MASTER THESIS

Integrated Product Design

Personal Thermal Comfort

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April 2022

To design a personalized **energy efficient heating solution** for the in-door environment.

BOSCH TU Delft

note

This is the final documentation of my graduation project titled Personal Thermal Comfort, to design a personalized energy efficient heating solution for the in-door environment. Under the supervision of both the company Nefit│Bosch and the faculty of Industrial Design Engineering(IDE) in Delft.

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preface

In the past years, I noticed a big change in outside temperatures in the Netherlands. Rotterdam now has to deal with hot summers and increased humidity. I live in a apartment way up high and it is an old construction with poor insulation. Winters are very cold and in the summer it’s very warm. During COVID-19 I really experienced how much the climate makes impact on my health, work, studies and etc. If you scale this up to all people then you see it’s not only my problem but it influences us all. This subject sparked my strong interest and ambition in developing a product that explores personalization, address user’s needs and bring warmth(heating) closer to the user.

Before I started, both thermal comfort and heating technology were relatively new to me. At times this project really challenged me and was one of the hardest that I have ever done. I am so fortunate to have an amazing group of people who helped me when I was lost and
encouraged me to push forward.

I would like to thank my supervisors, Henk and Bas. Your patience and critical comments really helped me to structure my work. Since this subject was relatively new to me it was easily to get lost and difficult to find structure again. Your comments really helped me to think about myself as a designer and how important it is to focus: distinguish the essentials from side issues. Thank you for being thoughtful and tolerant regarding my chaotic approach and late schedules. At the end I am very happy that you trusted my skills and supervised me to finish this project.

Next I would like to thank the department of Applied Labs at the IDE faculty for offering me a space and thinking along with my project. Besides I would like to thank the people from the PMB(Model Making and Machine Lab) at the faculty and especially Mickey, 3rd year student that helped me and taught me to sew the (prototype).

It was a huge honor to have and to work with two inspiring and enthusiastic supervisors from Bosch: André and Ralph. Thank you for giving me this opportunity to explore personal thermal comfort design. Thank you for letting me be part of the innovation hub were new ideas emerge and inspire new products to be developed. Your feedback, inspiring energy, creativeness, and passion for personal thermal comfort and new technologies have always motivated me to explore new ideas.

Ralph, thank you for helping me to get out of my comfort zone and to really start exploring ideas and push towards prototyping.

André, thank your for being such a considerate person and for your patience with me during the project. You analysed me quite well(book) and really am grateful that you guided me to the end of this project.

I really would like to thank the Bosch’s R&D team and other’s departments for sharing all the knowledge and resources, giving me opportunities to share my work and connect with other brilliant people.

A sincere thanks to all my friends staying with me during these months. Rogier, Fehmihan, Ferkan, Hakan, Yusuf and the Mustafa’s and all the friends who provided me with mental support.

Thanks to all the interview participants, for sharing their experiences, thoughts, and valuable feedback, which allowed me to get valuable insights and complete my final concept.

Finally, none of my work would be possible without the love and support from my family and my girlfriend, who provides me with endless support.

nefit|bosch

I feel fortunate to contribute to the field of thermal technology where the energy transition inspires new ideas aiming for a better and healthy world. My aim within this project is to show what the future of thermotechnology will be with respect to an increasing need of personalization and customizability. Main challenges are: energy efficiency, personalized and connected systems. The cooperation with Bosch and the faculty showed me that the future is near.

delft university of technology

The Integrated Product Design (IPD) Master's programme at the faculty of IDE focuses on conceptualisation and embodiment design, by applying systematic state-of-the-art theories and methodologies, and by integrating user, technology and business aspects.

company mentors

André Haverkort
https://www.nefit-bosch.nl/

university supervisory team

Chair: Ir. Henk Kuipers
dpt. /section: HCD/AED
Mentor: Dr. ir. Bas FLipsen
dpt. /section: Circular Product Design

executive summary

With the already happening governmental regulations(The Netherlands), an increase in consumer price of natural gas is noticeable. With COVID-19 and now the war in Ukraine energy resources are becoming increasingly expensive. 90 percent Dutch houses are heated with gas. Based on the energy consultant, gas supplies an average to 9769 kWh of energy per m3. Each house use up to 1500 m3 per year. 14654 kWh for a year on an average is needed for one household. A heat pump (HP) needs about 6513 kWh average per year depending on type house, size and season. From society we are going through a shift from gas to electricity. For a house this can be done with replacing a gas based boiler with for instance a heat pump. But it doesn't necessarily provide people the same scale of thermal comfort. Shouldn't we rethink the way we feel comfortable in our homes?

Design opportunities that contributes to Bosch's future vision and mission are explored. The problem at the heart of this project is defined as: To what extent can a product increase the personal thermal comfort of the user and be more energy efficient? And can therefore a personal product provide the necessary heat if the central heating temperature settings is set to 18°C? User-centered design and thermal comfort are the key methodology and research supporting this project. Both were used for exploring the relationship between users' behaviour (personal heaters) and the influencing factors, thereby providing valuable insights for all design directions.

This project is finalized with a product concept, “Ori”, a flexible Far Infrared (FIR) heater that has multi product configurations and use-cases. It applies various design criteria based on the inputs of thermal comfort research, user interviews, heating technology research, aiming and product flexibility configurations to create a personal experience for users. If the challenges are addressed, Ori could be a valuable product for Bosch's consumer products portfolio and offer the user financial benefit and a decrease in yearly electrical energy consumption. Ori uses up to 229 kWh per year which is nearly 10 times less compared to a conventional personal heater (2148 kWh).

The performance would be measurable through a simulation of a working HP, a room, a user, Ori and a Predicted Mean Vote (PMV) measurement device that address thermal comfort (ISO 7730).

In addition to this concept, this project has addressed possible opportunities and requirements in the field of FIR heating, which could be used as an input for other relevant product developments within Bosch's (thermal) comfort and wellbeing department.

a) project   b) stakeholders   c) chapters overview

0.Introduction

This chapter offers the project with the research topic and design aim. The involved stakeholders and an overview are also introduced.

a) project

The MSc. Graduation Project is the final project that finishes the Master's degree Integrated Product Design programm offered by the faculty of Industrial Design Engineering (IDE) of Delft University of Technology (TU Delft). The project started in June 2021 and will come to an end in 2022 with this report and a presentation at the faculty.

This project is defined in collaboration with Nefit | Bosch Thermotechniek B.V.(BOSCH) and the TUDelft. The aim of this project is to develop a design concept and a prototype. The development is realized by doing literature research, interviews and working closely with my supervisors. Page 5 and 6 show a detailed visual overview of the report.

This project started with the goal of **rethinking current heating scenarios and developing a product that provide personal thermal comfort** fitting in a world where energy efficiency has never ever been so important as the time we are living now(Figure 1). For additional background information please have a look at the Design Brief at Appendix A

This lead to conducting context analysis about the subjects involved. This chapter answered questions such as:

1. What is (personal)thermal comfort?
2. When is somebody thermally (dis)satisfied?
3. How do current products address personal thermal comfortand what are the frustrations?

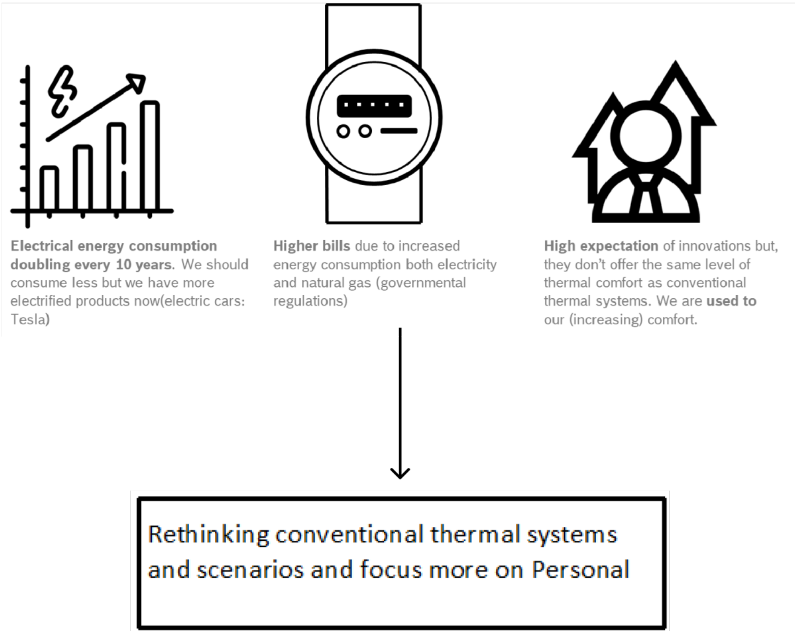


Figure 1: Effects of energy transition and developments on society. Conventional thermal systems focus more on room conditions than occupant experience.

After the background analysis, contextual analysis was conducted followed up by ideation and exploring design directions. This formed towards a design vision to design a concept and prototype.

This project focuses on personalization, customizability, flexibility and energy efficiency. Because of privacy reasons interviewees' information are left out. The next chapter introduces the stakeholders and their roles, followed up by the overview of this report.

b) stakeholders

The main stakeholder of this project is Bosch's innovation hub closely connected to Nefit | Bosch Thermotechniek B.V. Of course the potential costumer is also a stakeholder. The costumer is described later on.

Nefit|Bosch expertise lies in central heating technology. They design, manufacture and sell boilers, heat pump, solar heaters and other sustainable systems(figure 1).

Nefit|Bosch have been joined since 2004. In 1948 the Dutch-American Fitting Factory was created in Deventer: Nefit. In the 1980s, Nefit grew into the largest central heating manufacturer in the Netherlands with the invention of the high-efficiency heating boiler. Now, more than 130 years later, the Bosch Group has grown into an international, innovative global player. Leading on many different technological fronts, including thermal engineering. Nefit Bosch is one of the leading providers in the Netherlands.

1.1 Bosch's vision

Bosch is motivated by the desire to develop products that are "Invented for life," that spark enthusiasm, that improve quality of life, and that help conserve natural resources (Bosch, 2021). The vision of Bosch clearly reflects their current product portfolio. The soon to be designed product should also fit in their vision. The innovation hub is closely working with Bosch allowing product development and innovations happen faster.

Figure 2: Nefit|Bosch Thermotechniek B.V. product portfolio. These central heating systems are available for both companies and consumers.

1.1 R&D and Assembly

The Research & Development of Nefit|Bosch is also located in Deventer. Production and assembly for the home market and many other countries also take place here(Figure 3).

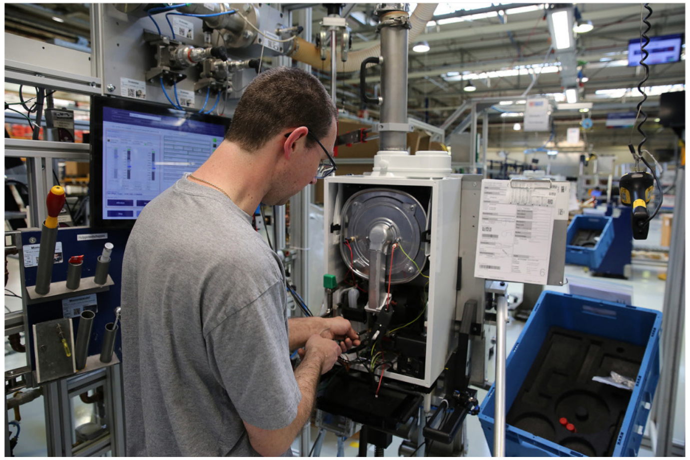


Figure 3:The R&D and the assembly production lines for different central heating systems are both located in Deventer.

c) content

The content section shows a visual on how the report is structured. It starts with an introduction on the report, followed by background analysis on topics like thermal comfort, central heating systems, . Consequently, diverging and merging all gathered input finishing with a (personal heater) product related interviews. The data from this research was synthesized into basis building blocks and a design direction was explored. This led to the design goal, followed up by focused product principle research and lead into the concept. Finally, finishing the project with the conclusion, requirements validation, challenges and further steps. The report is divided into 9 chapters, each chapter starting with a Gray page and an introduction. Every chapter, except the introduction ends with a outcome and contribution page of that chapter. Insights are shown in pastel yellow blocks or with figures.

0. Introduction

Introducing the project with the research topic and design aim. The involved stakeholders and an contents page to guide you trough the report.

1. Background & Context

Answers (sub)questions regarding thermal comfort, influencing conditions, heating systems and serves as an input for the ideation phase.

2. Merging

Merges the data from the background and context research. Current heating products,technologies and user needs. Besides creating heating scenarios and defining initial conditions this chapter also hints design directions.

3. Design directions

Focuses on additional research at Bosch and workshop sessions which provides the final direction and the revised design goal in the next chapter.

4. Conceptualization

After conducting research in different fields, it shows that there is need for more personalization improving expectation on thermal comfort. This chapter shows the revised design goal and the vision towards the final concept

5. Research and testing

This chapter answers the following questions: what principle is viable and feasible? What concept on behalf of research and testing can be chosen? and what challenges need to be addressed?

6. Concept

Introducing Ori, IR Heating solution perfect for placing both on the table top and under desk for keep warm during working or study. The chapter contains the prototype, configurations, user interaction and financial return and costs comparison.

7. Conclusion

Project is finalized with criteria validation, challenges and future steps to ensure product working leading to manufacturing. Product price is calculated and an advice is given.

a) thermal comfort b) heating systems c) user behavior d) outcomes & contribution

1. Background & Context

The second chapter provide background analysis, answers questions regarding thermal comfort, central heating systems, environmental conditions towards initial contextual conditions.

a) thermal comfort

Thermal comfort is the cornerstone of this project. A deepening research is done to understand principles of thermal comfort. It helps to define design requirements and helps to understand possible user-product relations. What are the perceptions and experiences of the users and how can a product address personal thermal comfort? Lastly it will allow to converge into possible design solutions and inspire the creativity process on the go. This chapter will be a short recap of all conducted literature studies and interviews.

a.1 definition

Thermal comfort is described as a condition of mind that expresses satisfaction with the thermal environment. Thermal comfort was introduced during the late 19th century as one of these environmental factors (Bluyssen, 2009). Generally seven thermal sensations are recognized: hot, warm, slightly warm, neutral, slightly cool, cool and cold(Figure 4). Standards such as **ISO 7730(European)** and the ASHREA standard 55 for North America are used to determine appropriate thermal conditions(figure 4). These standards define temperature ranges for a space that should result in thermal satisfaction for at least **80% of people**. These standards were based on Fanger's mathematical model in which the mathematical model was created on.

a.2 Fanger's Predicted Mean Vote

Fanger's Predicted Mean Vote (PMV) Model state that there are six variables which are believed to establish the human thermal comfort condition. These variables are the environmental factors: **Air temperature, Radiant temperature, Humiditiy , Air velocity** and the personal factors: **Metabolic rate and Clothing ensemble** (Bradshaw, 2006). Only **Air and Radiant temperatures** are within my reach of influence during this project. Fanger used these variables to create an index that can be used to predict the average thermal sensation of a large group of people. Fanger's model is based on theories of the heat balance of the human body. There is a heat transfer between the human body and the environment by conduction, convection, radiation and evaporation. The body's temperature control system tries to maintain an average core body temperature, meaning that there should be a balance between the heat production of the body and the heat loss to the environment.

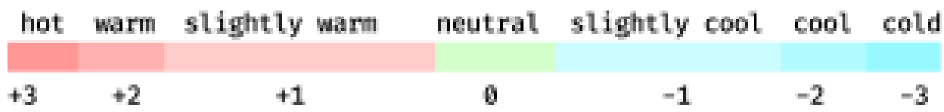


Figure 4: The seven thermal sensations are presented and used as a base for standards such as ISO 7730.

a.3 Overview of all thermal comfort factors

Factors of thermal comfort are very important. A deepening research have been done on these factors to get an idea on starting conditions. The factors are separated in human and environmental conditions. Human conditions are divided into physical, physiological and psychological effects. It will also be an important input for the design process later on. The research can be found in the appendix A. A short overview will be presented at the following two pages.

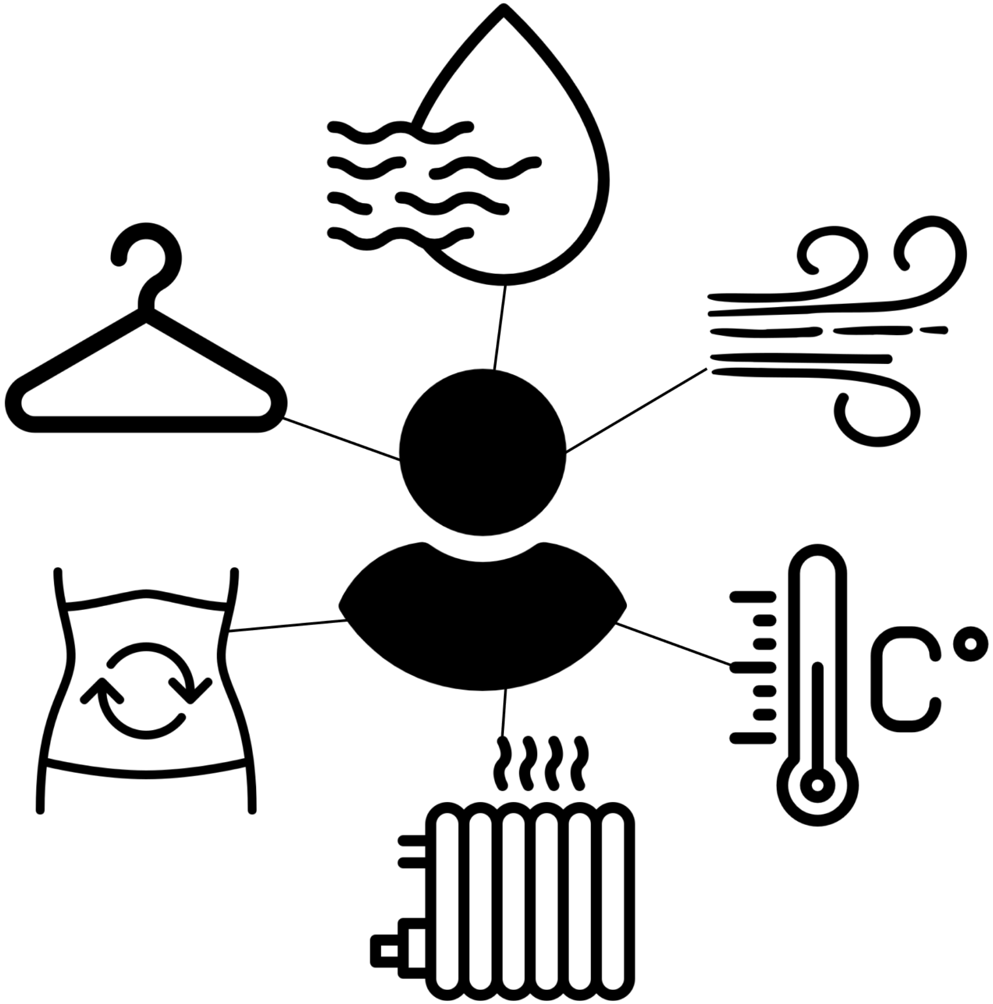
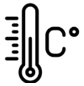


Figure 5: Envrionmental and human conditions that influence thermal comfort.

a.4 Environmental conditions

The environmental conditions that influences the thermal comfort are: Air temperature, Air temperature and Humidity. Metabolism and clothing are also taken into account when the PMV model is used. However it is considered as part of the human condition.



Most people call out indoor temperature but is referred to Air temperature. Air temperature in an enclosed space generally increases from floor to ceiling. If this variation is sufficiently large discomfort can occur, feeling warm around the head and cold at the feet.

Airspeed is measured by sensing the pressure produced by the movement of the air. Air movement can be a result from free and forced produced pressure as well as the occupants own body movement. The body heat transfer by convection and evaporation is significantly affected by air motion. When the air velocity is too high, the occupant feels unpleasant drafts. These drafts are considered most unpleasant at the neck, upper back, and ankles.

Humidity is the amount of water vapor in a given space. Relative humidity is the ratio of the actual vapor pressure of the air-vapor mixture to the pressure of saturated water vapor at the same air temperature.
Although human tolerance to humidity variation is much greater than tolerance to temperature variations, control is very important.

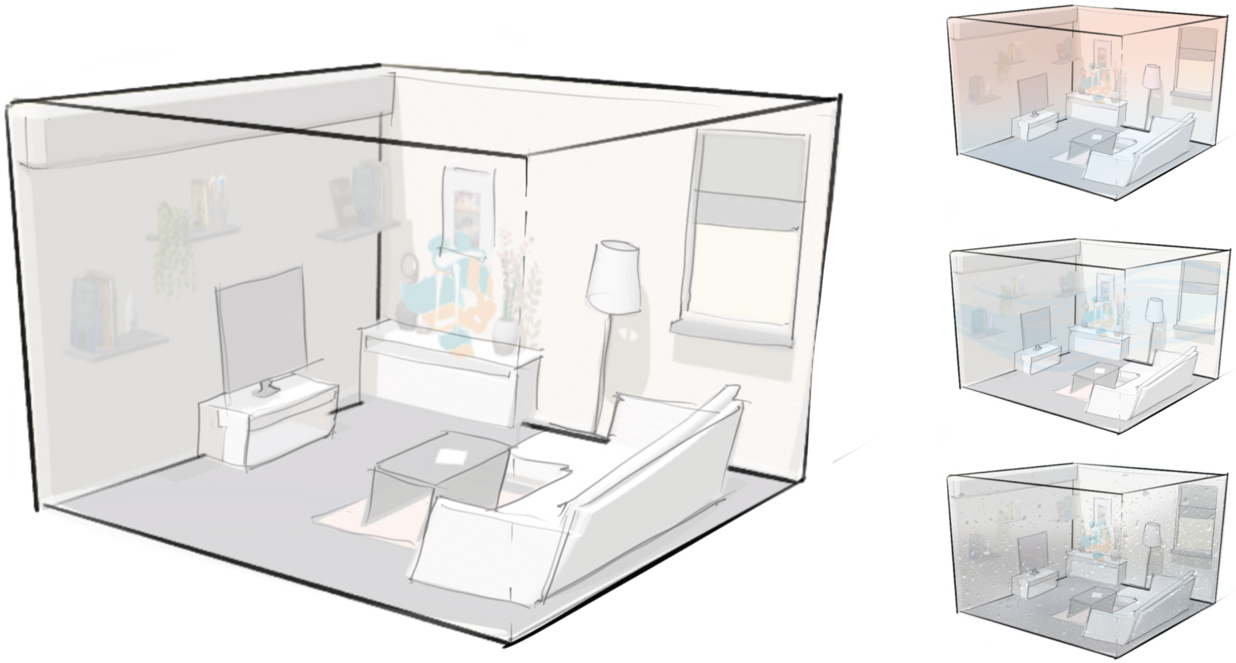


Figure 6: The environmental conditions: Air temperature, Air speed and Humidity.

a.5 Human conditions

Clothing is due to its insulation properties an important modifier of body heat loss and comfort. Insulation by covering body parts is measured with units of ‘clo’. A heavy two-piece business suit and accessories have an insulation value of about 1 clo, while a pair of shorts is about 0,05 clo.

A daily process of our body is to metabolize the food that we take, and converting this food into electrochemical energy. This energy enables us to carry out our normal bodily functions. As with every energy conversion there is a certain efficiency. Activity level is measured in terms of metabolic rate, or ‘met’. The most accurate method for determining met is through laboratory studies, where heat or oxygen productions are measured for participants conducting specific activities.

A total overview of the human body is presented and analyzed on the level of each individual body parts. The most sensitive body parts are generalized as following: face, neck, wrist, hand, foot, and the seat area.

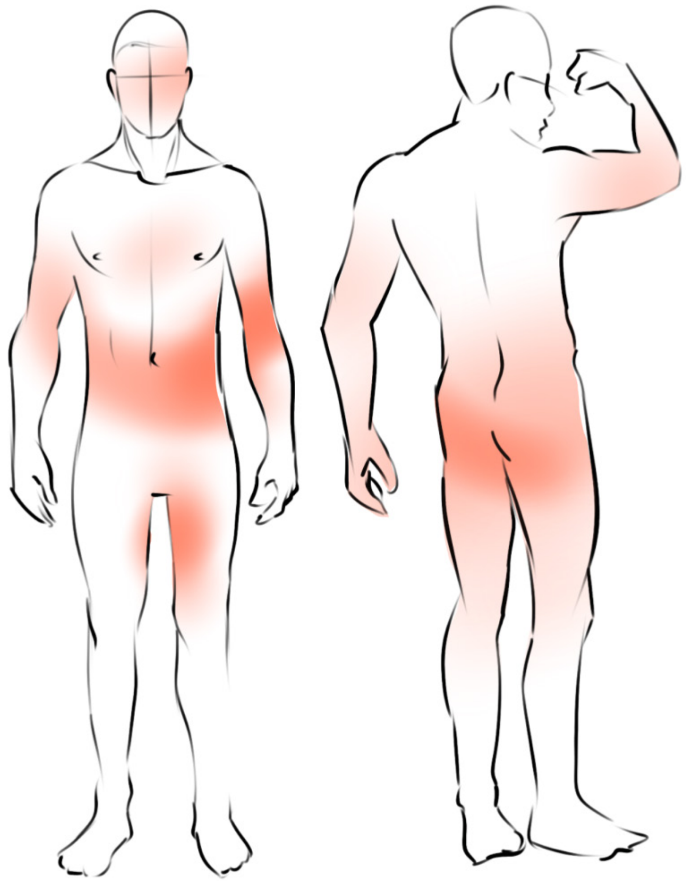


Figure 7: thermal sensitivity mapping focusing on heat sensitivity.
Luo, M.(2020). High-density thermal sensitivity maps of the human body. Building and environment, 167, 106435.

Human body summary

Human core temperature is mainly controlled by changes in skin perfusion and relatively less by changes in metabolism or evaporative heat loss. Humans are closely in contact with their environment and this controlling mechanism is in balance normally when the ambient temperature is around **23 - 25°C**, the internal temperature is about **37°C** and when the skin temperature is about **34°C**. The human body has thermal and cold receptors distributed throughout the skin, which respond to thermal sensations and trigger thermal control mechanisms to increase or decrease heat loss. The body then responds to the narrowing of blood vessels, whether it's increased or decreased blood flow, physical movement, or chills and sweating. It is possible to affect your **thermal sensation by changing your position, orientation towards a heat source, putting on/off clothes, or regulating heating systems all at the same time.** The behavioural reactions will include a personal comfort system.

Thermal sensation is greatly influenced by the human skin. When our skin comes into contact with an object, it can be deceiving because the human sense level at which heat is transferred to or from the body has a greater influence on the skin's perception than the actual temperature. This is dependent on the type of skin and the type of surface.
As a result, the material you choose should be based on whether it can avoid or induce local discomfort when touched.

The thermal sensation and comfort of different body parts can vary a lot. The overall sensation of the human body closely follows the worst local comfort level. In warm environments the head mostly influences the overall sensation and in cold environments the hands and feet mostly influence the overall sensation.

Physical variables and psychological responses alone are not conclusive about thermal sensation. Thermal sensation is related to how people feel and is a psychological phenomenon. Researchers fail to establish a law that can predict psychophysical reactions to thermal sensations, but studies show two important psychological factors, consciousness of the temperature and expectations.

The convective heat loss will be affected: noticeable in the fingers and toes as these lose heat more rapidly. Reducing these effects without the use of the heater and fan will make the system more energy efficient. The cooler temperature will also lower the surface temperature. The occupant will notice this as cool radiation from the w alls. As a general rule of thumb, if the mean radiant temperature is 5 degrees lower than the comfortable room air the occupant will feel uncomfortable. The mean radiant temperature (MRT) is defined as the uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body is equal to the radiant heat transfer in the actual non-uniform enclosure.

In Appendix B the PMV model and paradoxes are discussed. Too many factors influence the thermal experience but also how people vote their situational thermal comfort.

b) heating systems

An exploratory study is done on overall (most used) heating systems of Dutch households. Heating systems in this report are divided into two groups. Central heating systems(HVAC) and personal heaters. What kind of systems are we using? How much do they cost and how do they influence in-door conditions? What are future developments and what are opportunities? The full study can be found in Appendix A

b.1 Central Heating Systems

The indoor thermal prerequisites are part of heating, ventilation and air-conditioning(HVAC) installations. HVAC installations are used in homes and buildings to control the enclosed climate. "Heating" focuses on providing an ideal thermal condition where people can do their activities without experiencing discomfort. This ideal condition is maintained with many different systems based on different energy sources. Dutch households currently are mostly making use of natural gas boilers. As of today and in the future Dutch citizens consider to switch to sustainable, energy efficient systems: Hybrid systems, Heat Pump(HP), Solar Energy based systems and many more. In Figure 8 a heat pump system architecture is shown with its working principle. The Dutch government offers subsidy to citizens who want to invest in heat pump systems. Lastly, the government is also looking for more alternative energy resources like hydrogen.

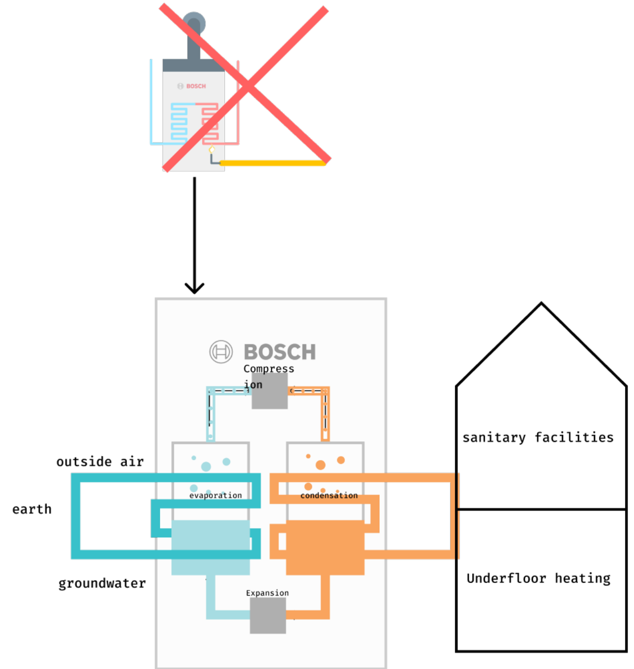
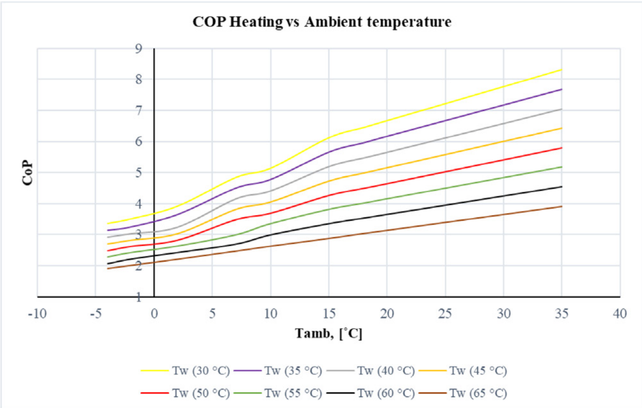


Figure 8: Going from natural gas based boilers to electrical heat pump systems. A short overview of how they work.

Since this project is focusing on personal heating solutions it is of value to know how much impact a central heating system has for maintaining indoor conditions. Bosch's interest is mainly oriented to having a HP scenario working at 18.For a more in depth analysis of these systems please have a look at the Appendix B

b.3 Temperature drop and energy efficiency

While heating systems are providing thermal comfort and acceptable indoor air quality, the product to be designed should be an addition for the currently existing indoor thermal comfort. Current (natural gas based)central heating system are highly inefficient considering the huge temperature drop (from 60 to 23 °C) from the radiators to the environment. New systems are low temperature heating meaning they are not exceeding temperature of **35 - 45 °C**. Bosch's idea is to add a product while decreasing the temperature setting of the HP. The results in the graph below (Gaona Reinoso, D., 2020, p. 29) show that reducing the ambient temperature to 18 from 22/23 the COP of all the different supply temperatures(HP) decreases thus improves with approximately 0.5.



Note. From Assessing the Demand Response Potential of Heat Pumps in All-Electric Buildings Equipped with PV, EV, and BES to Minimize Energy Costs, D. Gaona Reinoso, 2020,p.29. Copyright 2020

b.4 Personal Heaters

Increasing and decreasing thermostat settings of the heat pump will make it very expensive considering the high electrical energy consumption peak fluctuation. Operating costs hopefully will decrease when electricity prices drop. Heating at a lower temperature has an advantage: you have very even heat in the house.

Therefore have to heat your house a little differently than you are used to. With a full heat pump, for example, you leave the thermostat at 17 or 18 °C at night (instead of 15 °C). Because your house is well insulated (which it is, otherwise you won't start with a full heat pump), you won't lose much heat with this.

There are systems that are using natural resources(solar energy, for central heating) that provide the necessary indoor conditions. Currently these systems are very expensive, ranging from **€ 5000 euro's to €25.000**. Since most sustainable heating systems as the heat pump(HP provide a constant low temperature with a minimal energy consumption the designed product will offer a more direct thermal comfort.

Most electric personal heating systems range from **P = 400 W - 1500 W** of energy consumption. Most of these heaters are ceramic heaters or based on heat generated from a resistance wire. As a rule of thumb, you'll need roughly 10 W of heating power for every square meter of floor area in the room. Most personal heaters are developed for (bed) rooms.

Personal heaters eventually adress personal thermal comfort but only as a means of a secondary priority. The air temperature of a room is increased firstly which means that the total air volume is increased in temperature.

c) user behaviour

User behavior covers both literature and user interviews regarding use of central heating systems and personal heaters. The aim is to find frustrations and issues regarding these products that will serve as an input for designing a personal heater. Taking with me the large individual differences and that not all people will be satisfied(80%) a huge demand for personal heaters is expected.

With Covid a huge amount of time is spend in-doors. Therefore people will try to create a comfortable environment to work, study and sleep. Sometimes this means that rooms are shared and people will be around each other more often. Thermal comfort negotiations in-doors influences thermostat behavior. Individual differences like gender causes a different way of dealing on thermostat settings. Based on a study women are more likely to describe engaging in conflicts, whereas men are more likely to report engaging in agreements and compromises, both of which are associated with greater likelihood of adjusting thermostats within a given day (Sintov et al., 2019).

More problems may also arise when people are having HP installed at their homes. HP are relatively expensive in large fluctuations when changing thermostat settings affecting the montly bill. In figure 9 a scenario is presented with the projects starting point.

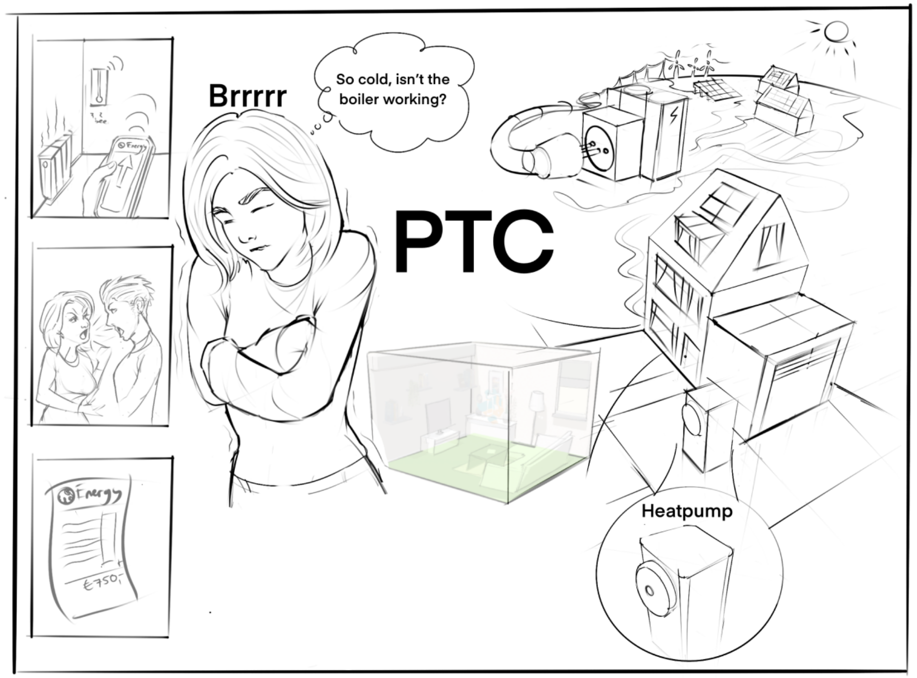


Figure 9: Many frustrations might arise due to future developments regarding the energy transition and comfort negations at home.

c.1 User interviews

In-depth interviews were conducted with twelve single and just married couples living in Rotterdam and Schiedam. The participants were asked if they wanted to do the interview online or physically(at their home) and because of privacy reasons names are left out.

1.7.1 the target group

1. The age ranged between 25 - 35 years old.
2. In total twelve participants with seven males and five females.
3. The target group owns a personal heater/cooler product
4. Both gas based kettle and heat pumps are available.
5. The target group just bought/rented their first house.
6. All of them were employed

Participants were asked for photographs of their applications but they rather didn't because of privacy reasons. However there was one participant that agreed and also took part with my ideation. The drawing/photo can be found in Appendix B(p.96).

The goal of these interviews were to get insights on when and how participants were interacting with both their central heating system and their personal heaters/coolers. Frustrations and issues were also considered and possible design directions could be put in relation with the background research in chapter 1.

The interviews were conducted either Online in their living room or at their house.
Some of the insights also overlaps with the background and immersion with the target group shown in the previous chapter.
The next pages show the participants and their quotes.

1.7.2 Questions

1. What kind of heating system do you have?
2. How many hours is your heater on each day? what time of the day?
3. What kind of thermostat do you have? Compared to older or newer thermostats what do you like/dislike?
4. What is your current thermostat setting?
5. Which part of your house is excluded from heating? Why?
6. How often do you change your thermostat setting?
7. What was your first and main reason to get a personal heater?
8. How often do you use your personal heater?
9. Do you store your heater somewhere?
10. Do you like to use the remote control knobs and how often do you change their settings?
11. What one thing would you say that your heater is missing?

1.7.3 Findings and insights

The interviews showed the following interesting insights with corresponding quotes by the participants:

Lack of knowledge regarding features of thermostat

5/12 users weren't looking into their thermostat settings that often. Most users were only interested in increasing decreasing the temperature of their living room/bedroom. Most thermostat come with a timer and application. The younger couples were more into these interactive features than older ones. It only needs to benefit costs.

"Why do I need to use these features if I am able to do it manually?" Does it really benefit the costs?"

"What features are needed and what not? Safety is most important"

Different preferences for heating/cooling

All participants had a very personal explanation when and where they were in need for cooling/heating. Season and physical condition was primarily the reason why they would have the need for warmth or cooling. Almost all male participants didn't mind the air temperature at home if it is acceptable. Most female participants had issues with coldness.

"I have to carry around my device and change the orientation frequently. The device I own is heavy and bulky. I want something to carry around and store it safely and quickly."

"For me it depends if I am coming from work or sport. During the winter I have great urge for heating in comparison with the summer."

More personalized experience for personal heaters/coolers

8/12 participants really didn't like their heaters/coolers. They needed to carry them from room A to B and it usually doesn't have more advanced features for tracking them for heating/cooling. Next to this they complained that it usually takes a while when the heater is heated up and reaches me. For cooling it is the same.

"It really is troublesome that my heater doesn't track me. All of the heating is lost. I really would like to have something that's more personalized and interactive"

Household insulation conditions affects the chosen centralized heater/personal heater

5/12 participants lives in relatively new households in Schiedam. They own a HP and personal heaters. They usually didn't have issues during the winter with heating. In the summer however it was always too hot.

d) outcomes & contribution

Since we are dealing with both the environment and the user/occupant it is important to know how the **PMV model** should be taken as a reference. The model can be of use to validate **product performance.** A PMV measurement tool such as the testo 400 IAQ is used for Standard-compliant determination of the comfort level per EN **ISO 7730**

Too many factors: human and environmental conditions that influence the thermal comfort condition of the human being. Two important psychological factors contribute to thermal comfort: **consciousness of the temperature** trough **visual feedback and control expectations** by adjusting the thermostat.

From a physical point of view it is important to know that in warm environments the head mostly influences the overall sensation and in cold environments the hands and feet mostly influence the overall sensation.

The most sensitive body parts are generalized as following: face, neck, wrist, hand, foot, and the seat area. **Taken into account that most body parts are mostly covered by clothing except the head/neck and hands.** Still it is hard to predict when and why an individual experiences thermal discomfort.

Since this project is about addressing thermal comfort closer to the human being the focus is going to be mainly **the torso(upper body without the head), hands, legs and feet.**

Central heaters are focused on delivering heat for entire households, whereas most personal (room) heaters are ranging from **P = 400 - 1500 W**. The **human body** generally generates **P = 100 W** of heat. Though if the person is not within an enclosed environment this generated heat is lost.

The interviews show that people experience large differences between each other in a household. Personal heaters don't perform as how they are currently. **Features need to be more personalized.**

Chapter 2 contributes towards a final concept in a way that it is clear what thermal comfort is and how both environmental and human conditions influences the thermal comfort state of a human being with respect to their indoor environment. Also both already existing as future (central) heating systems are decomposed and analyzed both on a system level as on human interaction level.

Initial indoor environmental conditions(IIEC) are defined and serve as an input for the design process. The product should not heat up the room entirely but focusing more an added heat towards the user. Product system decompositions serves as a technical input and already lays down a base to design a working principle, and thinking about energy efficient heating technologies.

a) current technologies b) needs c) scenario’s d) outcomes & contribution

2.Merging

This chapter focuses on combining background and contextual research. Additional research is done to find out about current and future technology. User needs are translated into possible design features. A
heating scenario is created and initial conditions are defined.

a) current technologies

The previous chapter presented how many factors influence the thermal comfort of an individual. There is an increased need for personalization. There are both central heaters and personal heaters at the present market. However both are not tailored down to the human needs but only to heating up a room/house. Both available technologies and future technologies are presented. Knowing what there is and what there will be helps understanding the design of heaters and creates a base for the design phase.

a.1 Personal heaters

There are many different types of electric heaters on the market like a fan heater, ceramic heater or infrared heaters for example.

Heaters are categorized based on the type of heating technology(usually a material that transfers heat):

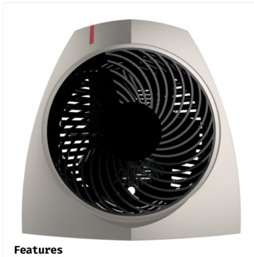
1. Filament/Extra thick filament
2. Ceramic/semiconductor
3. Composite heating elements
4. Infrared radiation
5. Convection heat

These heaters are mobile and are meant for different size spaces. Mostly aimed at heating a room/workspace. Some of them are combined with a fan to distribute hot air into the space. Most people choose heaters based on the prices, power consumption, sound and if it’s suitable for the space they buy it for. The price range for a heater ranges from 50 to 200 euros.

The categories show possible design directions. Current technology also shows what most people need and what is mostly used. In figure 10 the beste heater of 2021 is shown. The review is below:

The heater delivers an immediate temperature increase that built steadily and evenly across the room over **the course of an hour**. It is also **quieter** than most other ceramic heaters and it’s compact enough to tuck away in a corner. overheating and tip-over protection, and a plastic exterior that stays relatively cool to the touch—so you can warm yourself without having to worry. The heater does get mixed reviews from some owners who find it **slow to heat a particularly cold space** or have **problems with the airflow from the fan** (the heat only blasts in **one direction,** and while the fan should help to circulate the air around the room, the heat blast can be a little overwhelming).

source: https://www.nytimes.com



Features

Plastic / Metal

3 Settings: 1500W, 1125W & 750W

Mechanical Thermostatic Temperature Control

Cool Touch Cabinet

High Gloss Finish

Safety Tip Over Switch

Figure 10: Review of a conventional personal heater. What aspects are important and how do people choose the right heater?

It is important to read that personal heaters are mostly valued on how fast they can heat up a room. Mechanical parts such as the fan really influences this. Also important to notice is how personal(room) heaters are associated with personal heating.

a.2 (Future)Product Overview

A product exploration (Figure 11) has been done of both currently and future available personal heaters, coolers and products who can do both healing and cooling. Products can be categorized as: fixed products(wall mounts), mobile products and wearables. Each product make use of different heating technology.

The most energy efficient cooling/heating technology should be analyzed as well as the most energy efficient product system. As for both heating/cooling the Peltier effect(thermoelectric heating/cooling) is new and is used for wearable products. Infrared heating is the newest(energy efficient) heating solution. For cooling a combination of sprayed liquid and fan is used.

Cooling technologies

Cooling and heating technologies

Heating technologies

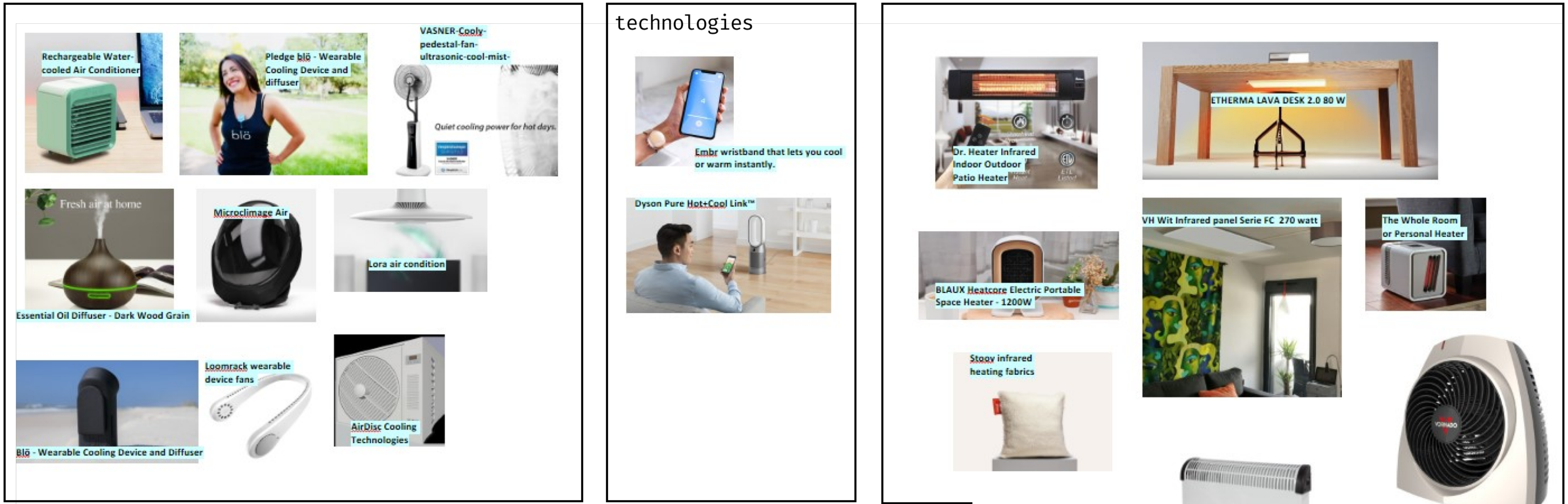


Figure 11: New products categorized on primary function(Cooling or/and heating). Standing out blo - wearable cooler with diffuser(liquid) that cools down user. Dyson with interactive tracking capabilities. Infrared heaters and stoov heating fabrics.

a.3 Product decomposition

In this section a personal heater is decomposed to better understand functional parts in which the product can offer thermal comfort. A system division helps to know how a personal heater can be designed. An electric convection heater is decomposed as an example.

1.3.1 Convection heater

A convection heater is a type of heater that uses convection (air)currents to heat and circulate air. These currents circulate throughout the body of the appliance and across its heating element. This process, following the principle of thermal conduction, heats up the air, reducing its density relative to colder air and causing it to rise. As heated air molecules rise, they displace cooler air molecules down towards the heating appliance. The displaced cool air is heated as a result, decreases in density, rises, and repeats the cycle.

1.3.1 Systems

The convection heater can be divided into subset of systems:

Type of heating technology ⟶ heating elements
Control system ⟶ temperature control and sensors
Heating distribution system ⟶ fan (through a medium: air)

All of these systems are connected through electrical circuitry.

The higher the amount of subsystems the higher the power consumption will be. Are these systems necessary from a functional perspective(Figure 12)?

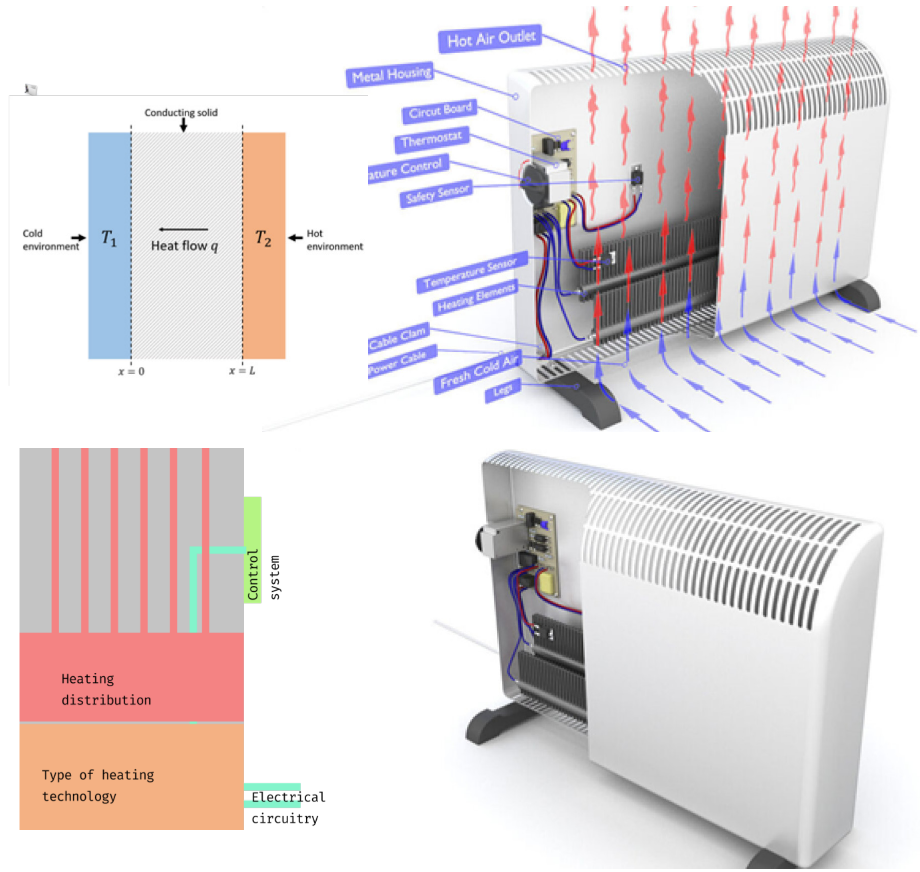


Figure 12: A typical convection heater with it's working principle. What parts are causing inefficiency?

a.4 Heat Transfer

Heat is the transfer of energy from a warmer object to a cooler object. For example, a lighted match (higher temperature object) will transfer heat to a large pan filled with water (lower temperature object). What is needed for heat transfer to take place is a difference in temperature between two objects. Without this difference, no heat transfer can take place. Heat can be transferred in three ways: by conduction, by convection, and by radiation. These three ways form a corner stone of the design of a heating system. For example heating trough radiation is a process where heat waves are emitted that can be absorbed, reflected, or transmitted. The product should contain an emitter/filament material that actively is able to transfer radiation energy from one point to another. To transfer from one point to another a general rule of thumb is defined(Appendix B with Dr.ir. C.P.G. (Paul) Roelofsen) the larger the distance between the user and heating source the longer it takes for the user to perceive warmth(heath difference).

In figure 13 a ceiling product idea is presented: The product is able to follow the user and provide heating trough an infrared heating beam in-doors, covering how the system is able to transfer heat from one point to another.

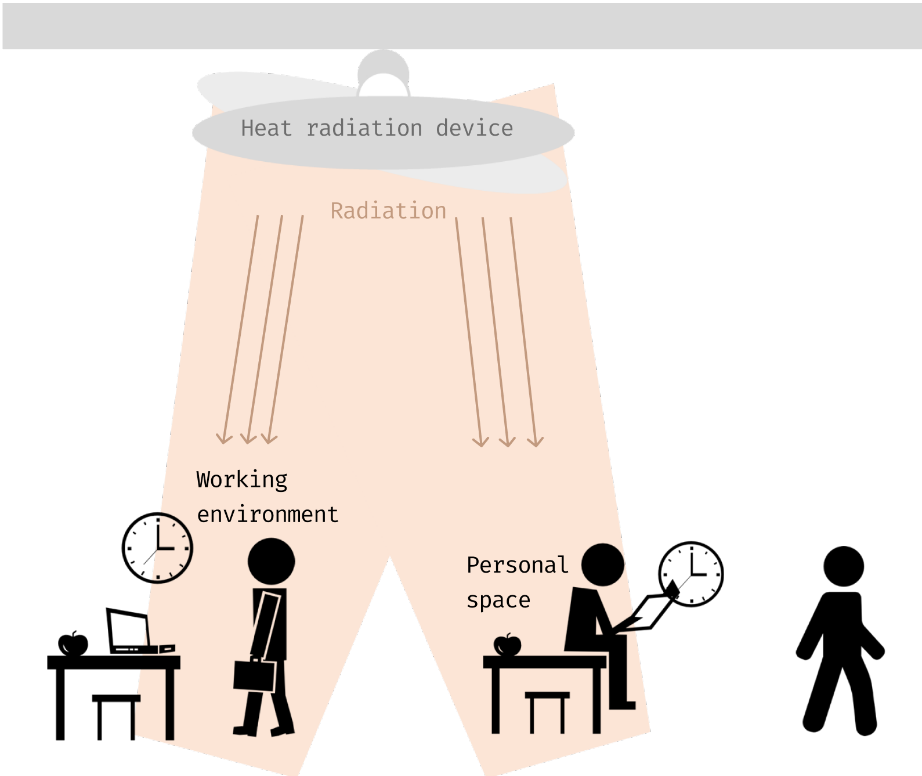


Figure 13: Pre-ideation based on the interview with Paul Roelofsen covering the part of transferring heat from one point to another.

b) needs

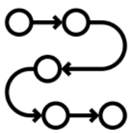
An user-oriented approach to design a personal heater concept for a user requires to design for their needs and goals. Literature research, field research and the current technology showed what these overall needs are.
The needs are gathered and categorized into different categories:

1. Human(individual) focus: heating people instead of heating spaces. Comfort is an individual right and privilege.
2. Static vs Dynamic: Comfort and well-being is more than a static indoor climate.
3. Information: the need for accessing essential information and to control the thermal environment.
4. Mobility: the need to be mobile within your household or workspace. Carrying should not be a burden.
5. Accessibility: Making a thermal comfort system accessible for individuals.

Human Focus

Heating people instead of heating spaces, the need for:
Direct heating aimed at user instead of surface/space or air.

Static vs Dynamic



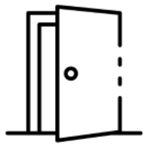
Static indoor condition vs a dynamic situation as a moving human being. the need for Flexible product that is able to be used at different conditions or can adapt to different environmental conditions

Information

Having access/control to information, the need for:

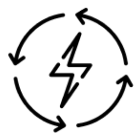
Knowing the current environment temperature.
Giving access to manually control or automatic control the personal heater.
How long it takes for heating up user’s body and advice on timer.
Continuously sensing body temperature and turning on and off or adjusting power settings.
Give insight on how much power is consumed or saved.

Mobility



Going from room to room(workspace), the need for:
Carrying the heater easily without effort
Using both wall outlet connection and/or working on battery for storage

Energy efficient



Heating technology, heating transfer(from heater to user)
Does the system really need (mechanical) parts? Simplicity vs Complexity not only influence design but also energy efficiency
Transferring from one medium to another from one system to another. Using Air/Water makes the heater less efficient.
Energy efficiency is also closely related to performance.

c) scenario for personal heater

For a personal experience, one individual is obviously taken as a starting point but a small group of users does not necessarily need to be excluded. One may also notice that most portable interactive products are also used/ experienced by two or three people at the same time. For instance: showing a video clip on your mobile phone to your friend, listening music on your JBL speaker with a friend or a group of friends(Figure 14).

The three parameters for IIEC need to be defined and serve as an input for the design process:

1. The ideal relative humidity for health and comfort is somewhere between 30-50%.
2. Airflow velocity in the range of 1–2 m/s is the ideal velocity to provide thermal comfort.
3. Air temperature(in-doors) can fluctuate between 20 and 23 °C. Suppose decreasing the temperature at the thermostat setting to 18 °C
4. The product should minimally provide an extra Δ 5 °C of heating. This range really depends on the distance(user vs device) and the heating technology.
5. Since body heat is 100 W the device should provide a range of 150 - 300 W. Comparable with a wearable/mobile device. The car seat can also be used as an example. A car seat heater has a maximal power of 100 W. The user-car seat distance is assumed as 0 m.

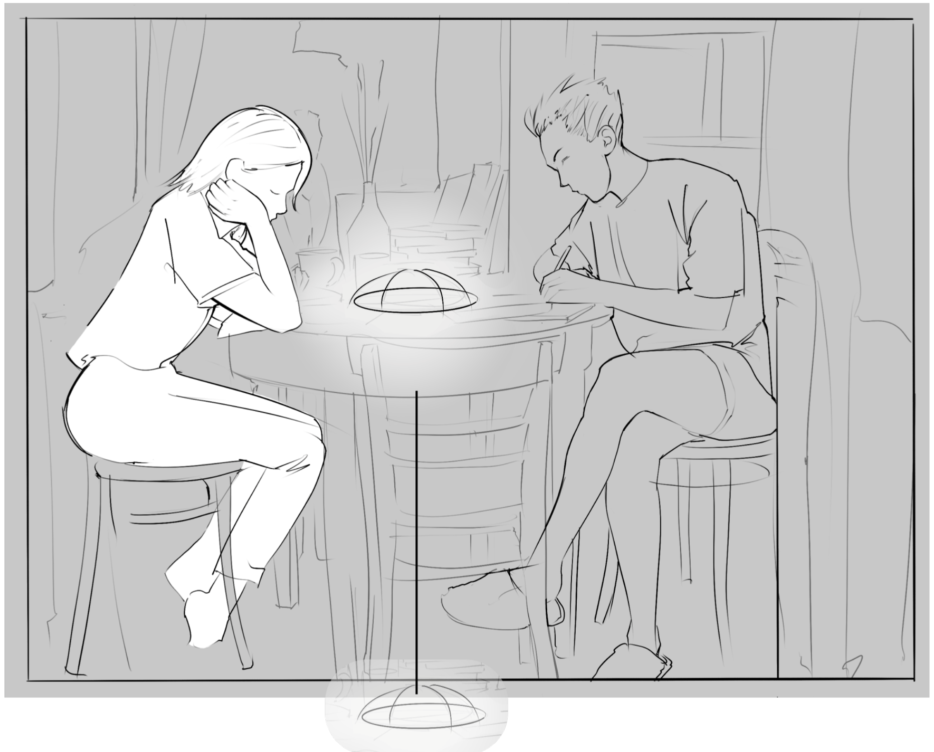
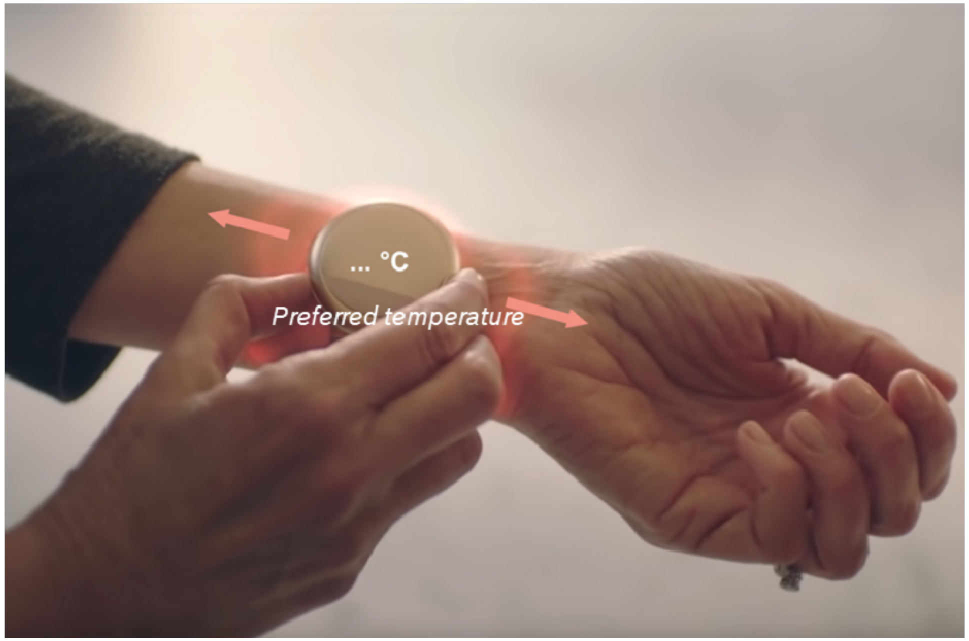


Figure 14: Initial indoor environment conditions that help define the product interaction vision, average values of thermal comfort conditions intersecting product reach.

c.1 The ideal solution space

The interesting opportunities for this project are between a really close human body system(wearable) and a central heating system. The central heating system is usually meant for heating a room (providing an acceptable air temperature, Fanger) instead of heating people. It's not tailored down to only one individual but more people together. That's why an ideal indoor temperature is always a range instead of being a fixed number. These ranges even differ more if you look at different continents: America and Asia for instance have a slightly different indoor temperatures and even thermal sensation.

The ideal solution would be a system that instantly works without having to preheat. The product should be close by: on the table on the floor or the ceiling(within reach of 1-2 meter).The product should be easily detachable carry-able to another room. A product with a wire usually prevents being mobile and thats why ideally a battery can be used to be wireless for a limited time. Challenge: With heating systems batteries are easily drained.



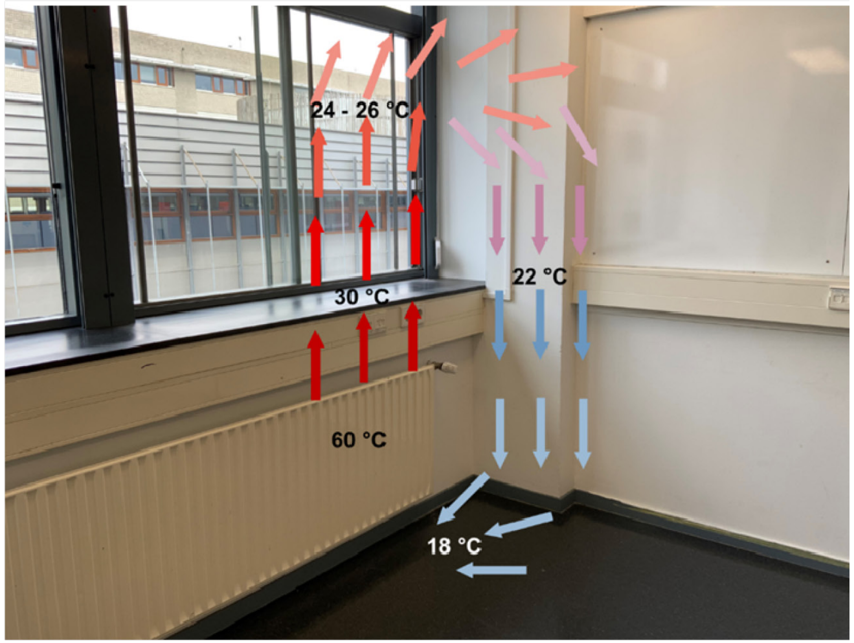


Figure 15: The ideal solution space defined from protable/small personal heating to central heating systems heating a room.

d) outcomes & contribution

Personal heaters are heaters that mostly focus on increasing room(enclosed environment) temperature. The user comes at second place. Most personal heating products are valued based their performance and their sound: how fast are they able to heat a room to an ideal air temperature and how quiet they are. Also the performance might be valued on how the fan(mechanical) works and where heat is 'aimed' at.

There might be interesting opportunities to be defined between fixed, mobile and wearable products within personal heating technologies.
A (personal)heating system can be subtracted into three systems: **heating technology, heating control and heating distribution(heat flow)**.

These systems are design parameters and helps for step by step addressing each part as a design feature. The heat transfer gives an overview of how heat can be transfered from the heat source to the heated object. In this case from heat source to user.
User oriented design focuses on designing the product focused on the user's need. A categorization has been made: Human(individual), Static vs Dynamic, Information and Energy efficiency.
The scenario helped define initial conditions based on background and context research. At least a range of Air humidity, Air velocity and Air Temperature has been setup.

This chapter contributes towards the design goal in a way that it provides the first possible directions gained from the needs and current technology.
The needs show that the concept should focus on primarily Human and Static vs Dynamic. Current technology shows how already existing products are valued and what aspects users overall value the highest: performance, sound and flexibility(aiming). The contribution of this chapter is understanding
the users and coming up with possible directions: a system that instantly works without having to preheat. The product should be close by: on the table on the floor or the ceiling. However the product should be easily detachable carry able to another room. Ideally it would be preferred that the product can work on battery. (Challenge: With heating systems batteries are easily drained)

1. The ideal relative humidity(RH) = **30 - 50%.**
2. Airflow velocity in the range of **1–2 m/s** is the ideal velocity to provide thermal comfort.
3. Air temperature(in-doors) can fluctuate between **20 and 23 °C.**
4. The product should at least provide an extra **Δ 5 °C.**
5. Since body heat is **100 W** the device should provide a range of **150 - 300 W.** Comparable with a wearable/mobile device. The car seat can also be used as an example. A car seat heater has a maximal power of 100 W. The user-car seat distance is assumed as 0 m.

a) workshops b) project requirements c) heating technology d) outcomes & contributions

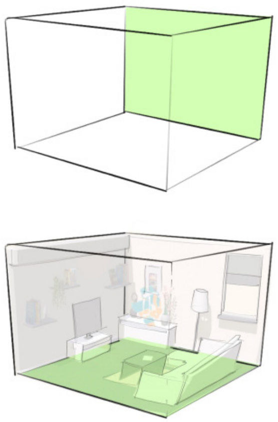
3.Design directions

Ideation that defines three main design directions. A final project requirement presented as a result of research and testing. A heating technology is chosen as a base for the conceptualization phase.

a) workshops

Two workshops were organised: one at the faculty of IDE in Delft and the other one at Bosch in Deventer(figure 16). Both Sessions were recorded on paper and on video to capture the process and to see how the participants was going trough the process. A format was used for drawing products in environments. This format basically shows two enclosed rooms where one of them has furniture and the other one is empty. The participants were firstly asked to answer the How to's categorized as below:

1. **Technology and features**
   - Heating technology and heat transfer
   - Human condition tracking
   - Mobility products
2. **Product physical execution**
   - Attaching/detaching mechanisms
   - Product distance vs heating
   - Aiming and tracking systems



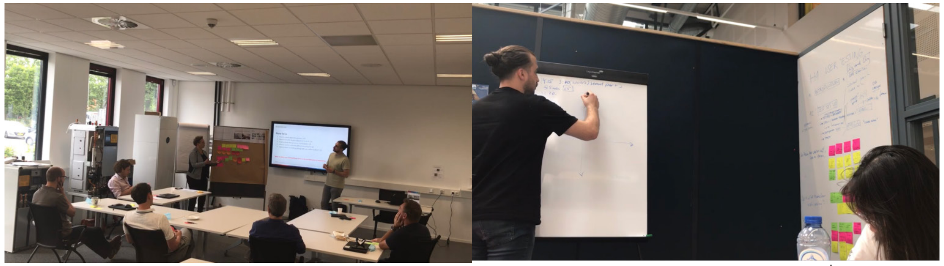


Figure 16: Workshop sessions both at the R&D department at Nefit|Bosch and with students at the IDE faculty in Delft.

Bosch Workshop Results

Idea 1: Integrating wearables ⟶ jewelry, clothing(gloves)

Idea 2: integrating heat systems with furniture(couch/chair)

Idea 3: Floor panel induction heating system with special shoes for heating

Idea 4: A personal heater that tracks your thermal comfort level and aims heat to the user.

TUDelft Workshop Results

Idea 1: tracking personal heater, when nearby it can

Idea 2: small chair/couch that wraps the body and select if you want to heat or cool

Idea 3: portable device that takes shape in different form and put on body offers heating/cooling. Combined with machine learning.

Idea 4: ceiling panel with user tracking. It turns on and heats/cools

a.1 Design Directions

Both the brainstorm at the faculty and at Bosch three design directions are formulated and visualized(Figure 17):

1. Mobile solution ⟶ easily movable, replaceable and store-able product.
2. Wearable solution ⟶ attached to the body.
3. In-door fixed/installed solution: which means the product is attached to one of the four walls. experience. A mobile solution is preferred. User tracking heater is preferred secondly.

Flexibility is central, since people move around the house. How can a product 'follow' the user while being energy efficient? Or how can the product be flexible for the user to carry around and adapt easily?

The most preferred ideas by Bosch and students from TUDelft are heating systems integrated in existing products. Integrating heating systems in a chair/couch table or wearables like clothing might not be ideal since a chair and a couch is not "movable" or flexible. At last participants mentioned that a heating wearable causes sweating and a 'sticky'

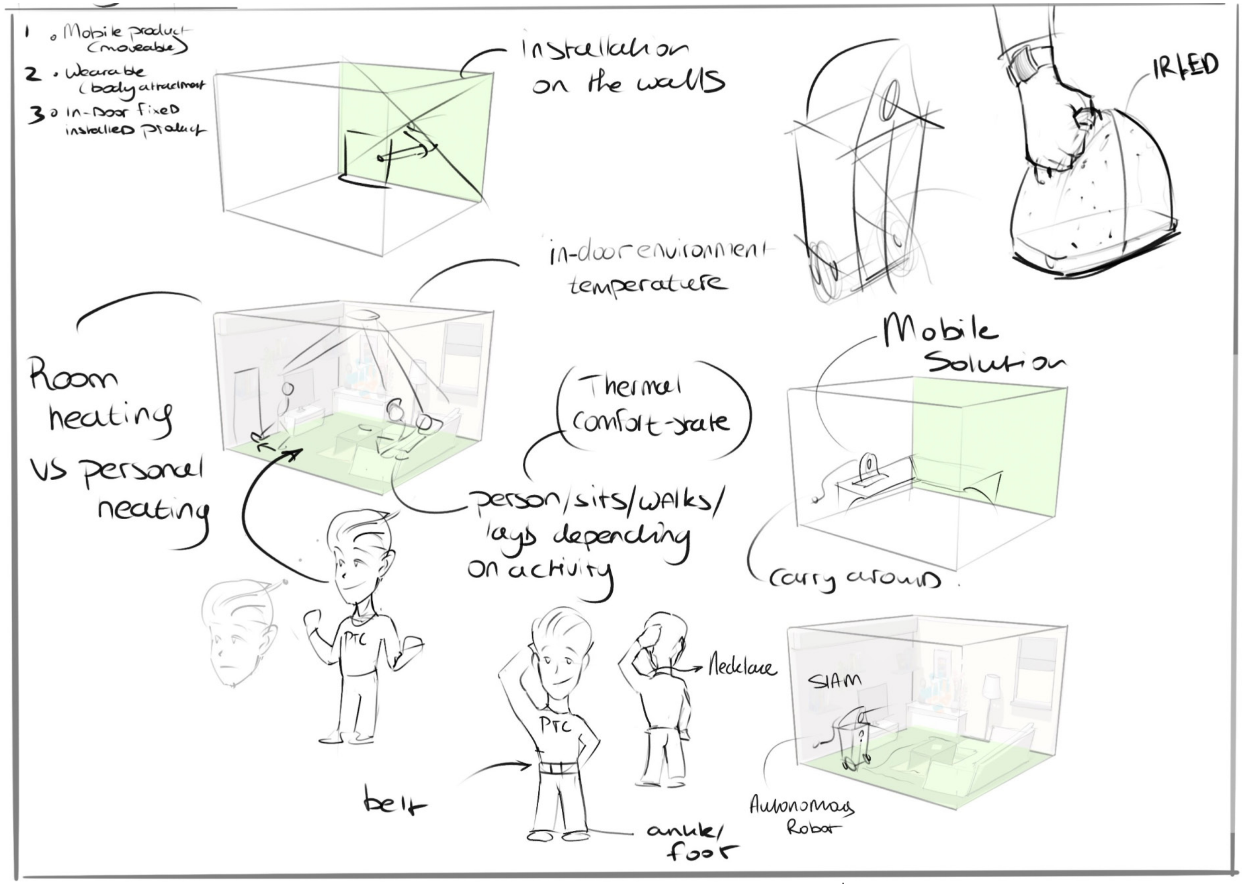


Figure 17: Workshop sessions both at the R&D department at Nefit|Bosch and with students at the IDE faculty in Delft.

a.1 Design Directions

Both wearable systems, mobile products and indoor fixed or installed systems were derived from the solution space that came to existence. Most participants had a preference for a mobile or fixed product since wearables are mostly causing inconvenience: most people gave an example of a watch or necklaces though they are not very convenient. Interesting to see both differences and similarities of how students preferred something like a mobile product to carry and Bosch workers mostly choose fixed solutions like couch heaters or ceiling solutions. Students were more likely to go for interactive solutions such as a robot or a product that uses an app. Bosch's workers were not necessarily interested in such applications. For me it is interesting to see that most of the students were service driven than physical product driven.

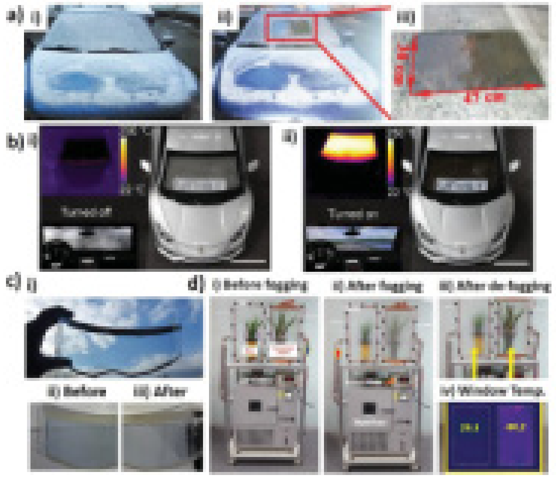
Three design directions are formulated:

Mobile products (caryable), wearable products and modular/fixed product(ceiling)

To the right a short outline of three personal idea's are shown. On the following three pages, each idea is explored, researched and explained.

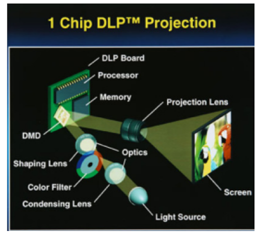
1.Transparent heaters

Using thin films of transparent heaters for windows in rooms. Applying it to room furniture, blending into a physical design. Not noticeable.



2. Heat projection mechanism

Using this projection technology to aim and redirect infrared heating to a specific location or person



3. Fold-able structure

Using fold-able planes to design smart structures that can **turn/twist and move with little effort.**
For instance, to design a pivot system to aim and direct heating/cooling at the user.

Figure 18: Workshop sessions both at the R&D department at Nefit|Bosch and with students at the IDE faculty in Delft.

b) project requirements 2.0

The final project requirements is presented on the next following pages(Figure 19). These requirements are formulated as a base for test and validate the prototype. These requirements can be altered when the design is becoming more detailed. Currently it stops at requirements 2.0

Human thermal comfort

1. The product should be easily and intuitively adjustable to needs and preferences trough an interface.

2. The product should be focused on body parts through which most heat is lost: **torso, hands and feet.**

3. The product should be able to make the user conscious of the **product core temperature (and ambient temperature)** but also how they can change it.

4. The product's material choice should depend on whether it can prevent or cause local (dis)comfort if it involves touching it.

5. The product should prevent the user from sweat.

6. The product is not responsible to conditions as changing posture, orientation towards the product, putting on/off clothes.

Heating source

1. The product use electrical power via the wall outlet **(230 V)**.

2. The product use FIR heating technology to provide thermal comfort at a distance range of maximum **500 mm** between product and user.

3. The product focuses heating adding a **Δ 5 °C** difference compared to the environment. The environmental conditions influences product performance:

    The ideal relative humidity(RH) = **30 - 50%.**
    Airflow velocity in the range of **1-2 m/s** is the ideal velocity to provide thermal comfort.
    The thermostat settings of the central heating(heat pump) is set to 18 °C thus **the ambient temperature is at 18 °C**

4. The product consumes a **P = 155 W.**

5. The product should have a **thermal fuse** build for safety when there is a short circuit or ground fault.

Design

1. The product should be protected by a sleeve when folded in.

2. The product should be protected by touching(oils from skin and others)

3. The product is flexible, meaning it has multiple configurations: take shape as both a standing and a laying position(two configurations).

4. The product is able to fold-in and out as a means of saving space but also to have different surface area for aiming(two areas).

6. The product overall has a divergent aiming setup that allows two users to be thermally satisfied.

7. The product is stable and rigid on a table top when standing and laying on the ground.

8. The product fits inside sleeve and can be taken to a workplace or to other rooms.

Wishes

1. The product works on batteries. The battery is around 1280wH which basically is a car battery.
2. The product has multiple aiming configurations(trough folding)
3. The product has an automatic and a manual setting: automatic setting that adjusts temperature to user distance and manual setting that allows the user to enter preferred temperature. The temperature setting is adjusting product core temperature.
4. The product has multiple shape and color variations.

Interaction

1. The product displays both the ambient and the product core temperature.

2. The product should save energy by automatically turning off when the user is not present.

3. The product should save energy by automatically turning off when the timer function is used.

4. The product should not be turned on when the product is at folded state.

Ergonomics

1. The product should be in the reach of the user to change orientation/direction.

2. The product is mainly shaped around the average hand length(P50) = **190 - 215 mm** and shoulder height(P50) sitting = **630 - 680 mm** for both male and female(20-30).

3. The product should effortlessly fold up, take and go and folded out.

4. The product corners should be rounded since the sheet is sharp. Sharp edges could cause injury.

5. The product should prevent the user from sweat

6. The product is not responsible to conditions as changing posture, orientation towards the product, putting on/off clothes.

Figure 19: Product requirements. These requirements are derived from background, thermal comfort, heating technology (user) research and with the ideation. The first initial requirements can be found in Appendix E.

c) heating technology

The heating technology obviously affects how heaters perform and how they are going to connect to other functional components(product architecture) as well as how they are going to relate to the user.

Not to forget that the project's focus is to provide personal heating while taking into account energy efficiency. The definition of energy efficiency: Using less energy without having to lose (heating) performance. Secondly, the performance is also related to how long the system takes to offer heating on demand. Heating transfer is an important factor: unnecessary transitions from medium(water/air) through mechanical parts causes delay and an increased power consumption. Less is more not only is meant for product aesthetics but also for designing a smart and simple working mechanism that doesn't need more material, power. With low-temperature heating systems on the rise new emerging technologies are noticed and compared with conventional heating systems. In Appendix C an overview of all "ways of heating" is setup and compared with relation to criteria: performance, safety, complexity, energy efficiency/power consumption, availability and costs.

With the presented set of requirements/criteria heating technologies are evaluated and a top 3(Figure 20) selection will serve as an input for the concept development phase. Normally these requirements are used and compared with already existing (central and personal) heaters. The following technologies stand out:

1. (Near/Fake)IR incandescent bulb / LED
2. (Far)IR Radiation
3. Radiant Heaters(Sun)

There are different types of personal heaters. Since this project is focused on the future of Dutch households, combustion type heaters are neglected. The overview mostly shows electrical solutions divided into EMR and others. The common personal heater offers heat by having an electrical current through a resistance wire. Nichrome, a non-magnetic 80/20 alloy of nickel and chromium. Electric space heaters that provide radiant heat are the most efficient types and are good options for warming up a room. Convection heaters are other types of space heaters that function by warming up the air in the room. Both radiant and convection heaters fall under the same price range.

Sustainable Energy Resources for Heating

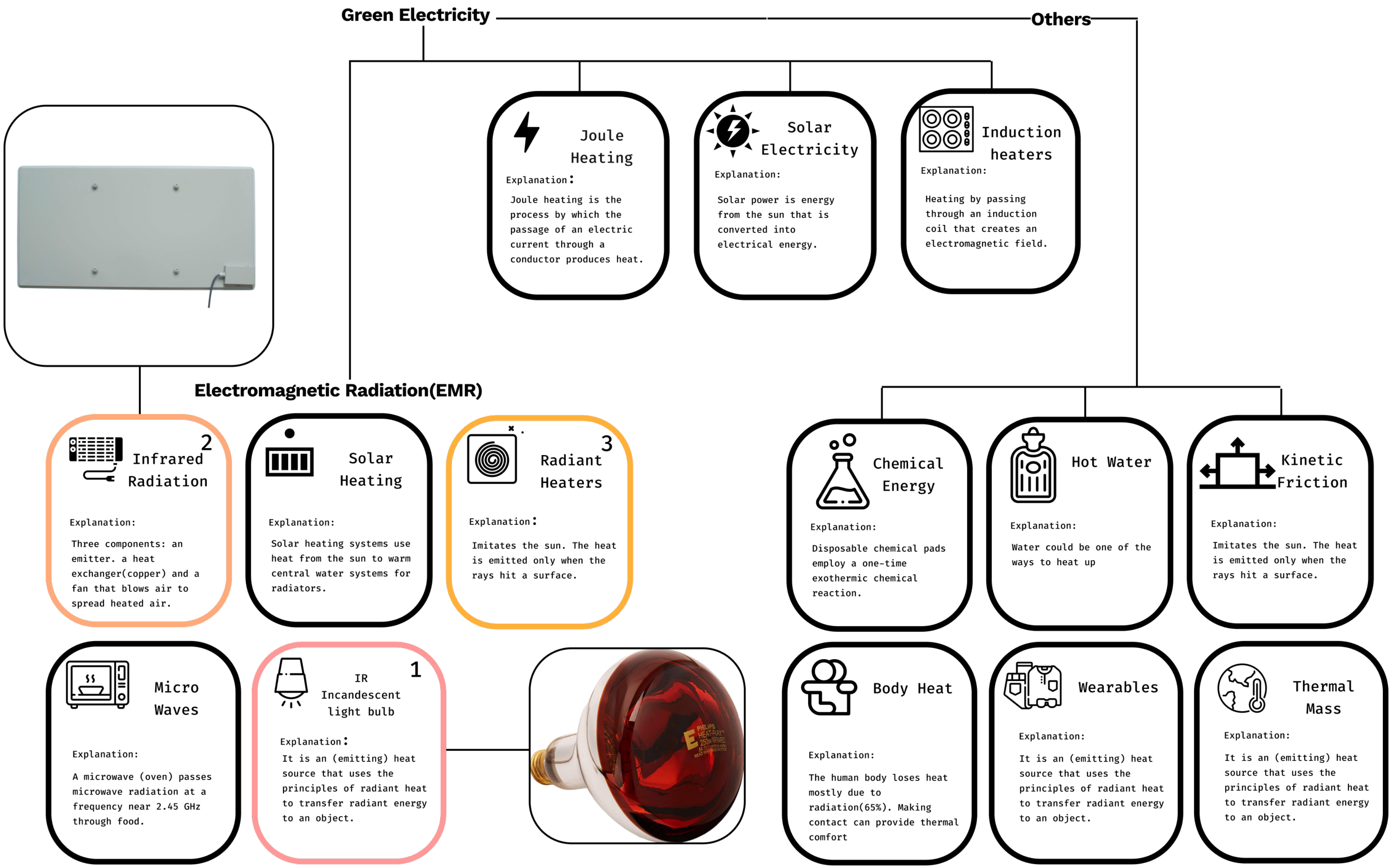


Figure 20: An overview of all sustainable Energy resources for Heating. The numbers are top three chosen technologies and the frames are given a color to exclude them from other heating resources.

c.1 Infrared eating

Infrared(IR) heating technology have been chosen as a starting point. IR appears a promising future: Due to low temperature warming and generally low energy consumption more IR panels are commercially sold and introduced. Another to this, most warming advances based on sustainable energy resources have one major issue: they involve and influence air temperature resulting in a lot of heat loss and very low energy efficiency compared to infrared heating.

IR heating has already been used in the history. A historic overview is shown in Appendix D.

Generally IR radiation is divided into the following(Brynes, 2008):

1. Near-infrared (NIR, IR-A): 0.75–1.4 µm in wavelength
2. Short-wavelength infrared (SWIR, IR-B): 1.4–3 µm,
3. Mid-wavelength infrared (MWIR, IR-C) also called intermediate infrared (IIR): 3–8 µm.
4. Long-wavelength infrared (LWIR, IR-C): 8–15 µm
5. Far infrared (FIR): 15–1,000 µm.

However with heating most systems are divided into two sections: **NIR and FIR**. The heat-producing wavelength usually covers **3 µm - 12 µm wavelengths**. These sections are known to emit the most heat. In Figure 21, the Plancks Curve is showing the radiation intensity.

Since warming with IR goes from source to user it is vital to know how retention happens and how these spectra carry on. Subsequently transmission and assimilation is exceptionally critical. In the event that the IR wavelength is shorter the more transmissive its warm is. This may well be useful for expansive separations between client and item. The **IR-B** and **IR-C(2 - 4µm)** is considered the waveband where they are the most excellent on both transmissiveness and retentiveness and is the foremost viable locale for warming in huge spaces. Between **5 – 8 microns(IR-C)**, the application is more for warming encased rooms like household ranges, workspaces, ponder rooms and there's no light radiated from the infrared heater. In Figure 21 the Plancks Bend appearing the radiation concentrated as well as the (ruddy line) the segment that emanates the foremost warm vitality.

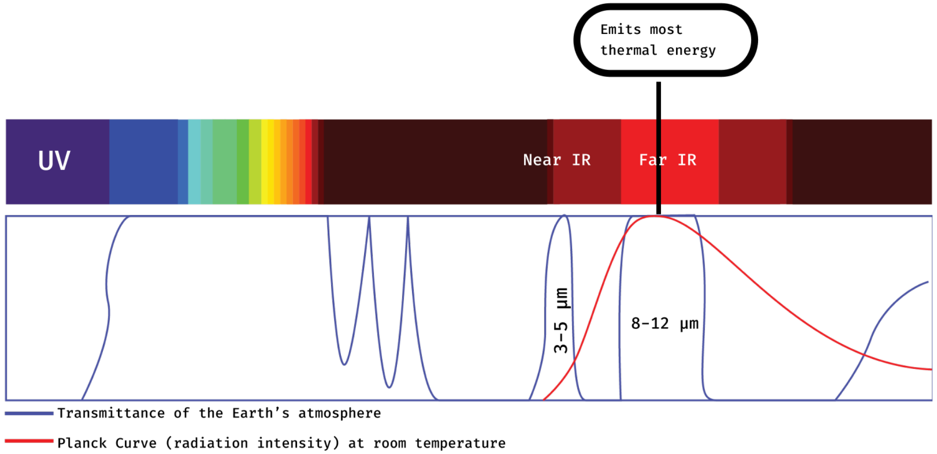


Figure 21: Plancks Curve showing radiation intensity and the a section where it is emitting the most heat.

c.2 Incandescent NIR Heating

Incandescent IR heating is used for the major cause of developing heat. The spectrum of black-body radiation emitted through the lamp is shifted to produce extra infrared light. Many warmth lamps include a crimson filter to decrease the amount of seen visible light emitted. Heat lamps regularly include an inner reflector(Figure 22). Though a fraction of the heat is also carried out trough the body. An infrared mild bulb is designed to emit infrared, while emitting as little seen light as possible.

Heat lamps are frequently used in bathe and toilets to warm bathers and in food-preparation areas of eating places to keep meals warm earlier than serving. They are also usually used for animal husbandry. Lights used for fowl are regularly referred to as brooding lamps. Aside from younger birds, different types of animals which can benefit from warmness lamps encompass reptiles, amphibians, insects, arachnids, and the young of some mammals.

he sockets used for warmth lamps are typically ceramic due to the fact plastic sockets can soften or burn when exposed to the large quantity of waste(heat) produced by means of the lamps, mainly when operated in the "base up" position.

The body of the lamp is commonly metal. There may additionally be a wire guard/encasing over the front of the body, to forestall touching the hot surface(inner plate) of the bulb.
It is expected that there is a loss of efficiency in both the emitted light and also the heat absorbed

Ordinary white incandescent bulbs can additionally be used as heat lamps, but crimson and bulbs are offered for use in brood lamps and reptile lamps. 250 watt IR lamps are many times packaged in the "R40" (5" reflector lamp) form thing with an intermediate screw base.

Heat lamps can be used as a medical therapy to furnish dry heat when different redress are ineffective or impractical.

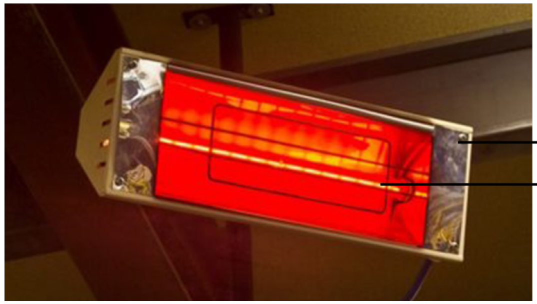


Figure 22: Infrared heating used at large factory buildings or at sauna's

c.3 Radiant FIR Heating

Usually FIR heaters have a FIR heating member: a filament or a material that is able to conduct electricity. When an electrical current passes trough the member is able to radiate in the far infrared spectrum. The most common used materials carbon nanotube(CNT’s) members, graphite/ graphene, graphite paste or thicker conductive (infrared) cable which is a combination of highly densed graphite with silver(Figure 23). The full panel decomposition can be found in Appendix D.

Carbon nanotubes can act to efficiently radiate in the far infrared spectrum as a result of an electrical current passing through. This creates an efficient heating article that is able to radiate in the far infrared in all directions without heating itself up.

When the voltage ranges from 10 volts to 30 volts, the temperature of the planar heater ranges from 50° C. to 500° C. As an ideal black body structure, the carbon nanotube structure 16 can radiate heat when it reaches a temperature of 200° C. to 450°.

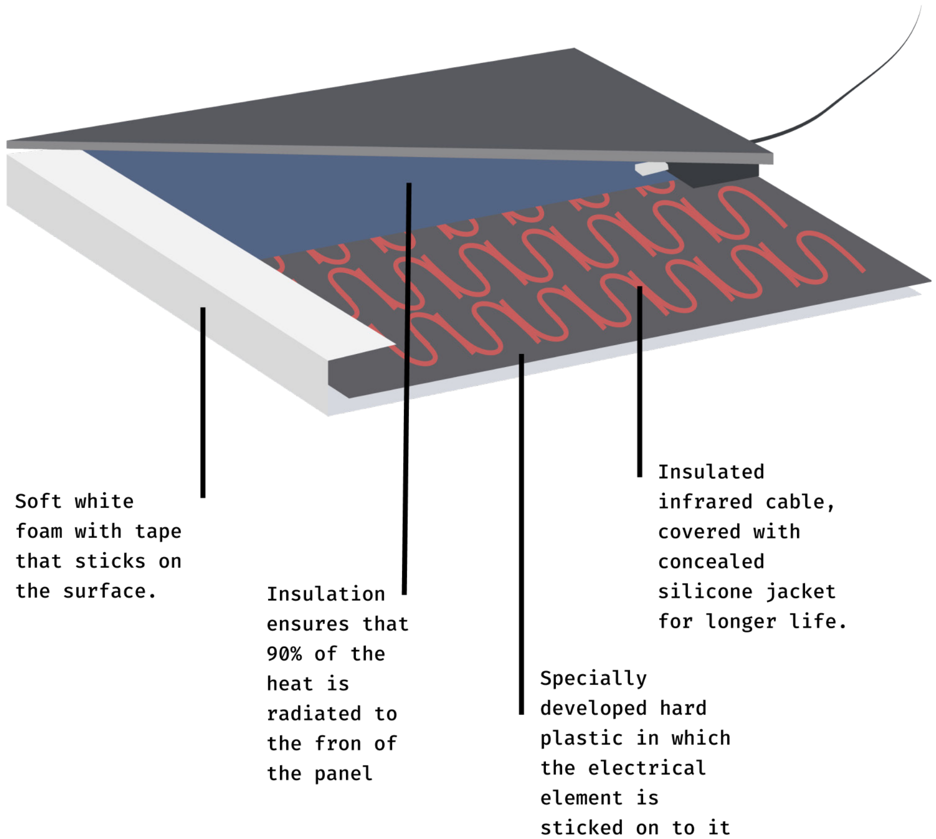


Figure 23: A typical panel heater architecture decomposition.

d) outcomes & contribution

Three design directions are formulated: Mobile products (cary-able), wearable products and modular/ fixed product(ceiling)

Three ideas are also of interest:

1. **Transparent heating** technology(used in front windows shield of cars)
2. **DMD projecting system:** using a projector system to project heat(rays) to a person
3. **Using folding techniques to design an aiming or controllable mechanism to project heat.** Using folding techniques for storing/carrying a product(compact).

An initial project requirements are setup to keep in mind what the design at least need to be validated for. And to explore certain conditions and values.
Infrared heating technology is chosen to develop ideas with. It is power efficient and doesn't need any preheating with NIR(incandescent IR bulb).
The best range of heating in terms of distance and absorption is at a **range of 2 - 4μm(NIR)**. NIR heating systems are used at sauna's and terraces.
Infrared panels(FIR) are also very common. **FIR range is in Between 5 – 8 microns.**
However they are not flexible rather flat and only cover one area. It is not dynamic: not able to move or change in direction.
An infrared panel is decomposed: insulated infrared cable is used and covered. They are attached to an thermostat connected to a phase and ground wire.

This chapter shows the design directions, initial requirements, overview of heating technology towards the conceptualization. The heating technology really sets the physical design parameters and is therefore important as an input for the conceptualization phase.

a) design goal b) concepts c) concept 1 & 2

4.Conceptualization

The design goal is formulated. Concepts are designed based on information input.
Two concepts are 3D modeled and an initial research is setup.

a) design goal

As this is a Integrated Product Design Master project, the overall challenge is to develop a personal heater that is able touch upon multiple areas: **aiming, mobility and energy efficiency**.

The design goal is to find a combined solution where these areas are addressed up to a certain point. Both the human needs, environmental context, energy efficiency, heating technology and product requirements serve as an input for developing three concepts.

The heating technology will primarily shape the product will look like. Infrared technology is taken as an input since the previous chapter shows how promising the technology is. Combining with the bases of personalized heating(personal thermal comfort) and the environmental conditions product can be shaped. The ideation of both at Bosch and the TUDelft gave an interesting input for the design directions. What are the most interesting? and how can these ideas relate to aiming flexibility?

On the right(Figure 23) a product shape design exploration has been done. One idea was coming from the idea of a mobile device like: JBL Speakers; A mobile speaker that enables music listening on the go. The JBL speaker can be put wherever you want and you can turn twist and change positioning to adress your need.

Mobility nowadays is very important. Mobile with work, studies and many other activities. Second idea was coming from the idea of having one device connected to multiple configurations for heating. Like a gaming console with controllers.

A simple product architecture of heaters helps to define product shape:

1. Operation
2. Control system(micro controller)
   User vs Product(buttons etc)
3. Heating Technology ⟶ IR Radiation
4. Product operating positions
5. Power/Battery
6. Cables

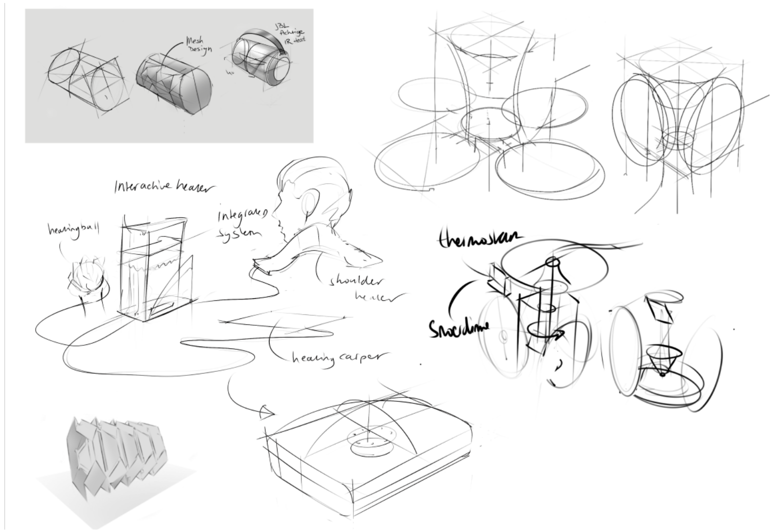


Figure 23: Exploring ideas while thinking of already existing product interactions.

b) concepts

The following page shows three concepts and all three use infrared technology as a base. Each concept has a description, product location, system overview and a price estimation. Both the system overview and the price estimation are based of on comparable technologies within the robotics or lighting market. The product location was served as an input for the brainstorm session. The initial system overview gives an idea on how components are connected but also helps price estimation.

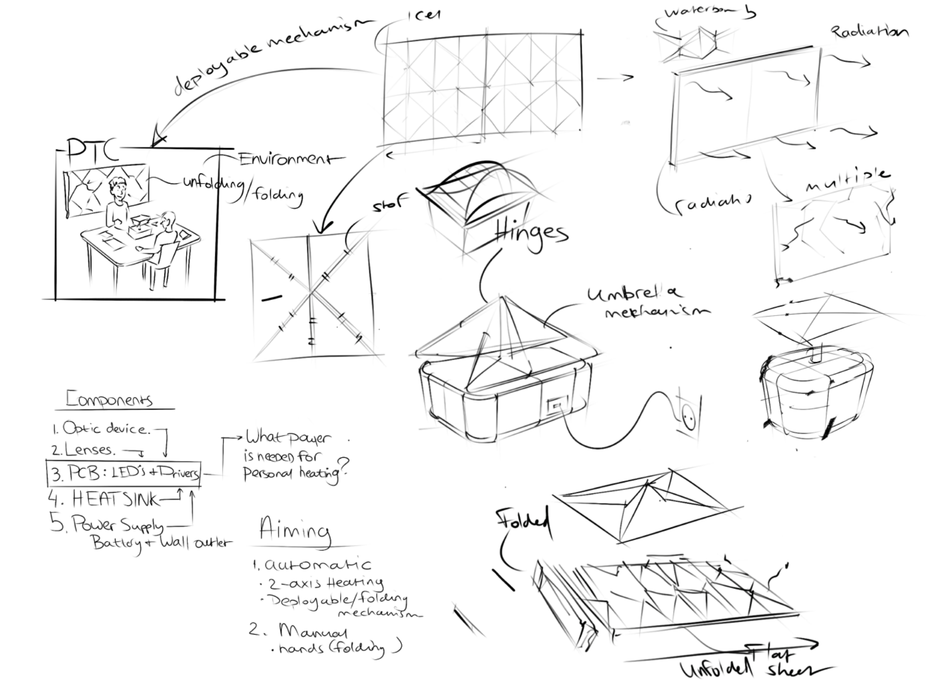


Figure 24: Ideas on planar movement and fold-ability

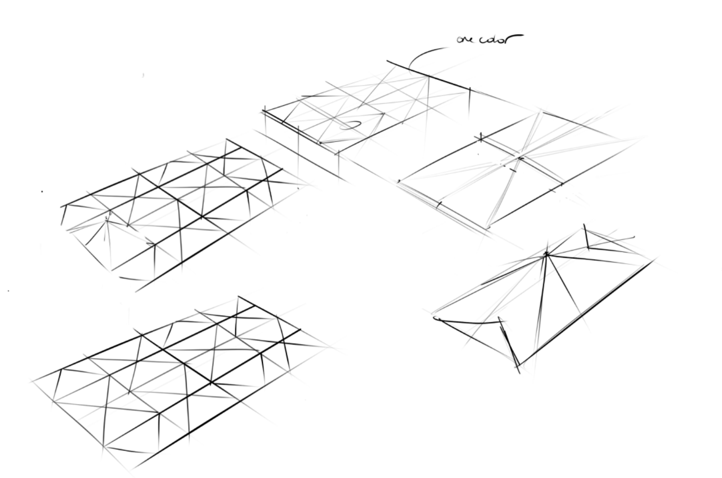
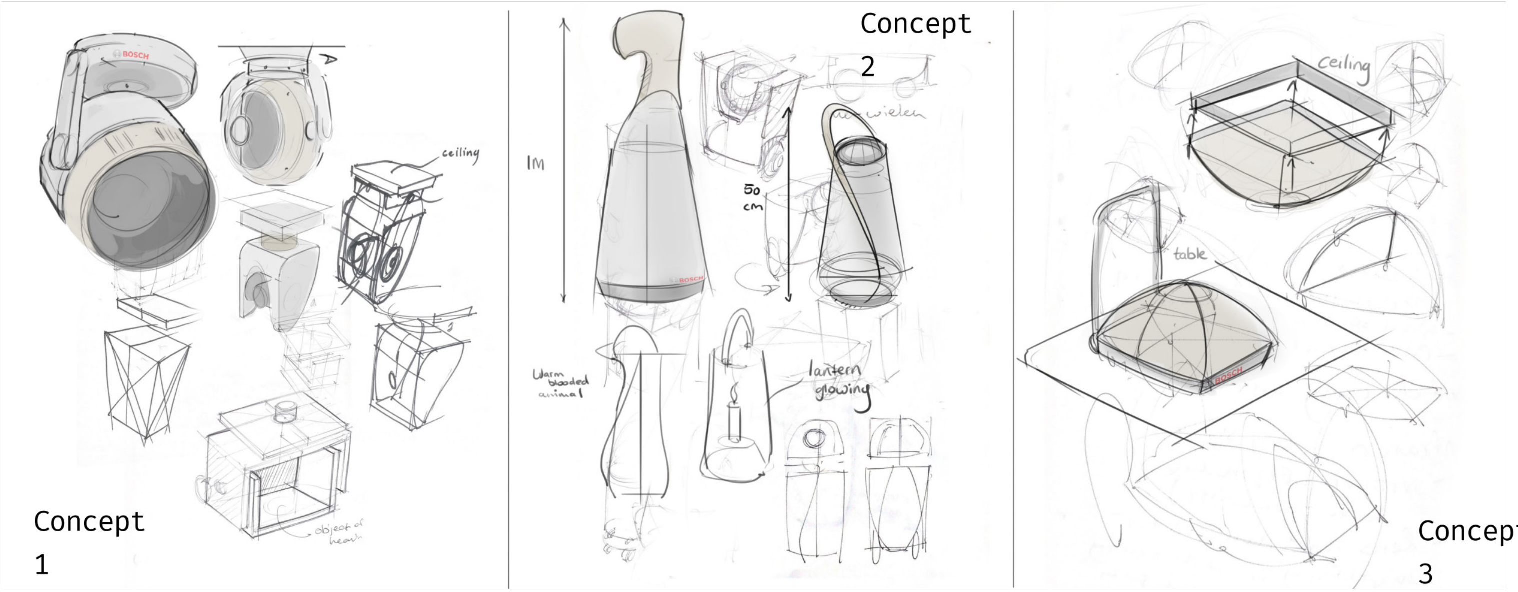


Figure 25: Origami movement

On the left an initial exploration on fold-ability was done to see how rigid origami can be used to get planar movement.



Description: a (human-seeking) ceiling solution that aims IR rays to provide heat achieving thermal comfort tailored down to the need of one individual.

Product location: The product is positioned in-doors and is fixed at the ceiling. A manual is needed to give a step by step to assemble the product at the right location.

System overview:

Infrared heating system (head)

Incandescent/LED IR Heating module

Aiming motors 2 axis

Sensors/tracking system

Encasing that attaches to the ceiling (screws etc.).

Price estimation:

100 - 300 euros

Description: A (personal) heating robot that is able to move and aims IR rays to provide heat achieving thermal comfort tailored down to the need of one individual.

Product location: The product working area is in-doors and is dynamic. Objects need to be avoided when maneuvering.

System overview:

Infrared heating system(head)

Incandescent/LED IR Heating module

Tracker roller motors and rollers

Aiming motors 2 axis

Navigation system

Rechargeable batteries LiPo battery

Self-charging unit

Price estimation:

600 – 1200 euro (depended of IR costs)

Description: a carriable and modular heating device that is able to be put on a table/ground or attached to the ceiling/wall.

Product location: The product is positioned in-doors and is semi-dynamic. The user is responsible for the device's position.

System overview:

Infrared heating system (head)

FIR Heating Panel/Film

Aiming motors 2 axis

Sensors/tracking system

Attaching/Detaching mechanism for the ceiling/wall

Carrying handle

Price estimation:

100 – 200 euro (depended of IR costs)

Figure 26: Workshop sessions both at the R&D department at Nefit|Bosch and with students at the IDE faculty in Delft.

b.1 Concept Selection

From Bosch's perspective Concept 1 is the most viable and feasible concept. The concept can be associated with the lighting field. As heating technology, there will be a filament material that is able to transmit the NIR spectrum(850 nm - 4μm) from large distances. The head containing the optic device is able to move and rotate along z-axis and xy plane. One issue might be ceiling to user distance. This is not standardized and will be a challenge to tackle. Concept 3 took attention from both TU Delft students as Bosch. It is a rather new concept that is focusing on planar aiming. It seems the concept might be feasible within the time frame and also energy-efficient since it is focussing on FIR heating.

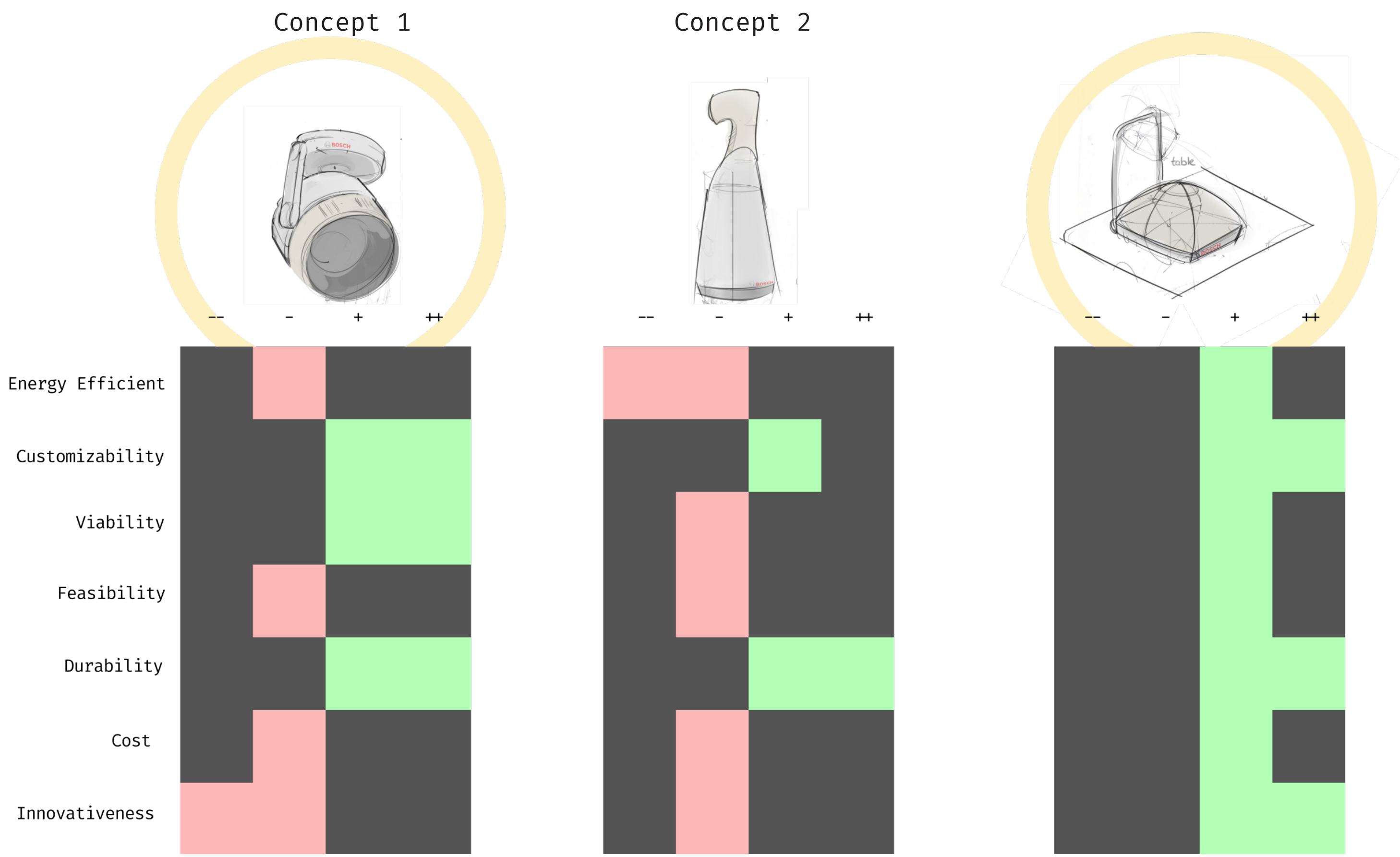


Figure 27: Workshop sessions both at the R&D department at Nefit|Bosch and with students at the IDE faculty in Delft.

c) concept 1 & 3

A simplified 3D Design of both concept 1 and concept 2 is presented here. Some product parts are explored. The purpose of these 3D models was to get an idea on the optic device and to model the reflection of the infrared spectrum.

Concept 1

Concept 1 (Figure 28) explores only turning on the Z axis. The optic device is able to increase/decrease heating surface area automatically. My assumption is when the surface area is decreasing, a temperature increase occurs(like a loop and sun combination). This optic device contains a sensor that is able to sense the temperature difference and the device will decrease the temperature setting for the temperature that is needed(making it more efficient).

Concept 3

Concept 2 (Figure 29) explores a fold-able sheet or curved surfaces that is able to reflect rays(FIR rays) to the user sitting across the product. The purple bands illustrate the FIR members. My assumption is that if the user is able to see these bands within that reflection the user is heated(facial side). A curved surface is ideal but not as a construction. A rigid solution is preferred for stability.

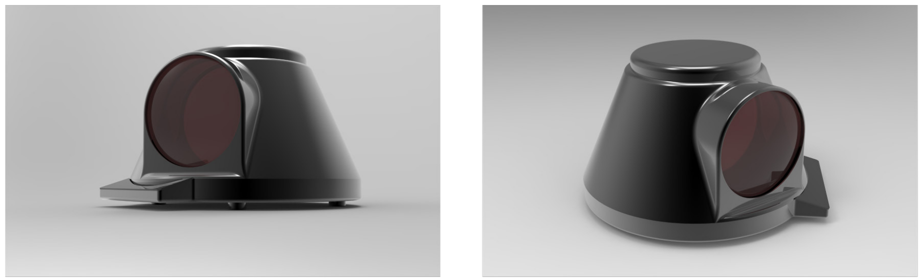


Figure 28:NIR concept 1 a projector for on table.

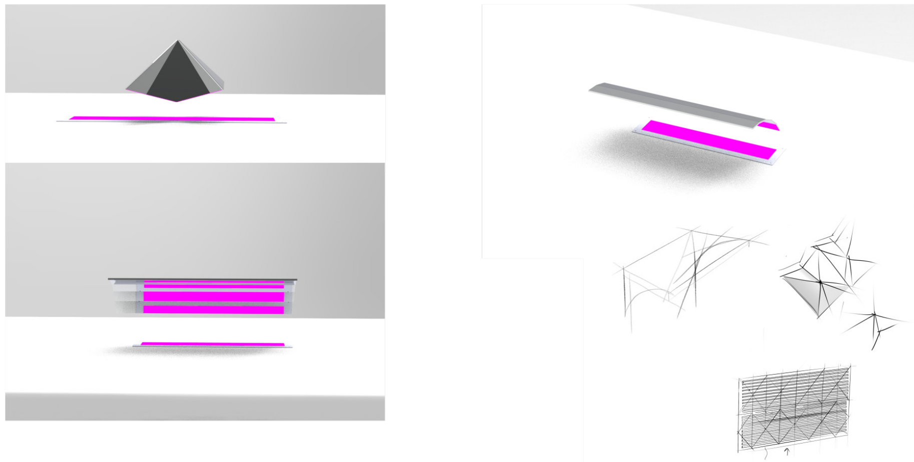
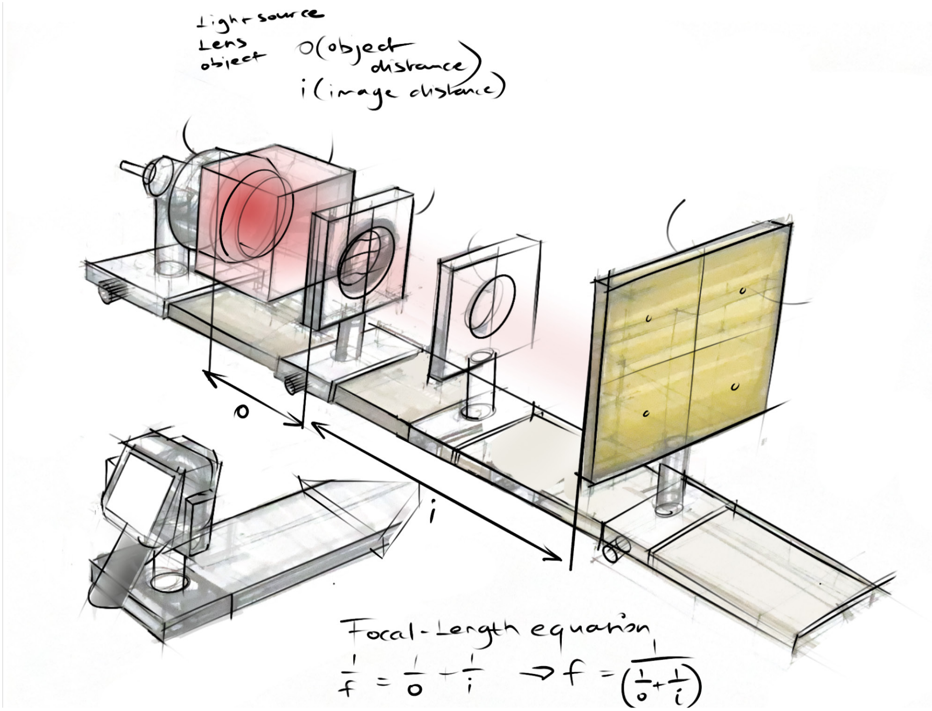


Figure 29: Exploration of a fold-able sheet concepts. Looking into ways where reflection can be used as aiming.

c.1 Research

Concept 1

In order for Concept 1 to work a small scale research needs to be conducted where aiming with lenses/reflective material is the main focus. Keeping in mind that safety for all is very important. A concrete plan is visualized for measuring the temperature distribution over the length. Since infrared is very reflective a thermocouple is difficult to use for measuring(reflective metal or heat dissipates fast). However an object that absorbs heat can taken as a starting point to measure(T) with a thermocouple. For more significant measurement a thermal camera can be used for measuring temperature over the length. A thermal camera is able to measure long wavelength infrared radiation emitted by an object.



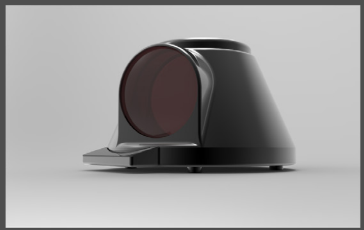
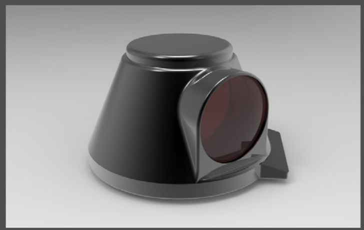
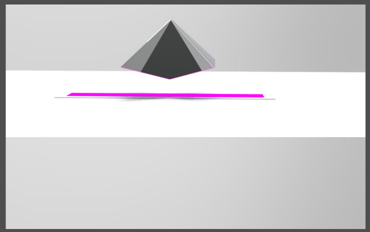
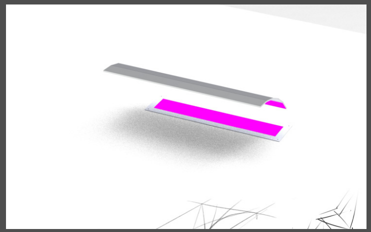
Concept 3

For Concept 2 it is difficult to see how FIR is traveling from the product to an object. Therefore temperature measurements need to be made by using a thermal camera. Absorption is difficult since the FIR sheets that are ordered are focused on making physical contact(Floor heating). Though the temperature distribution over the length of the foil can be measured. What will happen if the sheet is bending? What will happen if there is a fold-line

d) outcomes & contribution

Three concepts are presented to Bosch’s project supervisors. Based on criteria two concepts are of interest:

Concept 1: Infrared heat projector.
Concept 3: fold-able aiming/mobile heating panel

An initial project requirements are setup to keep in mind what the design at least need to be validated for. And to explore certain conditions and values.

Infrared heating technology is chosen to develop ideas with. It is power efficient and doesn’t need any preheating(IR Bulb/LED). IR Bulbs are mostly used as patio heating or for chicken breeding.

Infrared panels are also very common. However they are not flexible, they aren’t tailored down to user needs.

An infrared panel is decomposed: insulated infrared cable is used and covered. They are attached to an thermostat connected to a phase and ground wire.

This chapter shows the design directions, initial requirements, overview of heating technology towards a design goal

a) principle testing **b) interaction testing** **c) hinge testing**

5.Research & Testing

Principle testing with NIR Heating and FIR heating for concept elaboration. Both are compared and a the best technology is chosen based on project’s criteria. This chapter answers the following questions: what principle is viable and feasible? What concept on behalf of research and testing can be chosen? and what challenges need to be addressed?

a) principle testing

The purpose of “principle testing” is to validate if the synthesized ideas/concepts are viable and feasible by exploring fundamental **functional** product parts. The test leads to continue/discontinue for prototyping and further product elaboration. The complete testing content can be found in Appendix E. In this phase the concept is broken down into:

1. **The Heating Technology**
   Near Infrared Heating ⟶ Incandescent/LED Heating
   Far Infrared Heating ⟶ Heating Elements/Filaments
2. **Aiming**
   Lens and Reflecting ⟶ Optical Aiming Test
   Aiming with planes ⟶ Fold-ability configuration, curving
3. **Conclusion** with regards to heating technology comparison and how aiming will be turning out.
4. **Interaction:** Multiple product configurations for allowing the product to be used for multiple scenarios.
   a. Automated
      Challenge is to find a ‘less complex’ solution for allowing the fold able planes to automatically face towards an object.
      Energy efficiency and Costs are important criteria for idea selection.
   b. Manual
      Allowing the user to adapt the product themselves.
      Energy efficiency and Costs are important criteria for idea selection.

The first concept is a near infrared heating technology with the ability to aim heating rays by an optical device(automatically aiming).

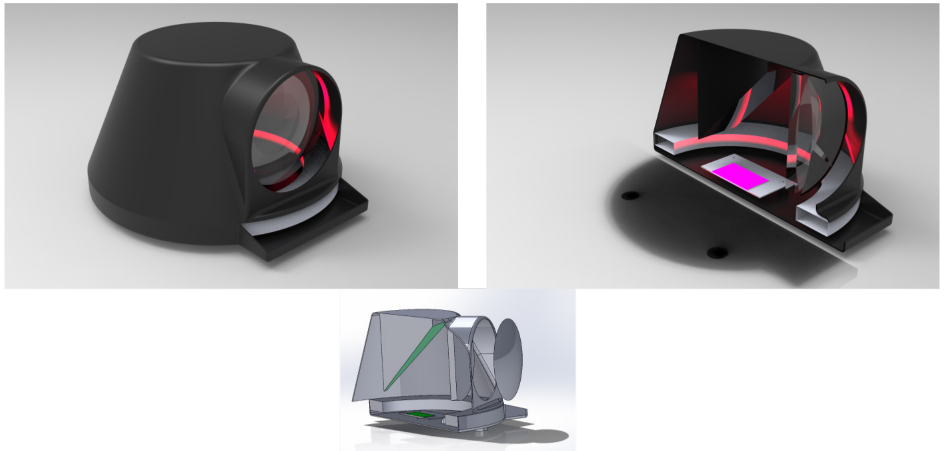


Figure 30: Workshop sessions both at the R&D department at Nefit|Bosch and with students at the IDE faculty in Delft.

The second concept consists of a far infrared heating technology with the ability to fold and unfold multiple planes for aiming and mobility purposes.

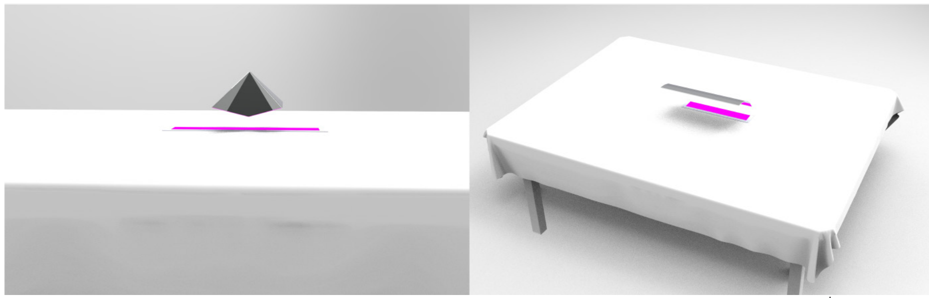


Figure 31: Workshop sessions both at the R&D department at Nefit|Bosch and with students at the IDE faculty in Delft.

a.1 NIR Optics testing

The purpose of this experiment is to discover if an aiming mechanism is effective for developing a personal heater with near infrared heating(NIR) as a heat source(Figure 32). In order to get a clear idea on how effective this optic device will be the most crucial parts: an infrared heating source(incandescent light bulb), a lens and an object is used.

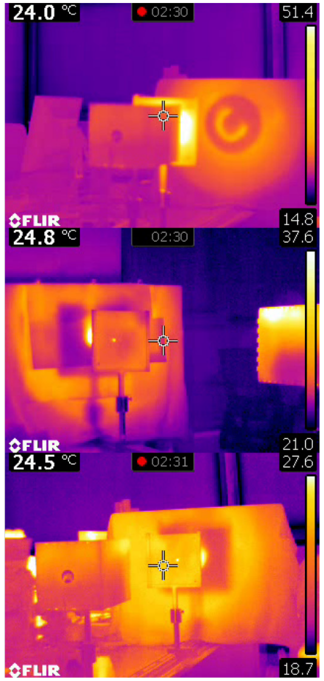
The following research questions are answered:

1. To what extend will an optic device work for IR(rays) heating?
2. To what extend are IR heat rays manipulatable without losing thermal properties.
3. What are the temperatures over the distance when a Fresnel lens is used? Additional questions:
4. What is the thermal absorption rate distributed over the distance when operating the IR bulb?
5. How much electrical power goes to IR light and heat?

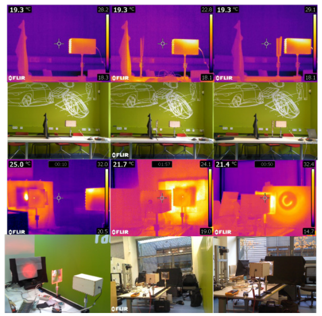
In order to execute this experiment an optics experimental setup has been build at the applied labs at the faculty of IDE in Delft. The additional questions help to decide upon energy efficiency and feasibility.

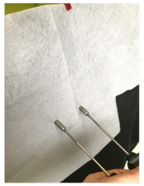
Conclusion

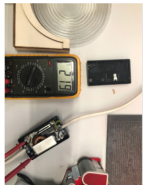
1. An optic device will work for near infrared heating. With a combination of aluminum reflective sheet the incandescent infrared bulb can transition from an omni directional heat source to a focused heat source without increasing temperature near the source. The Fresnel lens is an ideal addition to focus.
2. Only a part of the heat is lost. Aluminum has a very low absorption rate(5%) when it comes to 850 nm wavelength. It reflects 95% off the rays. The silicon Fresnel lens has a small absorption rate(5%). The glass Fresnel lens is the most suitable since it doesn't absorb any heat at all.
3. Peak source temperature is achieved at 8 minutes and 53 seconds.
4. With a P = 250 W the temperature distribution over the distance starts from an average of 107 °C(Δs = 0mm) to at object of 33,2 °C (Δs = 500 mm). The surface area temperature changes due to object and distance changes varies. For more data please have a look at Appendix E.
5. P = 30 W the temperature distribution is only measurable at a Δs = 300 mm starts from an average of 35 °C(Δs = 0mm) to 25,2°C(Δs = 300 mm). The P = 30 W measurement is done since the operating power of the FIR sheet is at 30 W
6. With the convex lens focusing on HA(Hand Area) results in a temperature increase of 3.8°C (Δs = 500 mm) & 4.3°C (Δs = 300 mm) compared to normal. Focusing on TA(Torso Area) results in a temperature increase of 1.2°C(Δs = 500 mm) & 1.8°C(Δs = 300 mm)



1. The thermal absorption rate was difficult to measure and is left out of the research.
2. Almost all electrical power is converted into heat: approximately 92% is heat and the rest will be lost into the light(red).







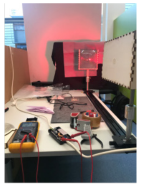


Figure 32: NIR Optics testing from material testing to the effect of heating using lenses.

a.2 FIR Panel/Film Testing

The purpose of this experiment and literature research is to discover what technology is being used for near infrared heating and how the temperatures are distributed(sheet) over the length(object)? For this experiment an infrared foil is used. The technical specs are to be found in Appendix E.

The following research questions are answered:

1. What heating technology is used what is the efficiency?
2. What are the temperature distribution over the distance?
3. To what extent will a panel/film fold and keep their heating properties?

Additional questions:

1. What is the thermal absorption rate distributed over the distance when operating the heating film?
2. How much electrical power goes to heat?
3. Can I increase the current without losing properties of the film?

Conclusion

1. There is a slight difference between the infrared panel and the foil. Both the IR panel and the IR foil contain **carbon nanotube (CNT) members(graphite)**, one or more reflecting sheets, and one or more insulation foam. Electrical energy may be applied to CNT member to generate infrared energy, and reflecting sheet may serve to shape and direct the emitted energy towards a target to be heated.
2. The data for temperature distribution is recorded and saved as a clip. Since both the panel and foil have a difference in shape, size and thickness both have different heat distribution. The heat distribution of the panel when **P max = 30 W** is **45 °C(0mm)** to at object of **30 °C(30 mm).**
3. The infrared panel was rigid and not able to deform easily. After doing a tryout when folding it was broken. The film however was able to fold and after having folded in the creases it seemed to work. It stability gave the same P = 29.73 W.
4. The thermal absorption rate was difficult to measure.
5. All electrical power is converted into heat 100%. Though the conversion to heat has a relation with the resistance of each member. Each member currently is measured at **R = 103 Ω** with the sheet of P = 30 W.

This experiment is executed in the Applied Labs at the TUDelft. For more information please have a look at Appendix E

The foil has been bought via Termofol, A company that provides both panels and foils. The foil is mainly used for heating underfloor/ laminate, ceiling and wall. The power consumption**(initially 220 W/m2)** with measurements: **250 mm x 500 mm x 0.1 mm.** For this piece I measured P = 30 W.

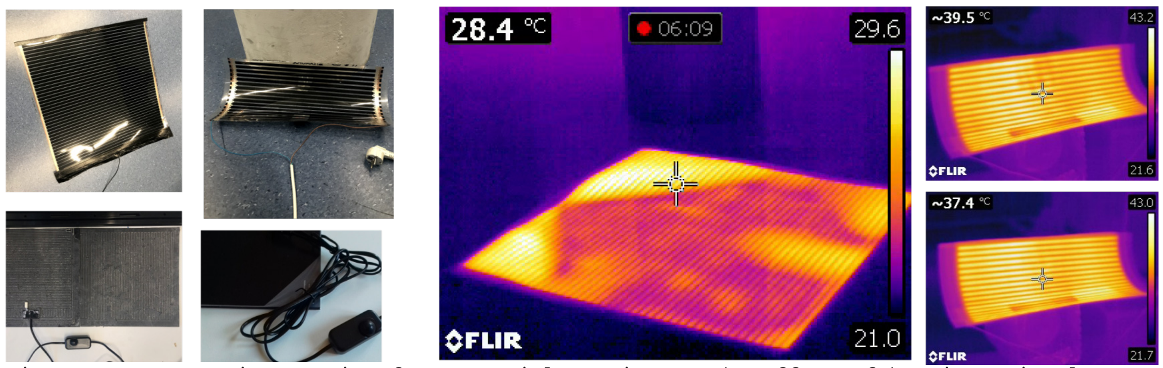
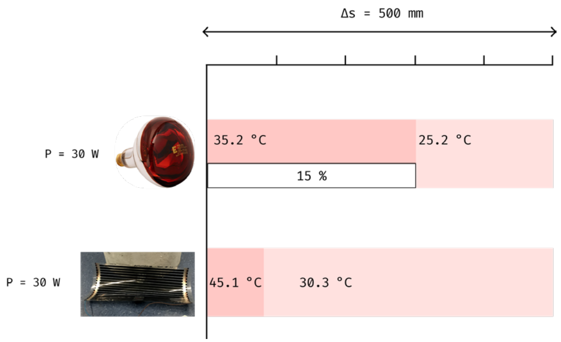


Figure 32: NIR Optics testing from material testing to the effect of heating using lenses.

a.3 Conclusion

Both heating technologies have interesting applications for comfortable heating. The NIR Bulb loses to FIR radiant heating when it comes to efficiency: 100% - 92% = 8% difference. The bulb loses energy because of the visible red light. The NIR Bulb has a Pmax = 250 W with a max temperature distribution of 72.1 °C(0mm) to at object of 33.2 °C(347 mm) making it more powerful compared to the film which has a P max = 30 W distributed on the surface area P = 29.73 W is 45.1 °C(0mm) to at object of 30.3 °C(30 mm). Comparing power consumption (250/30) = 8.3 times greater which will affect temperature distribution. At source the temperature difference factor is 1.6%. is over 10 times smaller (347/30) compared to the NIR Bulb. For P = 30 W the temperature



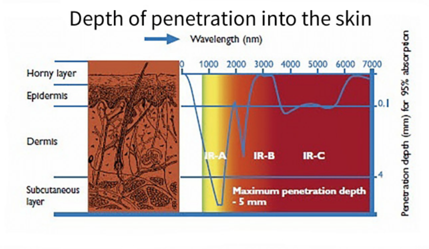
distribution is only measurable at a Δs = 300 mm starts from an average of 35.2 °C(Δs = 0mm) to 25,2°C(Δs = 300 mm). The P = 30 W measurement is done since the operating power of the FIR sheet is at 30 W .

Health issues

Considering human health, near infrared heating is more damaging since there is visible light. Higher power consuming lasers will cause damage to the eyes. With NIR there are no studies showing that it will cause permanent damage to the retina. For now people who are sensitive for light might get irritated and are advised to wear goggles. Most weighing health risks are related to skin damage: several studies show that NIR light causes an increase in MMP-1 activity in the same manner as is known for UVR(Barolet, 2016).

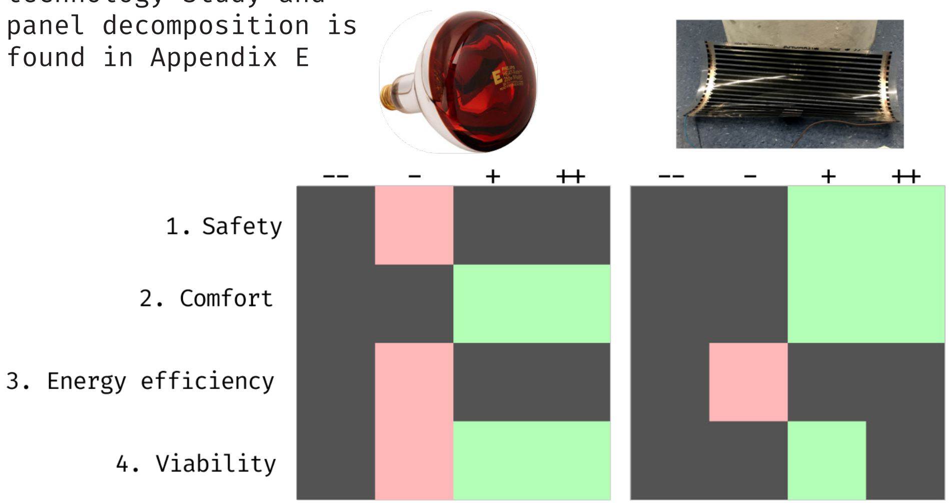
Depth of penetration and heat absorption

NIR infrared(850 nm) is only able to penetrator around 0.1 - 0.3 mm of skin. IR-A and IR-B(FIR) penetrates more deeper which makes heat absorption more significant.



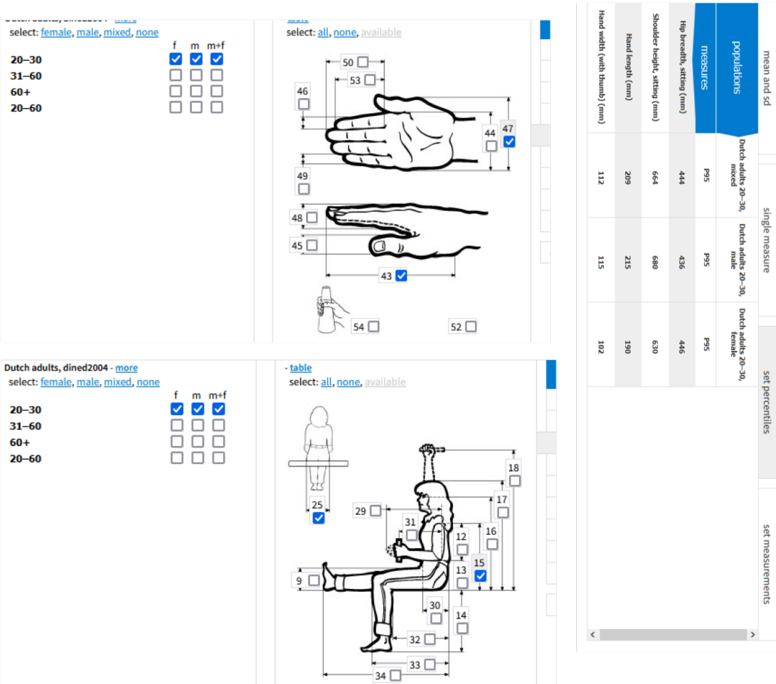
Decision

Because of mainly safety issues my final decision is to go for **FIR** using CNT sheets as a base. To get a better understanding of these FIR sheets a more technology study and panel decomposition is found in Appendix E



b) interaction testing

The purpose of the interaction test is to understand how NIR and FIR beams behave when reflected to a user sitting in front of the product. For a user sitting, human body measurements DINED table (https://dined.io.tudelft.nl/en) is used (P50). The 3D models are developed around these measurements to ensure body parts are beamed. The body parts focused are: chest and abs. For an approximation on how IR rays are reflected **the law of Snell's is used to design the reflective surface.** The reflective surface in the NIR concept is modeled as Aluminum with 96%. The reflective surface in the NIR concept is modeled as **Aluminum with 96%**



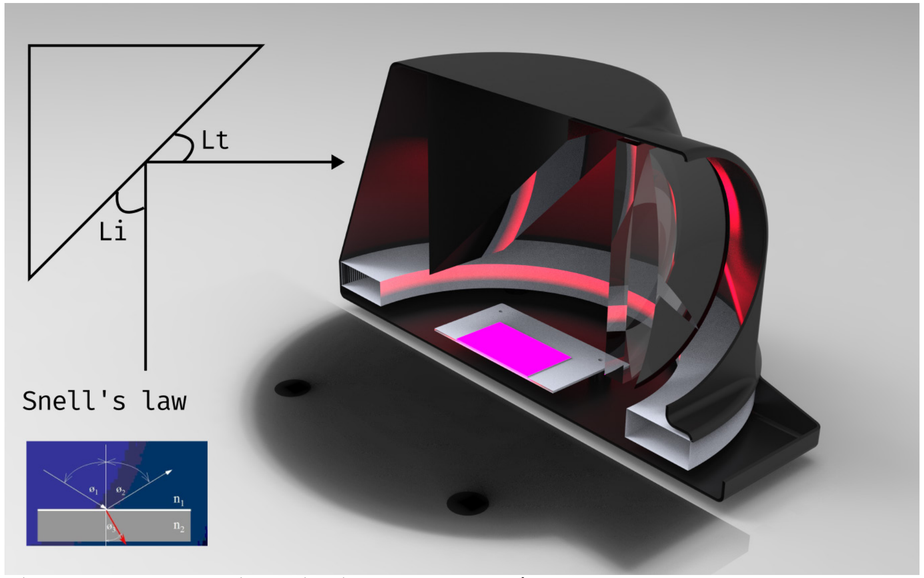


Figure 37: The basic principles of Snell’s law

b.1 NIR Concept interaction

Assuming that a NIR concept could be developed: how would the optic device look like and how are product parts linked to each other? In Figure 37 a product architecture idea is presented. This concept is placed on table/ceiling. The purple product part is NIR LED module (assuming they’ll exist in the future). The 3D model has been made to make sure how NIR spectrum would travel from product to user. Theoretically the light source should be aiming upwards and hit a surface in which is at 45 degrees angle leading light directly to the optic device. The optic device then can adjust the light beam area(reduce and increase area).

b.2 FIR Concept interaction

How would aiming be reflected assuming that a FIR concept could be developed? of the product look like and how are product parts linked to each other? For testing FIR has been modeled as visible light members. In figure 38 a possible planar shape is explored. The purple product part are FIR CNT's. The purpose of this 3D model was to have an understanding how reflection work in the model and thus how the FIR beams would travel from product to user. The curved planar surface helps to guide and reflect all beams to the user. The current rendering is oriented as such that the camera position is on the **height of the chest**. Curved surfaces are not rigid and are difficult to reflect to a full functioning product. Therefore the water bomb shape is rigid and has an additional benefit: it is able **to fold "open" allowing the beams** of each water bomb to **diverge to a specific area**.

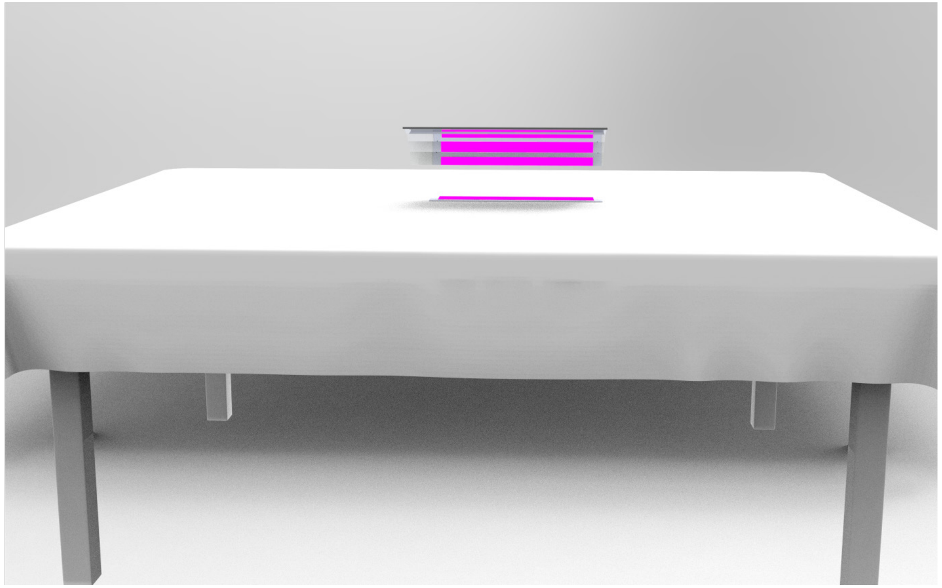


Figure 38: A curved planar testing is done to address FIR reflection on sitting position.

Assuming that a FIR concept could be developed: how would aim-ability of the product look like and how are product parts linked to each-other? For testing FIR has been modeled as visible light.

Decision

From the perspective of aiming NIR has potential to be developed. However a study needs to be done on how to develop an optic device that specifically aims NIR spectrum. Since both temperature and increase/decrease of the aimed surface area really depends on product positioning and target positioning the application of such device is complex and needs more study. Therefore in this project I choose to work on **planar aiming** through movement in stead of using lenses for aiming.

c) outcomes & contribution

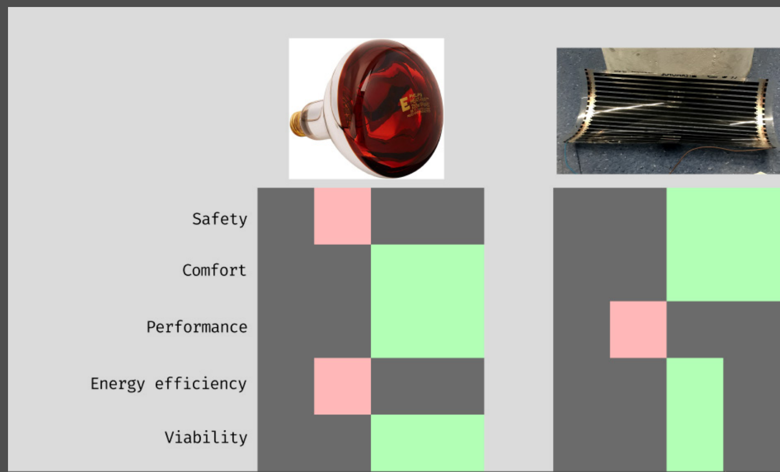
Both NIR and FIR are interesting directions. However FIR is more energy efficient and safe to use compared to NIR.

NIR infrared(850 nm) is only able to penetrate around 0.1 - 0.3 mm of skin. IR-A and IR-B(FIR) penetrates more deeper which makes heat absorption more significant.

For now people who are sensitive for light might get irritated and are advised to wear goggles. Most weighing health risks are related to skin: several studies show that NIR light causes **an increase in MMP-1 activity in the same manner as is known for UVR**(Barolet, 2016). MMP-1 breaks down the interstitial collagens (types I, II, and III).

Aiming NIR has potential to be developed. However a study needs to be done on how to develop an optic device that specifically aims NIR spectrum. Since both temperature and increase/decrease of the aimed surface area really depends on product positioning and target positioning the application of such device is complex and needs more study

This chapter shows the design directions, initial requirements, overview of heating technology towards a design goal



a) ori b) product configurations c) interaction prototype d) costs e) user research

6.Concept

The final concept is presented. Ori is an energy-efficient multi functional heater which is folded out into different product configurations offering directional heat at a max distance of 500 mm.

Ori, an IR Heating solution for placing both on the table top and under desk for keep warm during working or study.

Aim your system by click/fold magnets to you or/and your partner sitting across from you.

Freestanding, Quiet fast warm up and overheat protection, Portable, easy-to store and a take-with you product.

Energy efficient, low energy use, no overheating or tipping hazards!

Specification

Input:	AC 230V
Working power:	160 W ± 5 W
Temperature	45 - 70°C

When operating at maximum(70°C) do not touch!

Figure 39: 160-watt radiant foldable-panel heater provides space-saving warmth.

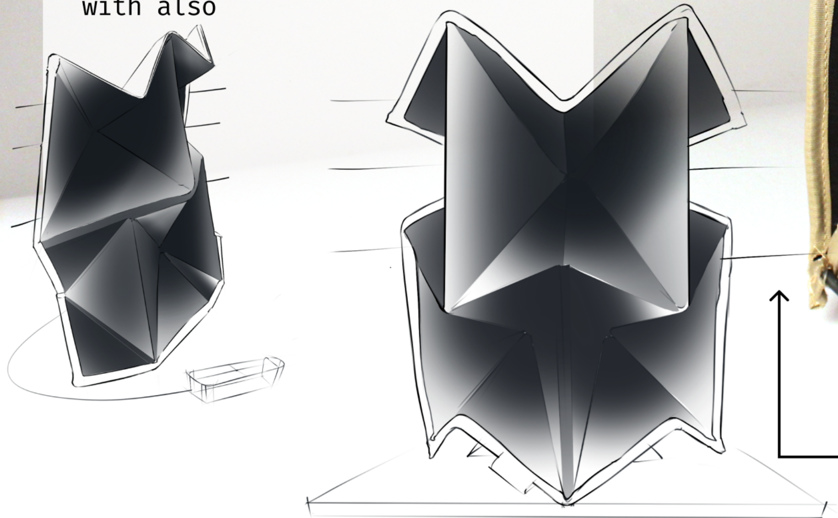
Human Focus

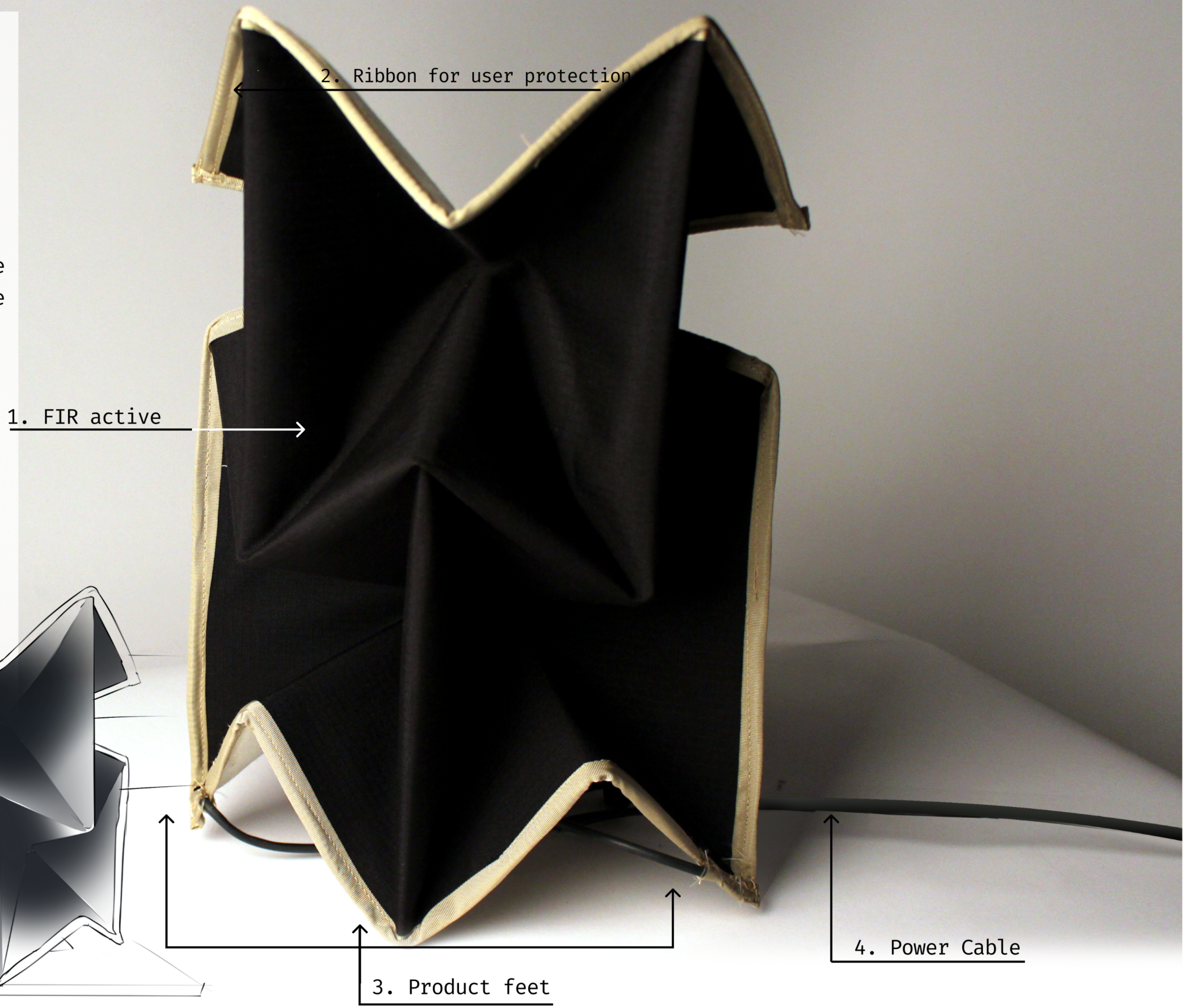
1. FIR dynamic planes

The Ori has an active heating side(black) which is able to continuously heat at a max distance of 50 cm. The planes are able to move collectively and are able to shape to multiple configurations. These configurations are explained at the next page.

2. Ribbon

The ribbon protects the stiff corners(damage prevention) with also





b) product configurations

Mobility

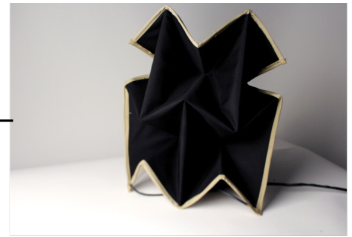
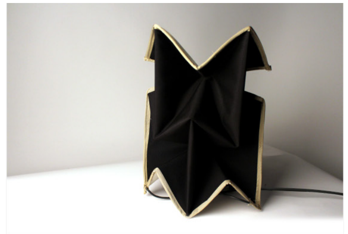
With the folding planes it is easy to firmly position a product. The product is lightweight and with the magnets the product can expand. The goal with theses planes were to able to turn the product easily and closely to direct heat to the user. The flexibility came out in the ability to decrease and increase surface area for heating and also putting it flat on the table top.

Magnets on the backside allow the product to have only two configurations. A fully extended to cover a large surface area and a folded one for small surface area. Next to this the product can lay down flat. Problem is that the top part is aiming at the top which is lost. However on the side Ori is still able to direct heat to the user at a measured 10 degrees angle covering the torso at table top. Ori can also be put on the ground allowing the legs to be heated. The top can be of use when the product is putted on the ground.

This product has fold-ability allowing the product to be compact to take along with you and to easily set it up anywhere inside a workspace/room.

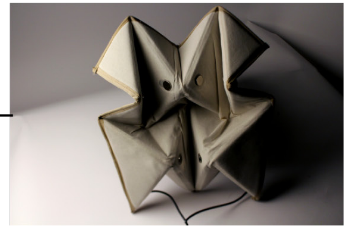
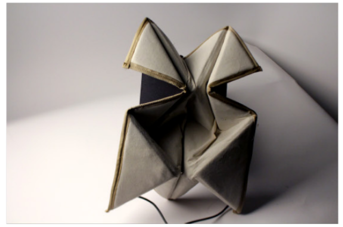
Product expansion

plane size increase

Magnets on backside

allows 2 way shape

Laying flat


Folding for storage

and for to go

Figure 40: Product configurations are shown from expanding in area, laying it flat to a folded shape for storage.

b.1 User Scenario (individual)

The user scenario shows how effortless Ori is: the user can fold-in, take and go, unfold, connect to the wall outlet and operate. The folded configuration allows the user to fit the product into a standardized back-pack or a bag. The product can put next to your laptop/ tablet and is designed to radiate from different angles. For the design the overall sit-height(p50) is taken as a starting point. The stand however allows a different angle in the vertical direction(z-axis). On table the user can feel warmth directed to chest or hands. When laid on ground the planes are on a an angel to aim and direct heat to users legs. The product is operated trough a controller and is turned on or off manually. Further more the device can operate on an automatic mode or manual mode. The automatic mode uses the distance from the product to the user as an input to turn on or off or to have an ideal temperature setting(high, medium low settings) The user can switch to manual mode to keep a fixed temperature if wanted and turn off manual. The display shows the product core temperature and also the environmental temperature(since the product works best at an in-door air temperature of 18 degrees Celsius). The pictures on the right the user shows how the product is being used.

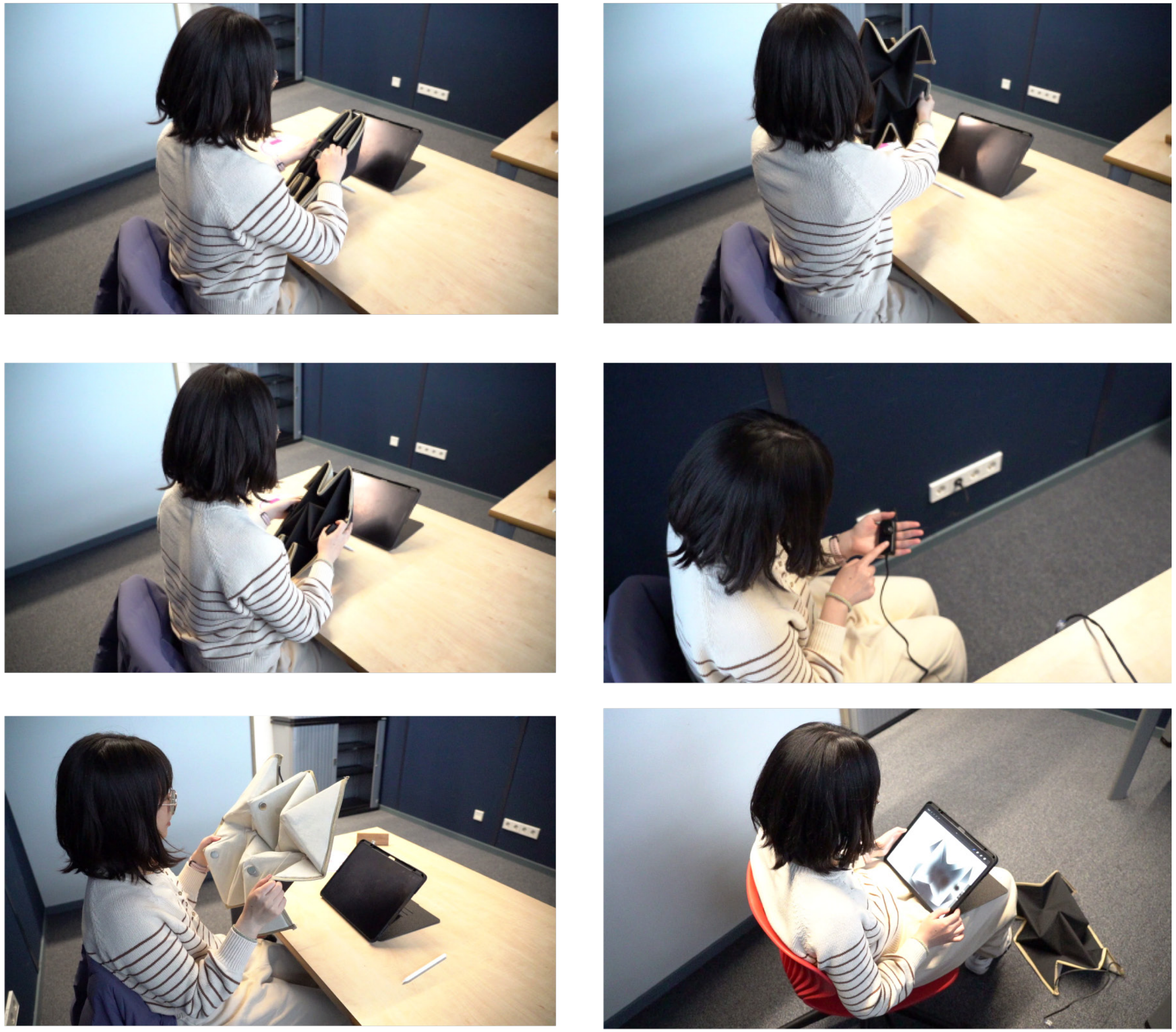


Figure 41: User-scenario in practice for both tabletop and floor.

b.2 Two person scenario

The two person scenario shows how the product can be put in position. It allows for two people to sit next to each other; the beams are divergent and travel to both users. The product position really influences the reachability and thus the performance of the product. The user is able to change the product position putting the user in full control of the product performance. The “standing” position of the product allows a tabletop configuration. Laying the product on the floor allows more direct heating to both users sitting across from each other. In Figure 41 both configurations are shown from both the tabletop and the floor.

Figure 41: User-scenario in practice for both tabletop and floor.

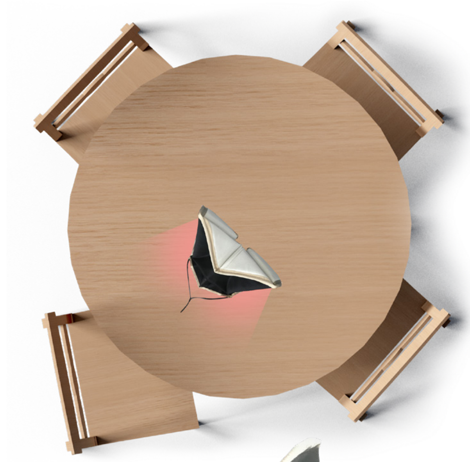
c) interaction prototype

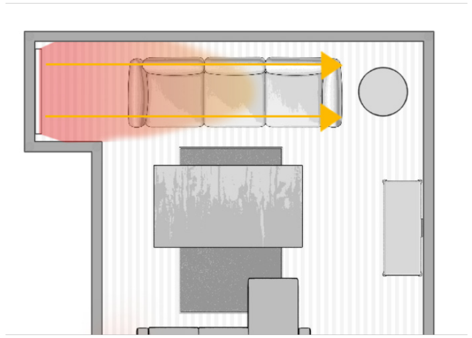
The interaction prototype specs:
L x B = 500 x 500 mm x 0.1mm (fully extended)
Mass = 3 kg
P = 30 W
Tmax(core) = 42.2 °C

The interaction prototype(Ori) gives an initial idea on how the product will be used, what parameters can be changed and what the challenges might be. On the right the product concept from the top is shown and is compared to a flat infrared panel in the living room(Figure 43). The main difference is how the planes allow the heat to be more concave which is ensuring a large surface area to be covered on a closer distance. Since the product could be changed easily(with the stand) the user is able to change the product in size and this has impact on how the heat travels to the user. However the heating beams intersect with each other amplifying the heat at closer level.

The product standard allows Ori to stand and to allow different angles. It is important since the angle allows to aim at different heights of the human body (TA). The stand is made of a combination of wood, steel and a plastic arm. Since the steel is magnetized it is easily to connect with the magnets on the bottom.

For full prototyping process please have a look at Appendix F.





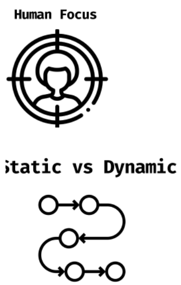
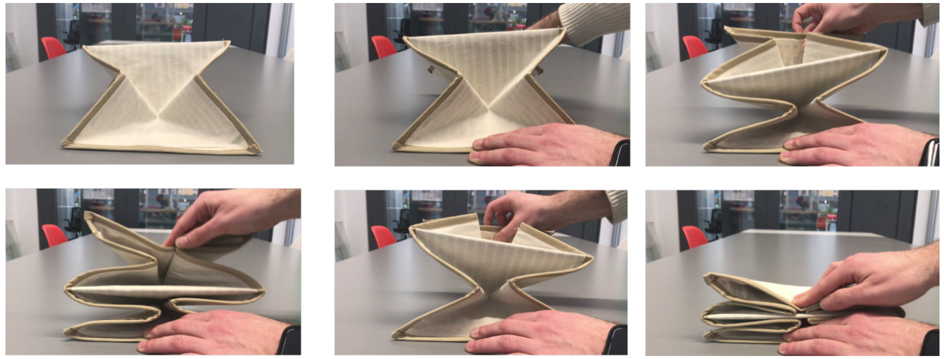


Figure 44: Ori prototype stand allowing different angles.

c.1 Planar aiming

Human Focus

The interaction testing focuses on how the planes are moving when applying the folding motion. In Figure 44 it is seen that the planes are easily to be fold with hands and also when extending the fold the more concave the radiation will be allowing a smaller surface area. The challenge here was to see how to fix these angles. With the current prototype however it was very difficult to fix these positions since it wants to forcefully fold out.



The next test was about the performance and observing what happens when the prototype is turned on. The max temperature is measured at 42.2 °C(Figure 45). It took about 9 minutes to reach this temperature. While turned on I tested on folding in and folding out. In the technical package the video-clip as well as the dataset could be found.

Further research need to be done regarding how much the planes interfere there radiation and how other planar interactions could be better suiting for a product concept like this. As seen in Figure 44 a start sequence of folding can be at a fixed position the third image is also interesting since the folding planes become smaller.

Performance wise and the idea of moving planes to preferred product shape will help ideally to address personal thermal comfort.

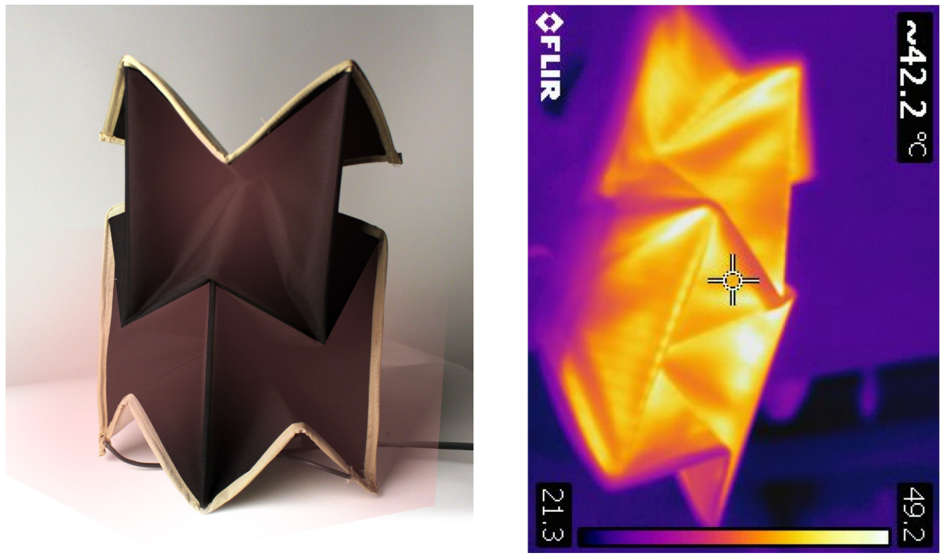
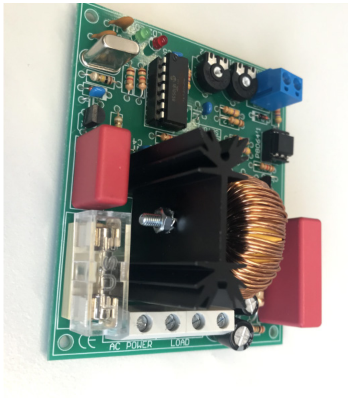


Figure 45: Peak performance of the prototype

c.1 Electronics and programming

Information

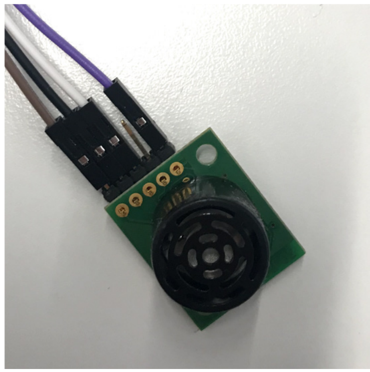
For a better interaction with Ori it is of importance to find out what feature is primarily needed. First of all regarding safety it is important that the device turns off when the user decides to leave the space around the “active area” of the product. The “active area” should act as a sensor measuring the distance from object/user to the product. In my prototype I’ve used an ultrasonic distance r instead of an IR sensor. An IR sensor would have problems since the device radiates in the IR spectrum. One difficult challenge is to position the sensor which is able to broaden the range(concave) to detect the user. The restriction for turning off the device is at 700 mm and larger. The product is meant for a max distance of 500 mm but since the user might move around the area, the turn/off sequence might deal with an overload. By increasing the distance to a larger number allows the user to move around at their current space without it having to turn off. Though these systems could be made more efficient the main idea is still on the designer table. Next, one important requirement is to add required provision of information: temperature control settings(High, Mid and Low, current ambient temperature and core temperature). At last some secondary functions might be off interest. Decreasing temperature automatically when putting device closer than 50 cm or 30 cm. Though these interactions still need to be tested it might be of importance to let the user decide if they want to manipulate the temperature themselves or automatically. More details regarding the program and interactions can be found in Appendix H.



The Velleman K8064 DC controlled dimmer is connected to the Arduino. A 47 uF (RC filter) capacitor in combination with a 22 Ω resistor is connected to get a desired PWM output. the Arduino’s default pre-scaler value of 64 and default clock speed of 16 MHz yield a PWM frequency of:
16 MHz / 64 / 256 = 976.5625 Hz

The SRF02 is a single transducer ultrasonic rangefinder in a small footprint PCB. Working: Sending out a sound wave at a frequency above the range of human hearing. PIR sensors don’t work in this application(heating).

Seeeduino Micro-controller board for rapid prototyping. Programmed with Applied C. In Appendix H you can find.



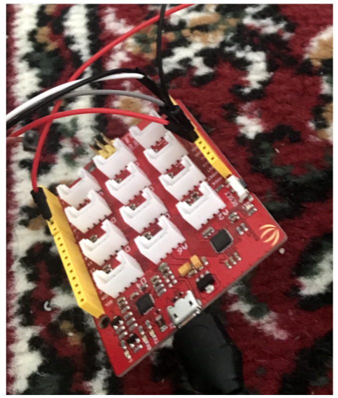


Figure 46: System components for interaction and information

c) costs

	Calculation model		
K_{Ft}	Manufacturing cost of assembled product for internal calculation:	**Ori**	€ 25.56
F_{OB}	Overhead factor for general operating expenses*	15%	
F_{OV}	Overhead Factor for Selling Costs	5%	
F_{W}	Total factor = product of (each of these factors+1) minus 1	30%	
	Totaalfactor = product van (elk van deze factoren+1) min 1	57.0%	€ 14.56
K_{V}	Sales price ex-factory (you have to pay if you pick up the product from the factory itself)		€ 40.12
	Margin brokering (for example: importer, wholesaler, supplier, distributor)	30.0%	€ 12.03
	Wholesale sales price		€ 52.15
	Retail (store) margin is very industry and offer dependent, is between 25% for a web shop and 300% for a service-oriented retailer in a beautiful building at an A-location. Strategy with a view to competition and stock, among other things, determines the margin.	100.0%	€ 52.15
			€ 104.30
	VAT (= Value Added Tax, = Sales Tax)**	21.0%	€ 21.90
	Recommended retail price, normal retail price		**€ 126.20**
	*) Before something is produced, everything usually has to be done: not only the design process, but also, for example, multi-stage prototyping, user research, market development, certification, patent applications and the like. If all this has to be factored into the product price, it can add up quite a bit.		
	**) high rate = 21%, low rate =6% (food, books), sometimes also levies such as the statutory disposal fee.		

Figure 47: Total costs for manufacturing to retail price.

With this calculation model, manufacturing costs, investment costs and hourly rate is taking into account to finally end up with the retail price costs. Unfortunately sewing costs was difficult to model in this cost calculation. Please have a look at the file “Cost price structure - Ori.xlsx” for more information regarding this model.

d.1 Financial Return

As mentioned in Chapter 2 - heating systems more and more Dutch citizens consider to switch to sustainable, energy efficient systems: Hybrid systems, Heat Pump(HP), Solar Energy based systems and many more. For this calculation it is considered that most households will install HP’s. Therefore a generalized model is used to calculate the yearly energy costs. Households from 2000-2010 and 2016-2017 are taken as a starting point(140 m2). First the standardized costs are calculated for both households. Then secondly it is calculated that the energetic value leading to an increase 2 °C is 1kW. The costs for electricity are at € 0.24 per kWh.

Reducing the indoor-temperature leads to a yearly cost saving 20.4% - 31.7% (€156.72 - €115.37) depending on the type of household, insulation and ventilation type. Bosch was interested in the financial return when decreasing temperature from 23-22 °C to 18 °C. Since this financial return could then be invested in a product such as the Ori to address personal (thermal) issues. Since this is a model the expected cost saving would differ for each household but overall it can be said that reducing the temperature saves cost but also increases HP performance. More information can be found in Appendix G.

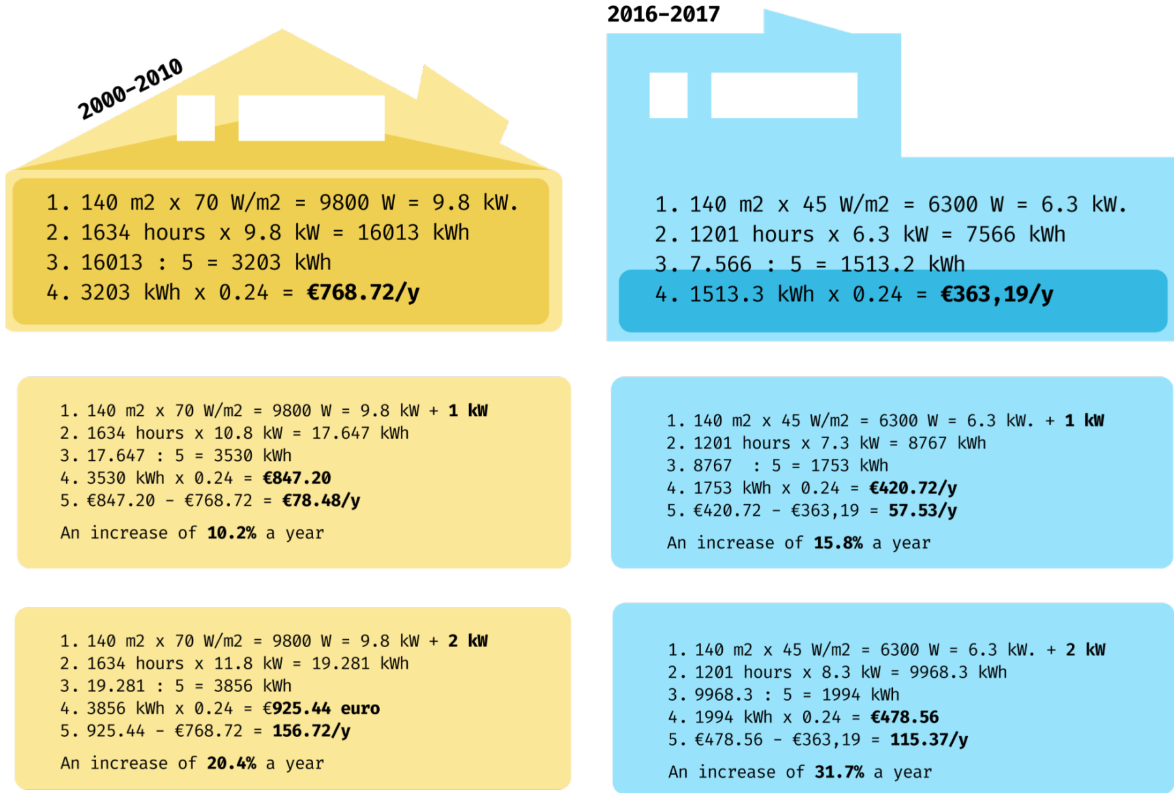


Figure 48: HP theoretical yearly energy consumption and costs.

d.2 Cost comparison

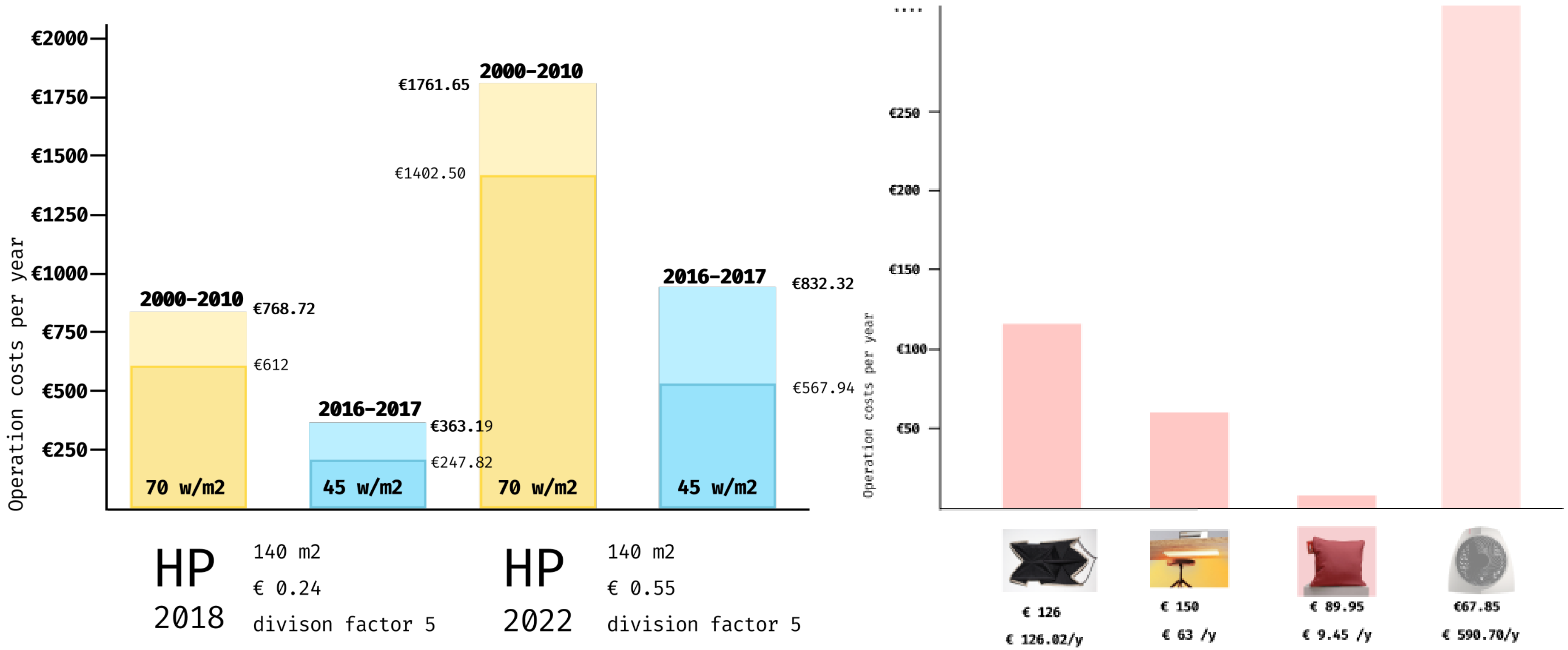


Figure 49: HP theoretical financial return and comparison. Energy consumption comparison with other heaters.

The two bar diagrams are presented. Diagram 1 shows two HP scenarios comparing the electrical energy costs per year for heating. Two types of households with two different COP's are compared. In 2018 the electrical energy costs are € 0.24 per kWh and in 2022 the costs are risen two almost double € 0.55 per kWh. The dark yellow and dark blue bars shows the theoretical decrease of yearly costs when the temperature is set to 18 °C saving almost € **265 - €** **359** over the year(2022). This financial return could be invested in for example a personal heater. The operating costs when using Ori is € 126.02 per year, which is affordable. Please find all calculations in Appendix G.

d) user research

Interviews were conducted with 10 people. 4 students and 6 single and just married couples living in Rotterdam and Schiedam. The result of this interview shows the how fruitful Ori is as a prototype and if Bosch needs to pursuit further development.

1.7.2 Questions

1. From the looks, what do you think this product is?
2. What do you think of this product?
   What price would you pay to buy this product if it's
3. available
4. Can you show me how to use the product?
5. Would you buy this product if no why not?
6. What do you think is missing with this prototype?
7. Compared to other heaters what kind of score would you
8. give this product? from scale 1 - 10
   Why do you give this score?

1.7.3 Findings and insights

Insights are gathered and an overview of quotes are given. The names of the interviewees are left out and new people are asked to join this interview.

Product look and feel

7/10 users were comparing Ori to a solar panel and where asking how it works? Only 3 users said something about a container since it is foldable.

"Is it a solar panel? How does it work?"

"I can hide something inside. What strange product is this?"

"The product has a nice look and feel, it is relaxing to see how it folds"

Participant about Ori

Almost all users where interested in this product. However they didn't know what it was for. After explaining it they were **comparing the product to stoov or something like a heating pad or pillow.**

Product price ranges from € 80 - € 120,-

Price estimation by participant

6/10 users said they would like to give **€ 80,-** for this product if the performance is as it is claimed. 4/6 said it would be around € 100 or higher

"The product has a expensive look to it. Since it has **multiple ways** to use it it will be an expensive product"

"The product could be compared with stoov heaters with the price: something **around € 80,- € 100"**

Participant about the use of Ori

7/10 users had a lot of doubts using the product. They were asking questions on how to put the product and what the function of the magnets were. A manual or explanation is advised. It took almost 5-10 minutes to completely understand how it works.

“Do I need the product like this or this? Oh there is a stand and then I can put it on the table?”

“How does it work?”

Participant about the use of Ori

6/10 users were interested to buy the product. 4/10 didn’t see any value in it because they already were owning a stoov or a personal heater. They weren’t fully convinced of the performance.

“It’s only felt a cm or 2”

“If the price is acceptable I would definitely buy it.”

“Depends if I can feel the warmth at a certain distance”

Participants about the flaws of Ori prototype

8/10 users were missing the temperature feedback control. They really wanted to know what temperature Ori could reach. **7/10** wanted to have an addition to put the Ori more stable on standing position.

Participants score heater based on other products

4/10 give a 5 3/10 give a 7.5 and 3/10 give a 6. The main reasoning behind the scores are about what stage the product is currently in(prototype). The participant who gave a 6 and a 5 have doubts on the performance. The participants that gave a 7.5 were really interested and asked when Bosch is going to finalize the product.

“I still doubts on the performance and how stable to product is going to be on my table top”

“I am doubting on the performance. My personal heater is way more faster. I am very interested the financial benefits. “

“I really would like to buy the product and use it on the-go. Are there going to be batteries?“

Note

These insights gave me the trust to further develop this prototype and to lift the product to the next level. Most participants were enthusiastic about Ori. However still the performance and the stability need to be addressed.

a) conclusion b) technology road-map c) challenges d) reflection e) references and appendix

7.Conclusion

In this chapter the project is finalized. Both a generic conclusion and project specific challenges are formulated. At the very end my personal reflection can be found.

a) conclusion

The conclusion will cover a road map where the main challenges are derived from. The road map visualizes the developments of each part of the product architecture. These developments help to understand what is available(and was) and what further elaborations are needed in order to finalize the prototype and to manufacture but also improve product and challenges. Of course combining user testing done with the previous chapter a concrete further steps are defined in order to explain Bosch how to act on product development and to further iterate on Ori. Finally through a validation of requirements this chapter answers the main question: **To what extent can a product increase the personal thermal comfort of the user and be more energy efficient?**

The Technology Road-map is presented on the next page. The core technology in which Ori has been designed is visualized. Ori uses IR film with CNT's. With (sharp) deformations one challenge is that these members will break down. With literature research it is found that these type of films are mechanically stable against large bending deformations(Kim, 2019). However in order to prevent these sheets for wearing down a pre-cut / pre-fold could be made where the members could be made more flexible by using flexible conductive CNT's. With these suggestions another two challenges arise: **on design and manufacturing level.** The members need to have a design that avoids the pre-cut/pre-fold lines as much as possible. On manufacturing level a final step need to be added: to pre-cut/fold the sheets in the desired shape for Ori, which makes it suitable for mass production.

On **core technology** and **performance** level the current prototype doesn't offer the distance and temperature for the user to feel the heat(delta = 5) (P = 30W). In order to increase the heating performance an approach is to increase the sheet thickness and thus the density of the CNT's allowing a much higher current going trough the sheet conductive layer(Kim, 2019). By calculation with the current sheet specs(thickness of 0.1 mm) and increase to 0.5 mm allows the P to be 155 W. With 155 W it is expected that the core temperature of Ori will be at 70 °C. The technical feasibility(Figure 50)is also explored with questions related to: solution architecture, solution performance, technical fit, evidence, IP position and estimated cost price. Please have a look at for a zoomed in view Appendix F(p.126).

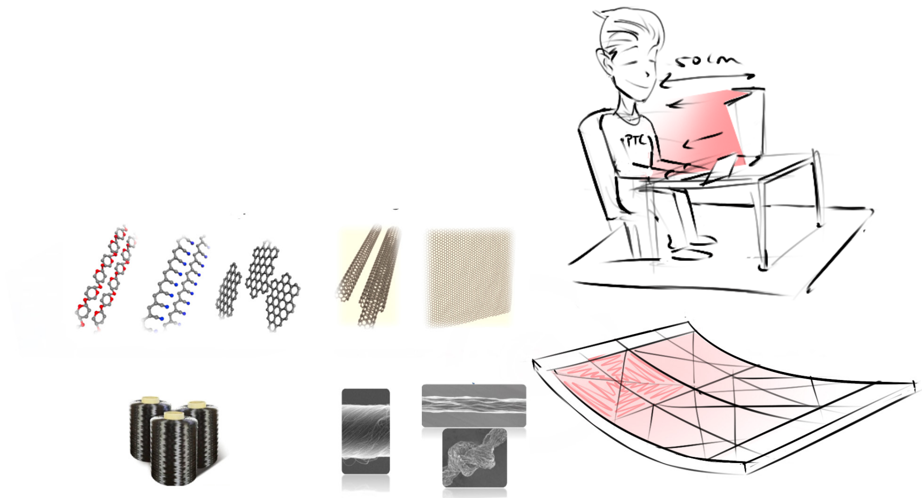


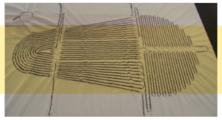
Figure 50: Technical feasibility with subjects and questions and answers(research).

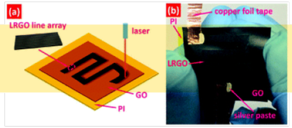
b) technology road-map

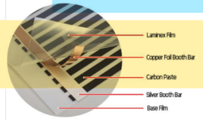
2005 | 2010 | 2015 | 2020 | 2025

Core technology (maturity TRL 3)

- IR radiating elements and sheets







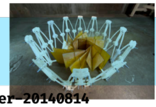
Manufacturing Challenge:

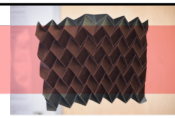
1. Design a press system as add-on for the sheet production line.
2. Design an assembly line.

Marpe Company in Korea http://heatingfilm.com/english/?page_id=129&ckattempt=1

Aiming

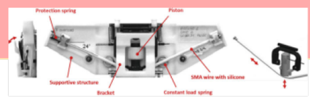
- None mechanical(motorized): meta materials, origami engineering
- Shape memory alloy ⟶ Nitinol
- Manual by user

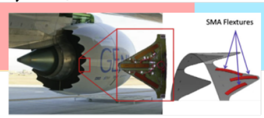




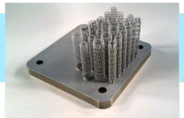
https://www.nasa.gov/jpl/news/origami-style-solar-power-20140814

SMA actuators implemented in antiglare rear-view(EAGLE) mirror





SMA actuator has been developed by Boeing



3d Printed nitinol

Safety

- Physical Safety
- Thermal fuse(electrical fail safe)

Temperature Control

- Thermostat

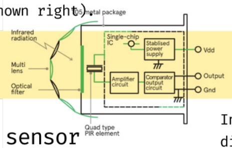
Smart radiator thermostat

In Panasonic's PIR sensors, there is an amplifier/comparator circuit inside the TO-5 metal that rejects the high-frequency interference caused by wireless devices (shown right).

Ease of use

Infrared sensor/Motion sensor

PIR sensors



IR Proximity sensor

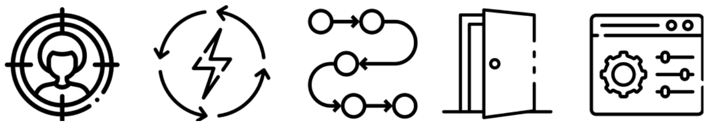
Increased sensitivity and better distinction

Ultrasonic Ranger

TRL 8/9	TRL 6/7/8	TRL 1/2/3/	TRL 8/9
Supplier	Development	Research	Bosch

c) challenges

Challenges are grouped on three levels: The design, manufacturing and prototype issues and the associated solutions. These challenges are formulated with regards to the project's starting point and main requirements. Below the product requirements are shown as symbols



c.1 Heating Performance

The heating performance is closely related to the environmental and human conditions and product technology. The start of this project was to design a product that would be an addition to a central heating(HP) system as a means of addressing PTC. Theoretically the HP is more efficient (COP improves with 0.5) when reducing the ideal indoor temperature ranging from 22 °C to 18 °C. Though people can experience (thermal) discomfort Ori can be the solution. Ori as a design explores targeted (low temperature) heating and energy efficiency trough FIR CNT's that are able to radiate heat at a distance between 30 - 50 cm. The core temperature ranges from 45 - 70°C(155 W) with high, mid and low settings.

Since the prototype is working at P = 30 W with a sheet thickness of 0.1 mm an assumption would be to increase the thickness that allows for a higher current going trough the members. Based on a study(Kim, 2019) with the increase of graphite(carbon) content added the resistance of the film decreased allowing a higher temperature range. These higher temperature will eventually radiate at a longer distance though it is impossible to measure and forecast how and what direction the FIR beams will radiate. As an argument in Appendix D(p.105) products that are closely related as a technology ensure that FIR is able to travel and radiate at larger distances.

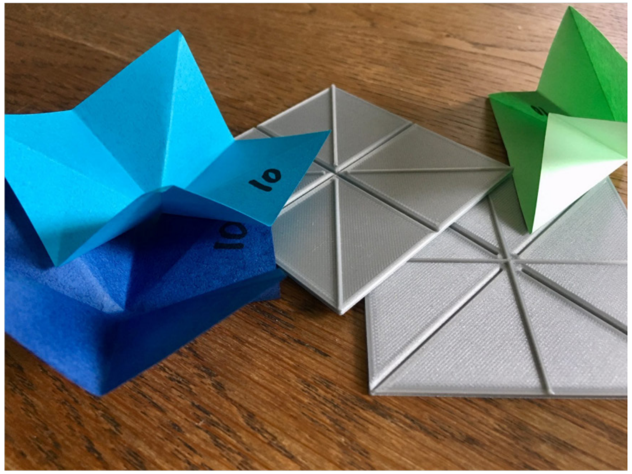
Based on already existing products and previous power calculations the thickness of the sheet could be increased 5 times leading to a thickness of 0.5 mm with an power estimation of 155 W for heating. With only a theoretical calculation it is not enough to validate the product performance. Therefore Bosch needs to get in touch with possible suppliers and discuss heating performances regarding the sheet thickness and propose a prototype sheet that could be ordered for performance validation. Below a supplier from Korea: Green IND http://heatingfilm.com/english/

c.2 Manufacturing

If the sheets are going to be manufactured in a way that sections are divided into planes, than the CNT members need to avoid the edges where these planes are folded around. Expected is that with increasing folding cycles the sheet might break down at these edges(this topic will be covered with the c3.design). Though for manufacturing such sheets with these fold lines the desgin of the CNT's members connected to the terminals need to be altered. One of many possibility in design is drawn in Figure ...

Next a proper material need to be selected which able to withstand such temperatures. Expected is that the sheet will be made out of PMMA. The glass transition temperature (Tg) of atactic PMMA is 105 °C which is 35 °C higher then Ori Tcore max is. Finally implementing this sheet into the feed for manufacturing.
A study The manufacturing process is shown in Fig. In the study the top rolls were used to press. The pressing was applied directly where the CNT web enters the winding roll during the process. At the very end of this process these sheets are cutted, packed and shipped.

A final step however should be added to allow these folded edges to pre-pressed(Ori). The pre-pressing should be done with a mold that's on top of the sheet. With a press these edges(lines) are pressed on the sheet(deformation). In figure 51 a 3D printed press is shown(PLA) that is able to pre-press paper into the water bomb shape. For the sheet(0.5 mm thickness) the press should be made of steel(mold) and attached to a press machine so that when the sheet rolls out immediately the press could form the water bomb shape. A close collaboration with the manufacturer is advised and concrete agreements need to be set up. The following questions are of importance:
To what extent could a press be integrated with the already existing sheet manufacturing process?
To what extent could the design be tweaked in order to make a foldable design without hinges?
How could these edges/folding lines be reinforced?
The last questions could refer to an exoskeleton design and could be found in the Appendix X



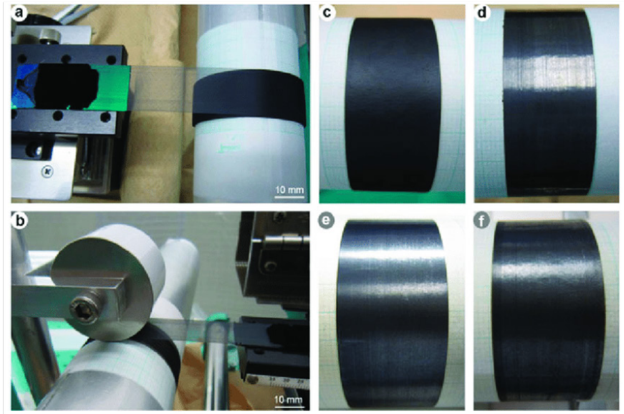


Figure 51. The CNT sheet processing combining with a mold-press that allows the sheet to deform after sheet manufacturing

c.3 Prototype issues

The folding mechanism has issues that need to be addressed in order to have steady performance over a period of time. Over the years the folding cycle will wear out the edges and will lead to wear down of the material (plastic as well as the CNT members(which are not flexible). Product malfunction can lead to product user safety problems f.e. exposed members and wires. This is a major issue and need to be tackled with protection or with a design solution.

Breakdown of Most importantly if these edges where down also the CNT members will break down causing problems and leading to product malfunction. In order to prevent this from happening these edges can be reinforced by an exoskeleton(like an umbrella) and sheet cuts with conductive flexible paths (for the CNT'members) connecting the planes to each other allowing folding without wear down.

Finally, stability is still an issue when standing upright. The stand is insufficient when it comes to rigid and firm positioning on the table top. Secondly the stand currently isn't a part of the design. It seems like a accessory and not something that needs to be part of the design. However in the "laying" configuration the stand need to be detached or else it will stick out and have the product be oriented in a different way than it needs to. The stand needs a different design and further detailing to validate the standing configuration.

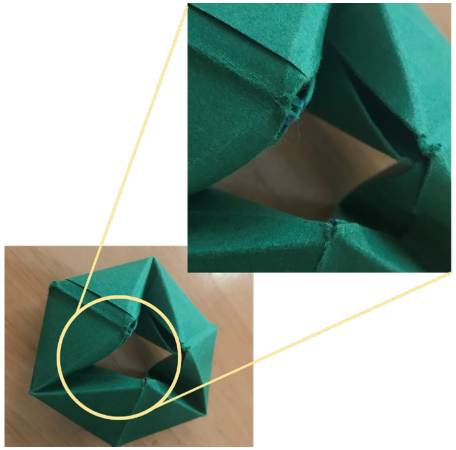


Figure 52: Product wear down when having a high fold cylce

Figure 53: Product stand issue: slippery and difficult to position.

c.4 evaluation

The requirements that initially was setup to design a personal thermal comfort product is validated. All requirements are gone trough. Three colors represent if the requirements apply with current Ori prototype.

- Green: The prototype addresses the requirement to some degree
- Orange: The prototype addresses the requirement partly
- Red: The prototype doesn't address it

Human thermal comfort

1. The product should be easily and intuitively adjustable to needs and preferences trough an interface. (orange)
2. The product should be focused on body parts through which most heat is lost: **torso, hands and feet.** (green)
3. The product should be able to make the user conscious of the **product core temperature (and ambient temperature)** but also how they can change it(display and knobs). (orange)
4. The product's material choice should depend on whether it can prevent or cause local (dis)comfort if it involves touching it. (green)
5. The product should prevent the user from sweat. (orange)
6. The product is not responsible to conditions as changing posture, orientation towards the product, putting on/off clothes. (green)

The human thermal comfort requirements are partially covert. The orange boxes are focusing on making the interaction final trough a device with a display. To have control and manage expectations are very important influences on thermal comfort.

Heating source

1. The product use electrical power via the wall outlet **(230 V).** (green)
2. The product use FIR heating technology to provide thermal comfort at a distance range of maximum **500 mm** between product and user. (red)
3. The product focuses heating adding a **Δ 5 °C** difference compared to the environment. The environmental conditions influences product performance: (orange)

   The ideal relative humidity(RH) = **30 - 50%.**

   Airflow velocity in the range of **1-2 m/s** is the ideal velocity to provide thermal comfort.

   The thermostat settings of the central heating(heat pump) is set to 18 °C thus **the ambient temperature is at 18 °C**
4. The product consumes a **P = 155 W.** (red)
5. The product should have a **thermal fuse** build for safety when there is a short circuit or ground fault. (red)

The prototype showcase a broad spectrum of performance issues and uncertainties. However they can be addressed and are explained in the challenges section. Most of these parameters are based on theoretical calculations and already existing products. The first step after this project would be to achieve the P = 155 W performance and record how it radiates.

Both Human thermal comfort and the heating source are fundamentally influencing on the product stability and performance. On the next phase, the focus will be addressing these two first before heading into concept detailing. Therefore the design of Ori can still be altered. This project has addressed possible opportunities and requirements in the field of Far Infrared heating, which could be used as an input for other relevant product developments within Bosch's (thermal) comfort and wellbeing department.

Design

1. The product should be protected by a sleeve when folded in.

2. The product should be protected by touching(oils from skin and others)

3. The product is flexible, meaning it has multiple configurations: take shape as both a standing and a laying position(two configurations).

4. The product is able to fold-in and out as a means of saving space but also to have different surface area for aiming(two areas).

6. The product overall has a divergent aiming setup that allows two users to be thermally satisfied.

7. The product is stable and rigid on a table top when standing and laying on the ground.

8. The product fits inside sleeve and can be taken to a workplace or to other rooms.

As a design the prototype shows issues on the stability when having it on a “standing” configuration. There is a need for a better solution for increased stability.

Interaction

1. The product displays both the ambient and the product core temperature.

2. The product should save energy by automatically turning off when the user is not present.

3. The product should save energy by automatically turning off when the timer function is used.

4. The product should not be turned on when the product is at folded state.

On interaction level a display is needed to display both the ambient and the core temperature of Ori. Other interactions are tested and validated.

Ergonomics

1. The product should be in the reach of the user to change orientation/direction.

2. The product is mainly shaped around the average hand length(P50) = **190 - 215 mm** and shoulder height(P50) sitting = **630 - 680 mm** for both male and female(20-30).

3. The product should effortlessly fold up, take and go and folded out.

4. The product corners should be rounded since the sheet is sharp. Sharp edges could cause injury.

5. The product should prevent the user from sweat

6. The product is not responsible to conditions as changing posture, orientation towards the product, putting on/off clothes.

Ori’s primary measurements where based on both the sit height as the hand length and can be validated. Though more products can be referenced from: speaker, tabletop coolers and more. Currently folding is very hard: put so much force to fold-in and to fit it into the sleeve.

Wishes

1. The product works on batteries. The battery is around 1280wH which basically is a car battery.
2. The product has multiple aiming configurations(trough folding)
3. The product has an automatic and a manual setting: automatic setting that adjusts temperature to user distance and manual setting that allows the user to enter preferred temperature. The temperature setting is adjusting product core temperature.
4. The product has multiple shape and color variations.

Batteries were explored, but due to high P = 160 W it is expected that a relative high power rate is needed: 1280wH. It seems not feasible but in the future it might be interesting. The automatic and manual setting need to be validated and tested with users.

d) reflection

This project enabled me to think about heating in the future. When people think of heating they think of central heaters or room(personal) heaters. We, as society are used to these conventional heating systems. The current societal developments;increasing gas prices and energy poverty are causing more stress when on the other hand technology improves our lives. It is time to rethink these thermal systems and to bring “heating” closer to the individual. At start of this project I had my personal goal formulated:

1. Gain In depth knowledge on thermal comfort and anything related to already existing thermal systems to innovations
2. To learn about product optimization that leads to energy efficiency.
3. To learn form Bosch: expertise on thermal technology.
4. To learn more about users and to tailor the product down to their needs.
5. I would like to do more co-creation sessions and dive into the User-Centered Design approach.

I didn’t know anything about thermal comfort or heating technologies. Thanks to my supervisors from Bosch I quickly gained insights on how heat pump systems work and how they compare with boilers(natural gas). Within my own research I found out about the differences between all kinds of heaters. I’ve gained knowledge about energy efficiency comparing product’s electrical power to their achieved peak temperature. All in all I’ve learned so much and I do think there is still so much to learn within the field of thermotechnology. Next it was really challenging for me to design a product that has multiple challenges such as flexibility, aiming and energy efficiency. Thanks to the participants I’ve dived into already existing frustrations and compared them to existing heaters and how they perform. Of course the project focused only on a handful of participants: 10 - 15 it gave me a better understanding on thermal comfort, experience, sensation both on the physical and psychological level. I really wanted to take as much as factors with me while designing the product causing me to be too ambitious. I must say all people who know me describe me as such: energetic, enthusiastic and always coming up with (new) ideas. In a design process there are multiple phases that makes it hard to keep track of the project flow. Therefore it is difficult to be your own project’s manager, note taker, visualizer, detailer, researcher, strategic planner and so on. To be able to switch between roles takes time and experience. Furthermore, I have my role as a teacher on two days, while working on my graduation for three days. Switching between those two roles was even harder at some time. It sometimes made me feel powerless and tired. Let alone it is difficult for a student to switch between all the roles mentioned earlier within the design phase. I took a risk starting off with this project. With my chaotic approach, I’ve managed to pass the finishing line.

In the future I would like to try to formulate short-term (achievable) goals and try to communicate them with friends, family and to project members. During the process I feel that I was mostly working on my own. Communication is not only about letting somebody know about your current situation but also about getting new and fresh ideas that contribute to the process. During COVID-19 I felt trapped in my own mind and space. Staying at home and working from home didn’t benefit me at all. Even arranging tools/facilities or making appointments with professors/teachers was too difficult. It had lead to delay. Getting in touch with my supervisors allowed me to look past the delay. I accepted it and had my motivation to push trough each phase. I am happy that I’ve experienced this project as such. I’ve kept my energy high and am thankful of support from family, friends and my supervisors.

e) references & appendix

References and Appendix are presented here.

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Please have a look at the appendix file for more...