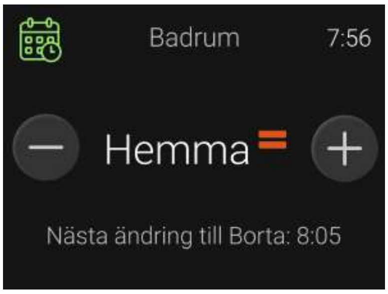

Figure 7.18: Early prototype that used a bar scale ranging the steps over or under a thermal baseline called Home ("Hemma")

The design choice for Ethermal was to utilize a temperature scale (fig. 7.19). This way, Ethermal follows first of Nielsen's [41] suggestions in designing for mental models; designing the system to conform to the users mental model, rather than aiming to align the users mental model for a different thermal scale. By choosing the temperature scale, users will be familiar with the terms it communicates in, since they know it from previous experience. This supports the calm technology principle: "technology can communicate, but doesn't speak" [10, 8]. A temperature scale is familiar and requires little to no learning, which is why it is compliant with users' mental models. They are able to anticipate how big effect an adjustment will result in and make an informed decision from this.

Figure 7.19: Ethermal thermostat main view in constant mode, showing the Celsius temperature scale

7.3.4 Providing complimentary information to ambient awareness

Since floor heating systems have high inertia, it does not have the ability to provide immediate physical feedback to adjustments. But heating systems hold constant peripheral information, for example the temperature in a room is sensed through one's feet and body. This ambient awareness should be considered a part of the interface of the system, as it is also a pattern for calm communication [10]. As calm technology is a type of non-intrusive design, which aims to be peripheral and not require users active attention. In relation to this ambient awareness, the thermostat display should also contain relevant information, to be available at a glance. Current temperature could be considered less important information, in relation to what is already perceived. Instead the thermostat information should complement what the user perceives through the environment, the UI should aim to fill in the gaps in order to provide a mental model of what the heating system is doing. In accordance to the calm technology principles, this information should allow people to shift their attention for a second, get the information needed, and shift back without being overwhelmed [10].

By making use of the peripheral information users get through ambient awareness, which allows them to know something without needing to actively investigate, Ethermal doesn't hold the current temperature in the thermostat as it can be considered redundant. Instead, to complement the ambient awareness, the user gets visual status indication on the thermostat which includes the target temperature, with the addition of the working direction of the system (the relational direction between the currently perceived temperature and the temperature goal) as seen in figure 7.25, 7.21. It also communicates that the system is not in equilibrium, however, when it has reached the target it does nothing.

Figure 7.20: Adjusting target temp. to higher

Figure 7.21: Adjusting target temp. to lower

Visual status indicators are considered one of the calmest ways of conveying a piece of information and are ideal for communicating low-importance and persistent information [10]. It was found in the evaluation and tests that the combination of ambient awareness, target temperature and system direction forms a mental model that supports the user in informed decision making. From this information the user can deduce if an adjustment to the settings is desired or if it was working in a satisfactory direction. This combination of ambient awareness and simple visual status indication strengthens the calm communication aspect of Ethermal, as it supports communication at a glance. Case [10] describes calm technology to ideally allow the user to briefly shift their attention to the technology, get the information needed and then shift back.

Showing the direction of the temperature in Ethermal (fig. 7.22) provides a conceptual model that is non-conforming with real system behaviour, as the system cannot actively work towards lower temperatures. However, the moving and colored element that constitutes the temperature direction, was found to be a simplification that worked better in supporting a mental model when deciding if interaction is needed. This further aligns with Norman's view on how conceptual models can describe complex systems in a simple way [44]. The design of the moving element aims to, through the metaphor and semantic meaning of the colors and the direction it flows, express its current operation as described by Monö [37].

Figure 7.22: Moving element communicating direction and no equilibrium

7.3.5 Using preheating behavior for automation in high-inertia systems

Since radiant floor heating is a system with high inertia, changes are slow to take effect and be perceived in the environment. A problem described in the user research was not having a comfortable temperature at the times it was desired in their heating schedule. The reason was that the system started heating at the time the user scheduled the temperature setpoint (e.g. scheduled heating at 06:00), which needed to be rescheduled multiple times in order to explore what time that needed to be scheduled to attain a comfortable temperature at 06:00. This was not conforming to the user's mental model and experience of scheduling and resulted in more ineffective scheduling either for their thermal comfort or from an energy consumption perspective. What the user expected to experience was the temperature that was set at 06:00. When designing a thermostat for a high inertia system, the developer should consider utilizing proactive setting behavior as a default for automated heating, since users will not always be able to anticipate the temporal aspect in those types of systems. This is in line with Nielsen's [41] description of instead choosing the option to design a product to conform with the users mental model, rather than trying to align the behavior and mental model of the user.

To create a pleasant user experience, Ethermal pre-heats by default when setting up a schedule, it starts heating before the setpoint in order to reach the desired temperature at the time the user expects. Ethermal has this visualized through a graph in the guided setup process (fig. 7.23). This informs the user about the preheat feature and decreases the uncertainty when adjusting their schedule. This is in line with users' mental model of scheduling heating and makes the process of setting up a desired temperature setpoint something they can get right at the first try, providing a good user experience.

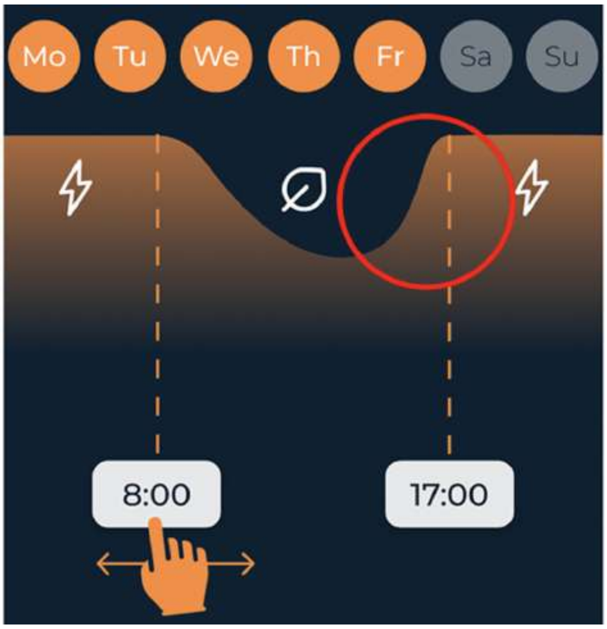

Figure 7.23: Pre-heating to setpoints in order to not having to consider the slow response

7.3.6 Providing easy access to permanent changes of recurring setpoints

The user research showed that people rarely interact with the devices when the comfort temperature is found. The initial process of finding a good temperature is therefore of importance and should allow for an easy way of making adjustments, as well as how the temperature might need changes with the season. Making permanent changes encourages less interactions between the system and user and also ties to and is supported by the Calm technology principle *The right amount of technology is the minimum needed to solve the problem.* [57]. Current solutions temporarily override the schedule when changes are made, or doesn't allow temperature changes at all in schedule mode and requires the user to reschedule with new temperatures to make the change reoccur.

Figure 7.24: The comfort temperature set to recur as 21° during the week

Figure 7.25: Adjusted comfort temperature set to recur as 25° during the week

Ethermal provides the controls for permanent schedule changes on the home screen of the thermostat in order to make it as easy and efficient as possible for the user in the initial phase of usage. Putting the more commonly used options shallow in the architecture adds to the systems efficiency, which is one of the factors for a usable UI [39]. The UI homescreen is largely taken up by these controllers and aims to create affordance for these changes. When changes are done, the user gets direct visual feedback both from the numbers changing along with microcopy that states that the Comfort temperature is adjusting. Ethermal expresses that it is "adjusting comfort" to 25° (fig. 7.25), which was initially set to 21° in figure 7.24. The more uncommon temporary changes are done through timers that are put deeper in to the system.

7.3.7 Slimming the feature set down and using appropriate microcopy

Found in the competitive analysis, site-mapping and cognitive walkthroughs several floor heating systems on the market provide a wide variety of functionality and features in their thermostats. Microcopy in an interface are short sentences or naming that tell users what to [32], and these features often share the same microcopy in-between devices, which as previously mentioned can provide powerful hints to the features and possible actions [32]. Carefully considering the microcopy, which are short sentences or naming that tell users what to do and address user concerns and can provide context to a situation, will help shape a mental model by helping the user anticipate an outcome. The problem area is that the function of the features are not the same despite the same naming. Thermostats are commonly also seen to have features that are redundant in the overview of the system. A common issue seen from the competitive analysis is that manufactures use different instances of temporary temperature adjustments as different features. This provides a conceptual model that appears more complex than the system needs to be. For example features such as boost, schedule override and timer. The boost feature varies between set temperature for a certain amount of time, to any temperature in any amount of time. While the option to set a timer is still provided, which can match the temperature for the same amount of time. A reduced amount of redundant features that is more aligned with the system actions would in this case be more useful and also inline with Norman's view on conceptual models [44]. There would also be more schedule override features that alter the current time slot in the schedule temporarily, e.g. until the next setpoint. This leads to redundancy and contradicts the Calm tech principle *The right amount of technology is the minimum needed to solve the problem.* [10], [8].

The developer should consider what features are truly needed for the system and keep it to a bare minimum in order to reduce the complexity of the conceptual model and redundancy. The designer should thereby also consider the microcopy and naming of features to support the user in forming a mental model that is in line with the system behavior and describes the feature, so that the user can anticipate what using it will result in. Ethermal have taken this into consideration by scaling down the provided functionality to the bare essentials to provide a less complex conceptual model of the system, for example only providing one temporary adjustment feature which is called *Timer*.

8
Discussion

The chapter discusses the study and the thesis. It involves discussions in the area of the studies process leading to its result, related works, ethical considerations, the result itself along with thoughts on future work.

8.1 The result

The behavioral archetypes
The behavioral archetypes were used due to its nature of being non-static, meaning that behavior can be shifted in between the archetypes depending on motivational factors or a change of interest. This was through the collected data seen to be an appropriate way of defining users behavior in real life. Users can for example shift in-between the behavioral archetypes when there is an increase of energy prices, which can turn the "comfort dependent" behavior into "consumption concerned" behavior. This makes it important to develop a solution that supports a change in behavior, which otherwise could limit the users perception of control.

Despite the effort of trying to make the behavioral archetypes representative of most users, it cannot be said to be representative for all users. The behavioral archetypes are generalizations based on the collected data, which has to be questioned due to sample size and the participant selection process. There is a risk that the data can be miss representative, resulting in behavioral archetypes that do not represent all users. There is for example a lack of consideration for different disabilities in the archetypes and is something that could be further developed in order to increase its accuracy and representability.

Calm technology
Depending on the environment, the UI element for communicating the current temperature can be more or less present through constant environmental temperature changes. If this fulfills the principles of calm technology can be questioned. An element on the thermostat that is regularly blinking and moving could be considered attention grabbing. There might be a different option available that works better for homes that experience regular changes in ambient temperature.

The system's ability to actually reach the target temperature affects how often the user will see the moving element. There is a possibility of having limited power to reach higher temperatures, or reaching lower targets in hot climates. If the system is not able to do so, it will provide constant feedback that it has a goal different from where it currently is, which can become attention grabbing and disturbing. What should be considered then is avoiding the possibility of choosing temperatures that are not reachable.

Temperature scale
In addition to using a temperature scale because of users previous knowledge of it, a strong reason for using it is compatibility with third party smart home ecosystems. Other systems, like Alexa, Google Home and HomeKit utilize the Celsius and Fahrenheit scales in their applications. If one were to develop a heating system that provided a different scale for heating to the user, as well as giving the possibility to integrate into other smart home ecosystems, it would pose a cognitive challenge. The thermostat would locally present its base heating scale, while using a third party smart home application would present the user with the Celsius or Fahrenheit scale. The connection between them would be non-existing.

Hydronic floor heating The project has focused on electrical floor heating systems, thus the behavioral archetypes and design considerations was developed through user research mainly with them in mind. Behaviour and needs for users of hydronic floor heating systems may be different, however, hydronic floor heating would also be considered a high inertia system. Through the general expression of the design considerations, they may be suitable to use in the development of hydronic systems as well, since they work through the same energy transferring principle.

Evaluation of the final concept - Ethermal
The final prototype has not been evaluated because of time limitations. It was made through refining the previous prototypes that were evaluated in regards to supporting users' mental model of system behavior and have taken the considerations that were found into account. If it will be understood and used successfully cannot be determined at this stage.

The participants in the interviews that lived in a multi member household were asked if there are moments when they have different temperature setting preferences for comfort than their household member. Those participants expressed that it was never a problem. However, for future research, this should be researched further as it can affect the gravity of the choice of having permanent schedule changes in the main view of the thermostat. Another risk of having permanent changes to setpoint temperatures on the thermostat is that "feel at home" guests can affect the comfort temperature. However, the Ethermal thermostat UI supports an easy way to change back.

This work has aimed to enhance the user experience from previous systems by creating a more effective and understandable system in order to make it usable and fulfilling of users needs. A lot of work was aimed towards simplifying the information and features compared to the current market devices, since the user research showed that the typical use behavior rarely means changing settings or interacting with the product. It is because of this the solution should try and conform with calm technology principles and inform the user with current system behavior. However, simplifying the information compared to current market devices will not insure a good product per se, since the researchers do not consider comparing Ethermal to the market devices as a metric that is reassuring, because they are considered by us to have a low level of usability.

In situations when controlling the temperature remotely, ambient awareness would not be available. It should be considered if remote control through the application might need to contain current temperature information. However, in the interviews it is was expressed that the remote control would be primarily useful for turning the heating off/on when traveling/going back.

The onboarding has not been evaluated to a great extent in this study. The feedback gotten from peers by an overview of the process was positive. Ethermal could be thought of as an inspiration of how the researchers consider it to support the users in understanding scheduled setpoints. This is a concept that is still in the need for evaluation and testing in order to understand its effects.

8.2 Method

Behavioral archetypes
The project has taken privacy aspects into consideration in the user research. This affected the participant selection process for the questionnaire and evaluations, this part of the data have been done with people internally in the company. The authors have tried to make it as representative as possible within these participants by asking people not involved in the project, but it can be questioned if this has had an effect on the validity of the findings.

Subjective experiment
The experiment done in section 6.3.5 was added when the data from the interviews showed that users tend to perceive the floor temperature and perceived temperature to be non-conforming. To build upon this data, the subjective experiment was done in order to get a better understanding of the perceived to real temperature. This method was highly subjective and is almost certain to vary depending on body temperature and person, but gave the researchers a slight insight to the issue, despite it not being done on scale or precisely measured. It also highlighted the difference and impact the floor material has on the perceived thermal level, which is a subject for future research.

Questionnaire about floor heating usage
The questionnaire that was done was sent out internally in the company that the project was written in collaboration with. This has increased the potential risk of the data being skewed. Even though almost half of the participants had not worked with heating systems, it does not cancel out the possibility that they are more knowledgeable within the domain as it is being developed within the company.

This could have led to a data set with participants that have more advanced needs but it a factor that is hard to fully confirm.

Usability tests
Usability tests were done in order to seek empirical evidence regarding the usability of the different prototypes that were developed. It resulted in getting an understanding of the users mental model of the systems along with usability issues that were present in the iterations. Certain tests set scenarios for the users which might not reflect how the scenario in real life would play out. The tests were also done in a short manner due to the available time and resources and would have seen a benefit of being conducted over a longer period of time. This is both because of the high inertia of the systems which is hard to replicate but also that it is interesting to see how the users behavior with the system would develop with time and the different seasons in a year. This leads to a more longitudinal study done in an environment with a tangible floor heating system would be beneficial in order to get more accurate results.

8.3 Future work

Due to resource and time limits that the thesis has encountered throughout the study, there have been areas and topics that have not been researched properly or have been left untouched. This section will present the areas and topics that the researchers suggest are relevant for future work.

Longitudinal studies are needed
These tests and evaluations that have been done in this study have only taken into consideration short term decisions and behavior, by instead presenting long term scenarios for the users. It is of interest to conduct a study that investigates the empirical and longitudinal effects of users' control preference and usage.

A longitudinal study would also be beneficial in order to truly test if the design considerations comply with Calm technology principles. The design considerations should be integrated into a working solution that has the ability to regulate temperature in a testing area or home. This would enable the researchers to fully understand the result and effect of the design considerations through empirical data.

Current temperature and target temperature in combination also showed success in tests. More tests between interfaces that hold current+target and only target+directional relation to perceived environment.

Installation conditions
Since licensed electricians are required to install this type of products, their installation conditions also dictate much of what is possible to provide in terms of functionality based on sensor setups. The device might be placed in a location where all sensors cannot precept the environment that is going to be controlled. This raises

the complexity of the problem with available information in relation to primarily controlling floor or room temperature. Furthermore, there are some situations when no sensor can be used for temperature regulation and need to be solved in alternative ways. What this means in regards to changing metrics and how users understand the settings have not been researched. This needs to be done for an understanding of those situations. The process of installation should therefore also be taken into account to a greater extent than this report does. This is an area that is subject for future research, and the impact it has on the final user's experience. However, based on consideration 7.3.1 "Aligning mental models by introducing the user to system functionality", we suggest not leaving all setup options solely to the electricians, since there is an opportunity to introduce users to more complex functionality by involving them to some degree in a setup process or initial personalization phase.

Master control of separate areas

A relevant area to research is the combined control of multiple interconnected floors in the home. For example: the kitchen and the living room might have individual heating systems installed, but are considered to be an area that should have the same level of thermal comfort on the floor. The individual comfort settings needed for the areas could be different for them to be perceived the same (the perception can be different depending on area of floor and floor type). The project has loosely considered and tried to address this; How two separate settings could be controlled through a single subjective setting, by having subjective scales or having named presets that takes the temperature out of focus in some prototypes. However, this is a very complex problem to find a solution to, and might not even have a good solution. But further research could positively find consideration points from looking closer at this problem. Consideration 7.3.3 "Choosing the thermal scale" and 7.3.2 "Considering the significance of thermal perception" should be taken into account to a great extent when looking deeper into this.

Machine learning and AI

This study has not had the ability to dive deeper into the possibility of using machine learning or artificial intelligence for heating in high inertia systems. It is of interest in understanding what potential solutions there are for designing systems that do not need setpoint scheduling, but rather heats based on occupancy. The current system might not be fast enough to reach temperature if it activates based on user action. Artificial intelligence predictions would be needed in those situations, since radiant heating has such high inertia [1].

Future research should also take a look at how to support users' perception of who is in control if using geo-fencing or smart-metering functionality. Since smart systems can easily cross invisible boundaries, and users feel that they are at the mercy of this technology rather than controlling it [22]. A problem in UX with smart home devices that are automated to real time changes is what a setting change means and who is dictating the experience. An important goal of future smart home research should consider how to properly extend system functionality to create more control both perceptually and practically [22].

UI conventions on small displays and less ergonomic device placements
When working with small screens and possibly less ergonomic placements of thermostats, such as being installed outside the direct line of sight, UI conventions are sparse. This study has taken into consideration general guidelines, for example minimum 10x10mm hit boxes for buttons. None of the prototype tests found the UI to appear too small, however it was not explicitly tested. Further research would most likely benefit from testing this, in order to support the usability of systems with small displays and less ergonomic placements.

9
Conclusion

This study has aimed to develop and explore how residential floor heating systems can provide a better user experience for its end users in order to increase usability. This in turn has been suggested by research can affect sustainability aspects by providing users with better means to utilize energy saving features [45]. The research question for the study has been:

What design considerations are important in regards to support users' mental model, when designing the UX of a floor heating system?

To answer this question, a set of 7 design considerations have been developed using user centered methods. Several methods were used to find user behaviors around floor heating, as well as the relevant design considerations and exemplify these in a concept - Ethermal, that aims to support users behavior and mental models. This has been done by analyzing the domain and the current floor heating system solutions on the market. Furthermore, user research methods have been utilized in order to understand the user needs and behavior within the domain of floor heating systems, through questionnaires and interviews, resulting in a set of 4 behavioural archetypes. The collected data has been synthesized and has stood as the base for ideation methods on possible solutions. Further in the study, several prototypes have been iterated and evaluated in order to provide information in the user interface that aims to support, or is compliant with, users' mental models. The iteration and evaluation of prototypes also aimed to achieve a good overall user experience in the prototypes, along with refining the design considerations by testing them in the prototypes. The set of design considerations that the study has resulted in are the following:

1. Aligning mental models by introducing the user to system functionality
2. Considering the significance of thermal perception
3. Choosing the thermal scale
4. Providing complimentary information to ambient awareness
5. Using preheating behavior for automation in high-inertia systems
6. Providing easy access to permanent changes of recurring setpoints
7. Slimming the feature set down and using appropriate microcopy

The result also describes four behavior archetypes that exemplify different motivations and behaviors in regards to floor heating usage. The result finally presents a design concept, Ethermal, a thermostat with an accompanying application, which exemplifies how the behavioral archetypes and design considerations can be taken into account when designing a floor heating system. Ethermal aims to be an instance of what a user interface and user experience could look like when the considerations are implemented, rather than what a floor heating system interface should look like.

In relation to developing pervasive technology in home environments, a goal was to consider calm technology principles to keep the concept socially sustainable in regards to attention conservation. Ethermals thermostat takes this into consideration by providing relevant information that complements what is perceived through the environment, as well as aiming to communicate the information in a way that is understandable at a glance. Ethermals thermostat holds information in the main view that aims to support the user in the decision to interact, rather than requiring the user's active attention and interaction with the device.

In summary, the project has answered the research question through the resulting design considerations and has exemplified it through Ethermal.

Bibliography

[1] Swedish Energy Agency. Underfloor heating, Oct 2015.
[2] Alper T. Alan, Mike Shann, Enrico Costanza, Sarvapali D. Ramchurn, and Sven Seuken. It is too hot: An in-situ study of three designs for heating. pages 5262–5273. Association for Computing Machinery, 5 2016.
[3] Frances K Aldrich. Smart homes: Past, present and future, 2003.
[4] Nick Babich. Sitemaps & information architecture (ia): Adobe xd ideas, Dec 2019.
[5] Louise Barkhuus and Anind Dey. Is context-aware computing taking control away from the user? three levels of interactivity examined, 2003.
[6] Scott Benson. Leveraging mental models in ux design, May 2018.
[7] Mats Bohgard, Stig Karlsson, Eva Loven, Lars-Åke Mikaelsson, Lena Mårtensson, Anna-Lisa Osvalder, Linda Rose, Pernilla Ulfvengren, Anna-Lisa Osvalder, and Pernilla Ulfvengren. *Arbete och teknik på människans villkor*, page 355–360. Prevent, 2015.
[8] Calmtech.com. Our world is made of information that competes for our attention., 2022.
[9] Camunda. Bpmn 2.0 symbol reference, 2022.
[10] Amber Case. *Calm Technology: Principles and Patterns for Non-Intrusive Design.* 2016.
[11] Ned Chapin. *Flowchart*, page 714–716. John Wiley and Sons Ltd., GBR, 2003.
[12] Nicola Combe and David Harrison. A review and application of usability guidelines relating to domestic heating controls. *Intelligent Buildings International*, 6:26–40, 1 2014.
[13] Alan Cooper, Robert Reimann, David Cronin, and Christopher Noessel. *About face: the essentials of interaction design.* John Wiley & Sons, 2014.
[14] Jill DaSivla. A guide to competitive analysis for ux design, Jun 2020.
[15] Julia K Day, Claire McIlvennie, Connor Brackley, Mariantonietta Tarantini, Cristina Piselli, Jakob Hahn, William O'Brien, Vinu Subashini Rajus, Marilena De Simone, Mikkel Baun Kjærgaard, et al. A review of select human-building interfaces and their relationship to human behavior, energy use and occupant comfort. *Building and environment*, 178:106920, 2020.
[16] Interaction design foundation. What is brainstorming.
[17] Interaction design foundation. What is user experience.
[18] Interaction design foundation. What is wireframing.
[19] Google designsprint. Crazy 8.
[20] Radina Doneva. Behavioural archetypes instead of personas, Jan 2021.

[21] Steven Douglas. How to do a ux competitor analysis: A step by step guide, Sep 2019.

[22] Paul. Dourish and Adrian (Adrian John) Friday. *UbiComp 2006 : ubiquitous computing : 8th international conference, UbiComp 2006, Orange County, CA, USA, September 17-21, 2006 : proceedings*. Springer, 2006.

[23] Eurostat European Commission. Energy consumption in households, June 2021.

[24] International Organization for Standardization. *Ergonomics of human-system interaction — Part 210: Human-centred design for interactive systems*. International Organization for Standardization, Vernier, Geneva, Switzerland, ISO 9241-210:2019(E) edition, 2019.

[25] Kim Goodwin. *Designing for the digital age: How to create human-centered products and services*. John Wiley & Sons, 2011.

[26] Bruce Hanington and Bella Martin. *Universal methods of design expanded and revised: 125 Ways to research complex problems, develop innovative ideas, and design effective solutions*. Rockport publishers, 2019.

[27] Rex Hartson and Pardha S Pyla. *The UX Book: Process and guidelines for ensuring a quality user experience*. Elsevier, 2012.

[28] Brent Huchuk, William O'Brien, and Scott Sanner. A longitudinal study of thermostat behaviors based on climate, seasonal, and energy price considerations using connected thermostat data. *Building and Environment*, 139:199–210, 2018.

[29] Rikke Hagensby Jensen, Yolande Strengers, Jesper Kjeldskov, Larissa Nicholls, and Mikael B. Skov. Designing the desirable smart home: A study of household experiences and energy consumption impacts. volume 2018-April. Association for Computing Machinery, 4 2018.

[30] John Chris Jones. *Design methods*. John Wiley & Sons, 1992.

[31] James R. Lucas. *Fatal illusions: Shredding a dozen unrealities that can keep your organization from success*. AMACOM, 1997.

[32] Sheena Lyonnais, Bailey Lewis, Caleb Kingston, Antionette Carroll, and Marc Schenker. Writing ux microcopy: The four cornerstones: Adobe xd ideas, Oct 2019.

[33] Bella Martin and Bruce M. Hanington. *Universal Methods of Design: 100 Ways To Research Complex Problems, develop innovative ideas, and Design Effective Solutions*. Rockport Publishers, 2012.

[34] Alan Meier, Cecilia Aragon, Therese Peffer, Daniel Perry, and Marco Pritoni. Usability of residential thermostats: Preliminary investigations. *Building and Environment*, 46:1891–1898, 10 2011.

[35] Alan Meier and Escholarship Org. Title how people actually use thermostats, 2010.

[36] Sarah Mennicken, Jo Vermeulen, and Elaine M Huang. From today's augmented houses to tomorrow's smart homes: new directions for home automation research. In *Proceedings of the 2014 ACM international joint conference on pervasive and ubiquitous computing*, pages 105–115, 2014.

[37] Rune Monö. *Design for product understanding: The aesthetics of design from a semiotic approach*. Liber, 1997.

[38] Jacob Nielsen. Usability 101: Introduction to usability, Jan 2012.

[39] Jakob Nielsen. *Usability engineering.* Morgan Kaufmann, 1994.
[40] Jakob Nielsen. Ten usability heuristics, 2005.
[41] Jakob Nielsen. Mental models and user experience design, Oct 2017.
[42] Jakob Nielsen. Using "how might we" questions to ideate on the right problems, Jan 2021.
[43] Jakob Nielsen and Thomas K. Landauer. A mathematical model of the finding of usability problems. *Proceedings of the SIGCHI conference on Human factors in computing systems - CHI '93*, 1993.
[44] Don Norman. *The design of everyday things: Revised and expanded edition.* Basic books, 2013.
[45] Therese Peffer, Daniel Perry, Marco Pritoni, Cecilia Aragon, and Alan Meier. Facilitating energy savings with programmable thermostats: Evaluation and guidelines for the thermostat user interface. *Ergonomics*, 56:463–479, 3 2013.
[46] Therese Peffer, Marco Pritoni, Alan Meier, Cecilia Aragon, and Daniel Perry. How people use thermostats in homes: A review. *Building and Environment*, 46:2529–2541, 2011.
[47] Daniel Perry, M Pritoni, C Aragon, A Meier, and T Peffer. Making energy savings easier: Usability metrics for thermostats. 2021.
[48] Eva Maria Schomakers, Hannah Biermann, and Martina Ziefle. Users' preferences for smart home automation – investigating aspects of privacy and trust. *Telematics and Informatics*, 64, 11 2021.
[49] James Scott, AJ Bernheim Brush, John Krumm, Brian Meyers, Michael Hazas, Stephen Hodges, and Nicolas Villar. Preheat: controlling home heating using occupancy prediction. In *Proceedings of the 13th international conference on Ubiquitous computing*, pages 281–290, 2011.
[50] Helen Sharp, Jenny Preece, and Yvonne Rogers. *Interaction design: beyond human-computer interaction.* Wiley, 2019.
[51] Michelle Shipworth, Steven K. Firth, Michael I. Gentry, Andrew J. Wright, David T. Shipworth, and Kevin J. Lomas. Central heating thermostat settings and timing: Building demographics. *Building Research and Information*, 38:50–69, 1 2010.
[52] Hannah Snyder. Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104:333–339, 2019.
[53] Henrik Sunde. How design can affect user response and behavior. 2017.
[54] Judith Symonds. *Ubiquitous and pervasive computing : concepts, methodologies, tools, and applications.* Information Science Reference, 2010.
[55] Ruth Tamas, William O'Brien, and Mario Santana Quintero. Residential thermostat usability: Comparing manual, programmable, and smart devices. *Building and Environment*, 203, 10 2021.
[56] Energy saver US Department Of Energy. Radiant heating.
[57] Mark Weiser. The computer for the 21st century, 1991.
[58] Mark Weiser and John Seely Brown. *The Coming Age of Calm Technology*, pages 75–85. Springer New York, New York, NY, 1997.
[59] Christopher D. Wickens, Justin G. Hollands, Simon Banbury, and Raja Parasuraman. *Engineering psychology and human performance*, page 22–23. Routledge, 2016.

[60] Heetae Yang, Hwansoo Lee, and Hangjung Zo. User acceptance of smart home services: An extension of the theory of planned behavior. *Industrial Management and Data Systems*, 117:68–89, 2017.

[61] Indi Young. *Mental models: aligning design strategy with human behavior*. Rosenfeld Media, 2008.

A

Appendix 1

A.1 Competitive analysis

Competitor	Type of interaction	App compability	Main features in device (according to manual)	Features in application (according to demo verison, video reviews or appstore)	Onboarding/ guided user installation	Installation via	Program schedule via	Heating
Device 1	Capacitive buttons	Their own	Adj. temp, frost protection home and away/vacation and paus setting, open window detection.	Frost protection, weekly schedule, away/vacation settings, economy mode and zone control.	N/A	Licensed electrician	App	Floor
Device 2	Touchscreen, voice (swipe possible)	Their own, HK, GH	Adj. temp, heat&cool mode, heat, cool, follow me mode, weekly schedule, away mode, home mode, sleep mode and eco+, geofencing and energy graph	Adj. temp, heat&cool mode, heat, cool, follow me mode, weekly schedule, away mode, home mode, sleep mode, eco+, geofencing and energy graph.	Yes, intro to settings through app during setup	Technician or user	App and thermostat	A/C
Device 3	Side touch scroll	Their own, GH	Adj. temp, heat&cool mode, heat, cool, fan	Adj. temp, heat&cool mode, heat, cool, fan, week schedule, timer, vacation setting.	Yes, intro to settings through app during setup	Technician or user	App	A/C
Device 4	Touchscreen (press only)	Their own	Raise/lower temp, manual mode, schedule mode, boost, comfort, eco, energy graph, frost guard	Frost protection, weekly schedule, away/vacation settings, economy mode and zone control.	No	Licensed electrician	App and thermostat	Floor
Device 5	Capacitive buttons	Their own	Week program on/off, timer, energy graph, regulator mode, Change mode, temp.,, Wifi-connect	Hotel mode, multi-room view and control in app, open window-detection..	No.	Licensed electrician	App and thermostat	Floor
Device 6	Touchscreen, voice (swipe possible)	Their own, 3rd party, GH	Change mode, adjust temp, boost timer, configure schedule 1, configure schedule 2, configure schedule 3, see energy consumption	Multi-room view and control in app, open window-detection, 3 Economic programs, Constant mode 1 Flexible Boost, 1 Holiday mode	No	Licensed electrician	App and thermostat	Floor
Device 7	Physical buttons, voice	Their own, HK, GH, 3rd party	Adj, temp	Window open detection, energy saver, rooms, smart regulation, Complete eco system, sheduling, change mode.	Limited, options mentioned in app onboarding	Technician or user	App	Boiler Radiator/ floor
Device 8	Touchscreen, voice (swipe possible)	Their own	Change program, temp, programing, weather, floortemp+airtemp, configure schedule, Holiday, bedroom, living room, bathroom, kitchen, custom, fixed	Ambient air temp, weather, natural language programming, energy + temp history, "smart" geofencing	No	Technician or user	App and thermostat	Floor
Device 9	Capacitive buttons	Their own	Adj. temp, timer, scheduling	Wweather, natural language programming, energy + temp history, scheduling, Geofencing	No	Licensed electrician	App	Floor
Device 10	Capacitive buttons, voice	Their own, HK, GH, Alexa, 3rd party	Adj, temp	Raise/lower temp, geofencing on/off, boost heating, timer function, Multi-room view and control in app, Geofencing, weather-based reg., energy saver.	Yes, intro to settings through app during setup	Technician or user	App	Boiler Radiator/ floor
Device 11	Capacitive buttons	Their own	Adj. temp, frost protection, home, away, power regulation, schedule.	Adj. temp, schedule, Geofencing, "Multi zone control"	No	Licensed electrician	App and thermostat	Floor

Figure A.1: Full competitive analysis table

A.2 Sitemaps

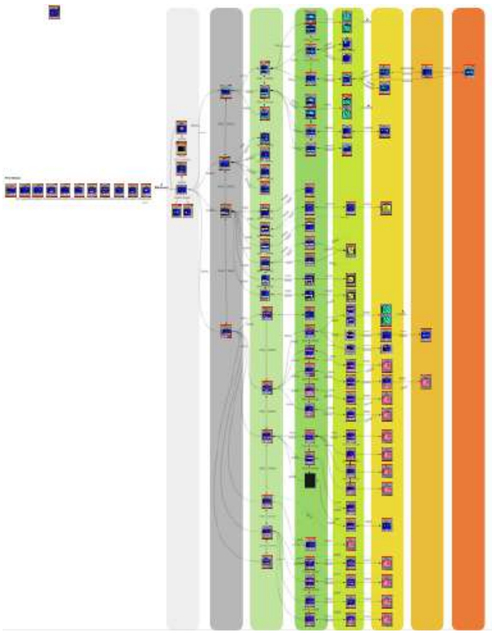

Figure A.2: Sitemap - device 5

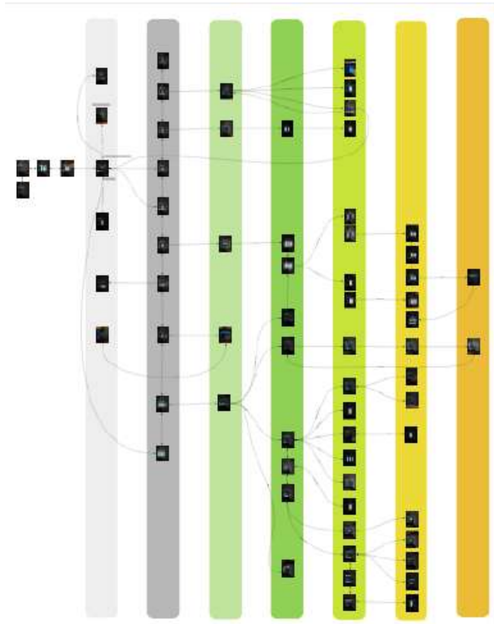

Figure A.3: Sitemap - device 6

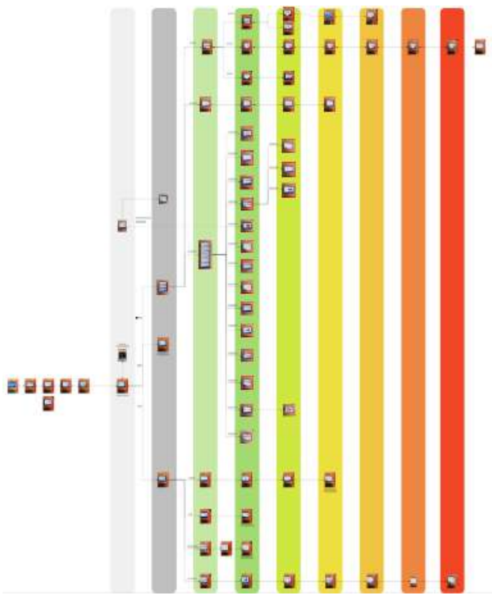

Figure A.4: Sitemap - device 11

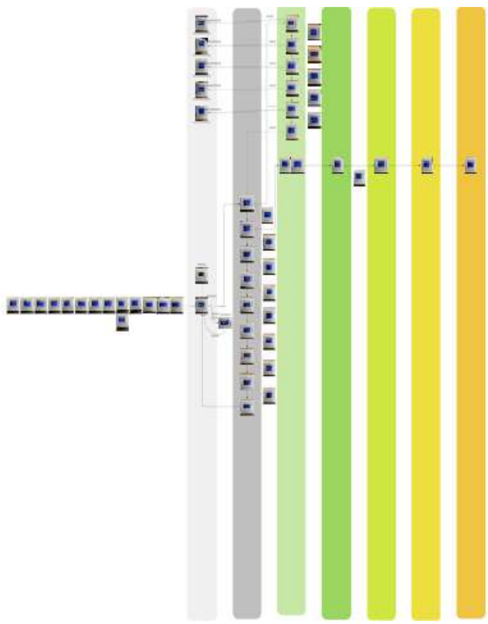

Figure A.5: Sitemap - device 4

A.3 Flowcharts

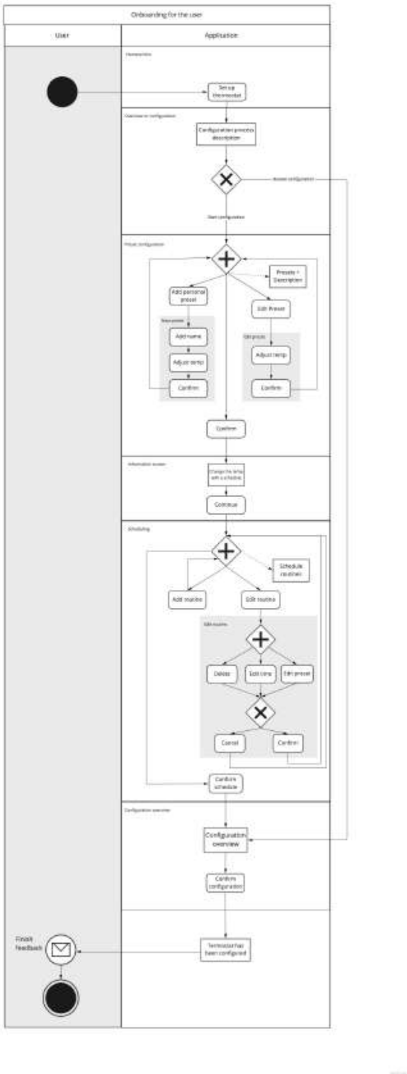

Figure A.6: First flowchart iteration

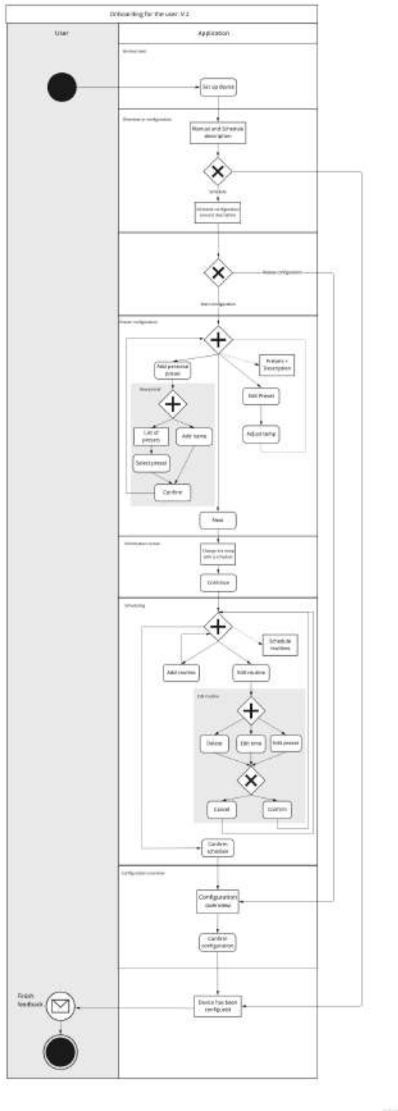

Figure A.7: Second flowchart iteration

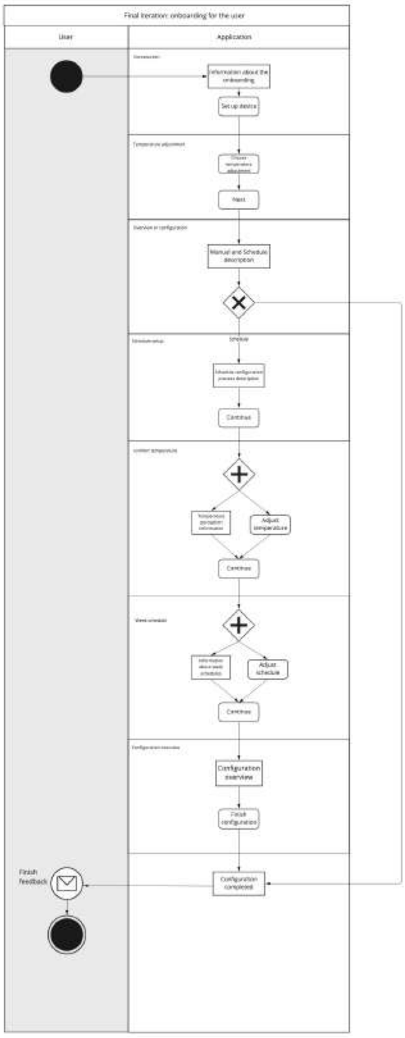

Figure A.8: Final flowchart iteration

A.4 Wireframes

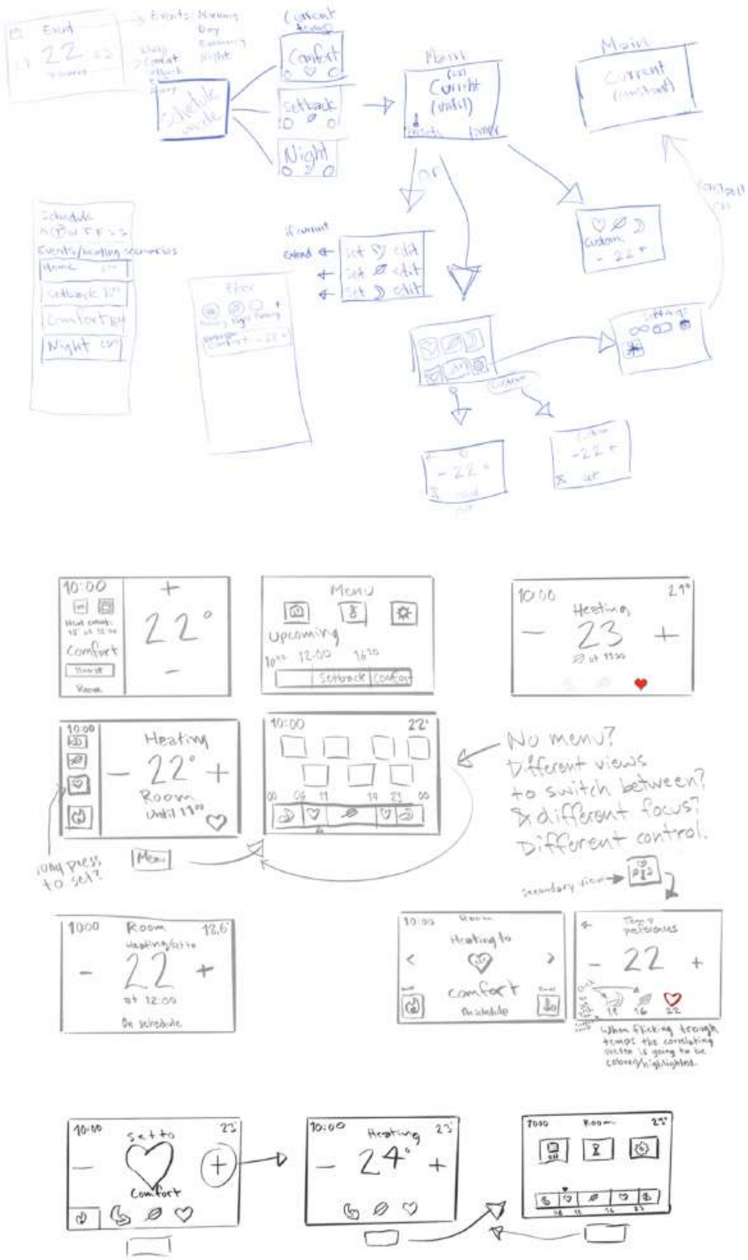

Figure A.9: Thermostat UI wireframe sketches

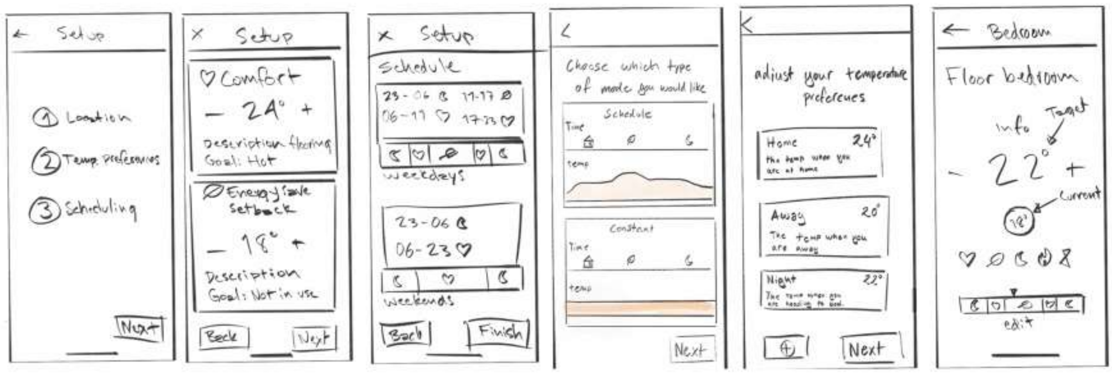

Figure A.10: Application UI wireframe sketches

A.5 Prototype iteration 2

Figure A.11: Prototype 2.1 all frames

Figure A.12: Prototype 2.2 all frames

Figure A.13: Prototype 2.3 all frames

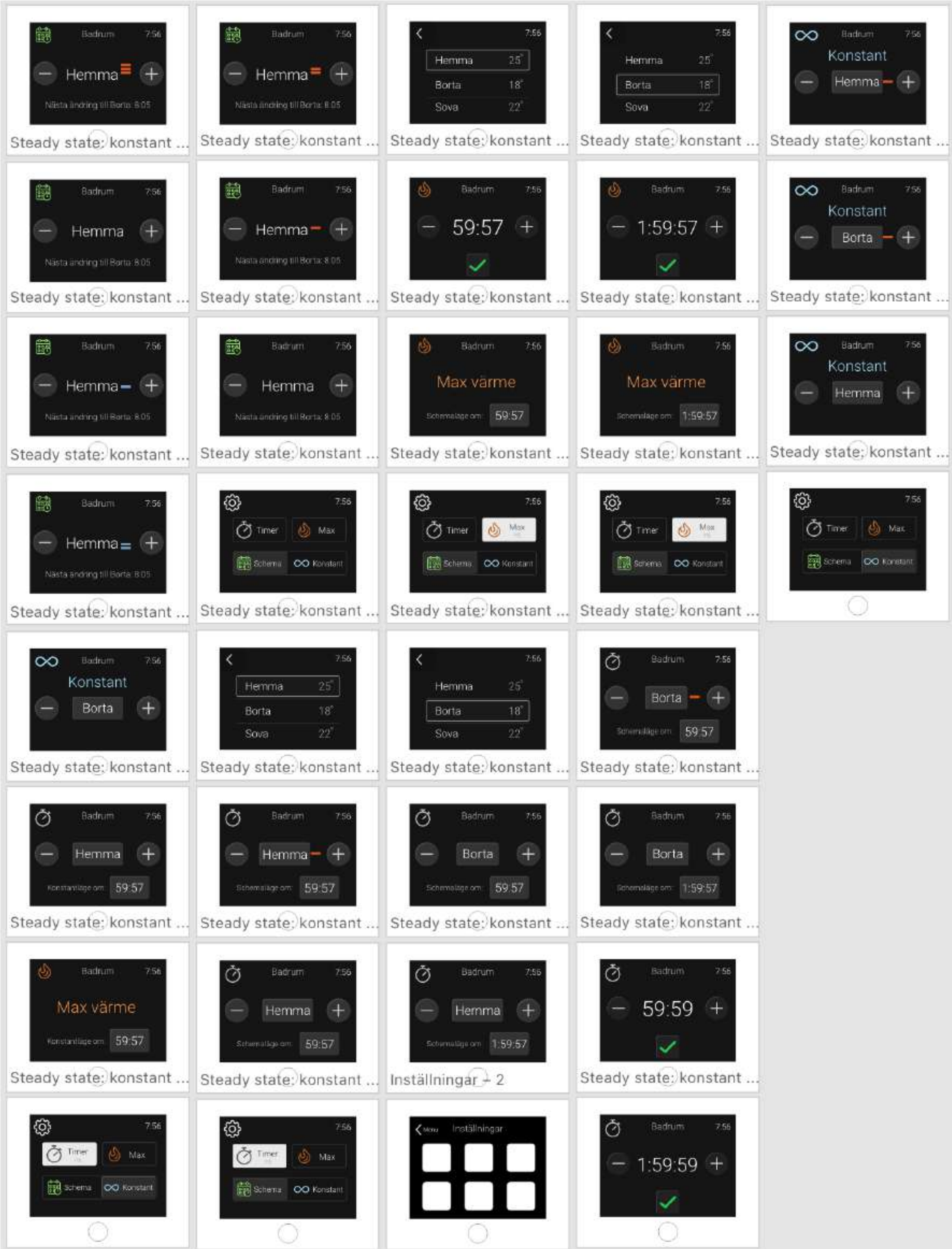

Figure A.14: Prototype 2.4 all frames

A.6 Result

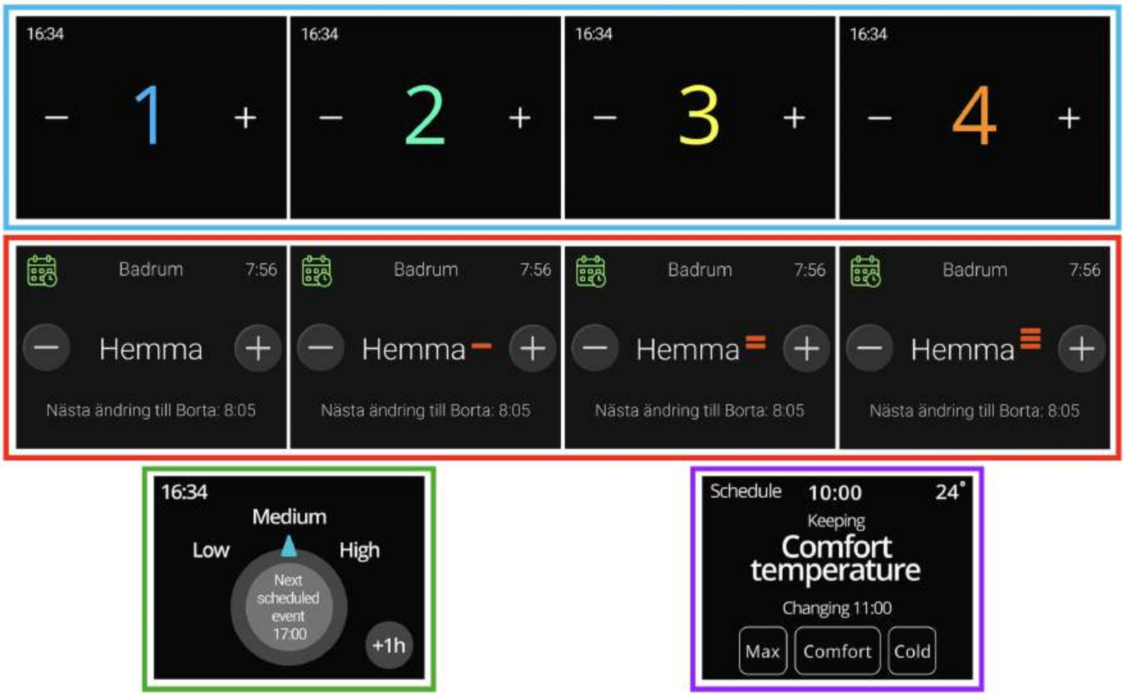

Figure A.15: Heating scale variations