Appendix A

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

STUDENT DATA & MASTER PROGRAMME
Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Ulusoy
initials: M.T. given name: Taner
student number: 4148150
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ★ IPD / Dfl / SPD
2nd non-IDE master: MSc. Science Education
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: ★ Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **
Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Henk Kuipers — dept. / section: HCD/AED
** mentor: Bas Flipsen — dept. / section: Circular Product Design
2nd mentor: Ralph Plantagie / André Haverkort
organisation: Bosch Thermotechnology B.V.
city: Deventer — country: Netherlands
comments (optional): Ralph.Plantagie@nl.bosch.com
Andre.Haverkort@nl.bosch.com

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 — Page 1 of 7

chair: Henk Kuipers — date: - - — signature:

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ___ EC
Of which, taking the conditional requirements into account, can be part of the exam programme: ___ EC
List of electives obtained before the third semester without approval of the BoE

★ YES — all 1st year master courses passed
NO — missing 1st year master courses are:

name: — date: - - — signature:

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED / NOT APPROVED
Procedure: APPROVED / NOT APPROVED

comments

name: — date: - - — signature:

IDE TU Delft - E&SA Department /// Graduation project brief & study overview /// 2018-01 v30 — Page 2 of 7
Initials & Name: M.T. Ulusoy — Student number: 4148150
Title of Project: Personal thermal comfort product

Personal thermal comfort product

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

In 2015, 196 parties (including the Netherlands) adopted the Paris agreement aiming to limit global warming(United Nations, 2015). The agreement helped to define laws and strategies for a better future. The Dutch government (Ministerie van Algemene Zaken, 2021) decided to stop extracting gas from 2022 due to earthquakes in the north of the Netherlands. The Netherlands is already taking steps to clear out both natural gas and it's CO_2 emissions. Because of governmental regulations we see an increase in consumer price of natural gas(Figure 1, CBS). These regulations are aimed at reducing the energy consumption. This partially can be covered by insulation and electrical heating solutions. But it requires behavioral change as well. Nobody likes change: we are used to the convenience of gas and the low running costs. We don't like to invest money in electrical heating solutions that don't offer the same benefits. Not even our societal responsibility move us to change.

On the other hand, history shows us that we are able to endure and adapt to changes if people see benefits.
At the beginning of the 17th century wood was mainly used for heating. A big wood shortage had led to the transition to the use of coal. Similar thing happened when natural gas was found in the north of the Netherlands (Ringelberg, 2019) . People can tolerate change, but only if it really has significant impact. The reality is that we see a scarcity of raw materials and now the aim is to reduce energy consumption. From society we are going through a shift from gas to electricity. For a house this can be done with replacing a gas heated 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?

1. United Nations. (2015). Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
2. Ministerie van Algemene Zaken. (2021, April 8). Afbouw gaswinning Groningen. Gaswinning in Groningen | Rijksoverheid.nl. https://www.rijksoverheid.nl/onderwerpen/gaswinning-in-groningen/afbouw-gaswinning-groningen
3. Ringelberg, S. (2019, July 15). 3 voorbeelden van ramp gedreven energietransities. Transitiepaden. https://www.transitiepaden.nl/post/3-voorbeelden-van-ramp-gedreven-energietransities

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introduction (continued): space for images

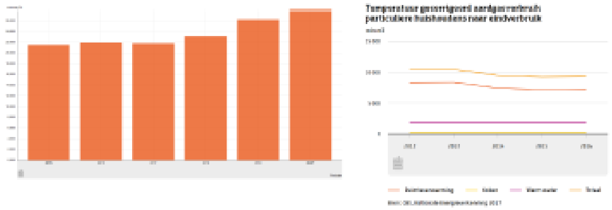


image / figure 1: Gas prices increasing(left) and use of gas for heating(right) all households Netherlands(Red)

	percentage te koud	N
Koop voor 1945	18	164
Koop 1945 – 1970	9	155
Koop 1971 – 1980	7	179
Koop na 1980	7	201
Sociale huur voor 1945	18	51
Sociale huur 1945 – 1970	22	166
Sociale huur 1971 – 1980	19	103
Sociale huur na 1980	7	96
Particuliere huur t/m 1970	19	85
Particuliere huur na 1970	15	39
Totaal	13	1239

image / figure 2: Different perception thermal experience and problems with cold during the winter season.

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

As humans, we are really focused on our (thermal) comfort. We need thermal comfort in order to do our studies, work, reading, hobbies and many more activities. The need of thermal comfort is something we have in common, however we do differ both physically and mentally. People have a difference in perception on warmth and coldness (Figure 2). These differences has impact on how we perceive being in a comfort-state. Currently, we can see that comfort has manifested itself in being mobile and independent. Products like our smartphones enable us to fulfill our own needs by just a touch on our screen. The product should be able to provide the needs of an individual on demand and needs to be mobile.

90 percent of our houses are heated with gas. Based on the energy consultant, gas supplies an average to 9,769 kWh of energy per m3. Each house use up to 1500 m3 per year (Figure 1). 14653.5 kWh/th for a year on an average is needed for one household. A heat pump needs about 6513 kWh electrical average per year depending on type house, size and season. That's more than two times than what people are used to consume on electricity. On top of that, we see an increased air conditioning sales(2019, RTL Nieuws) during the summer due to heat waves and we therefore are continuing to increase our energy consumption(AD, 2020). A solution for this is to build or renovate houses with better insulation. However this doesn't completely solve the problem.

Based on the above, the focus will be on developing(analyzing, user research) product solutions that fulfill the thermal comfort needs of one individual. The project will revolve around the gap(s) between warming/cooling a whole room and the human being. This graduation project will explore design opportunities for Bosch that contributes to their future vision and mission. 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?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

Design a product or product-service system that fulfill the thermal comfort needs of the user. To what extent can a product or product-service system aimed at an individual contribute to their thermal comfort needs and be more energy efficient?

1. Literature study and research on thermal comfort needs of the user at home. What are the gaps and how is the current market addressing those needs?

2. Through the project I will work with both the innovation hub of Bosch and also with Bosch's engineering department. I will use design and research methods and explore the possibilities for Bosch.

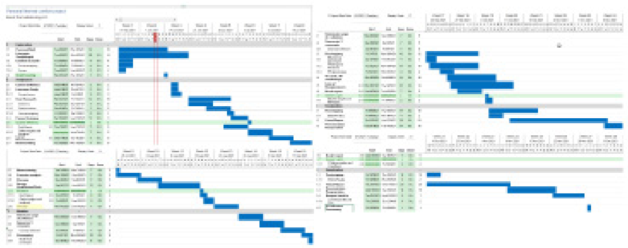
The deliverable of the project will take form in a product concept (prototype) and a report and product pitch for Bosch to use internally. The concept will be developed by going through the process of research, design, visualization, 3D Design, and prototyping. The report will also be a document that will include all design processes and personal thermal comfort (user) research. User-oriented research will be conducted and issues regarding already existing products will be collected and addressed. Technological trends and developments regarding heating and cooling are taken into account.

The solution that I expect to get is a wearable product that is able to react by heating/cooling on physiological conditions (health) of the user. One idea of Bosch is to have an heat beamer with mirrors that is able to aim directly at the user. Another idea might be a thermal bracelet that heats up or cools down. Lastly the solution can be comparable to a mobile product like a JBL speaker: to bring your thermal comfort device with you anywhere you go.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date end date



On the week/biweekly basis(not in gant chart):
- I will meet with Andre and Ralph physically and discuss my process and findings.
-Every two weeks or three weeks mentor meeting/expert meeting.

I am going to research what the user needs are considering that we want to offer personal thermal needs. What is the most important function of the product for the user? To what extent should the user be in control of the product?

There are overlapping parts during the analysis and ideation and prototyping phase. Since design is an iterative process, I can use the feedback and tweak the design or get additional knowledge, inspiration to adapt the concept. I would like to think of offering myself the room to do things parallel.

During the summer it is important to think what to test. Since it is hot in the Netherlands it might be interesting to dive into cooling more then heating with testing. Or perhaps considering different testing environments.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

In the past years, I noticed a big change in 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 I really experienced how much the climate makes impact on my health, work, studies and etc. If you scale this up to all people than you see it's not only my problem but it influences us all and I do believe that it is our responsibility to come up with solutions.

My first year on my masters, I've had the opportunity to work on projects that were related on human centered design. I've developed a major interest on human product interaction. During my second year I've invested my time into learning more about human health and psychology as well as using machine learning for product design. Machine learning gave me an understanding of the base of current AI technology, gave insights on new technologies and trends whereas health and psychology gave me insights on human behavior. Both expertise fields combined gave me an understanding on what product functions could be automatized and how it's impacting human behavior. For this project it could mean that I can develop a product that is static where the user is able to customize functions to their own needs or to design a dynamic and automatized product. Something in between is also possible. The human side really considers how much impact it will have on the users health, psychology and behavior.

Personal learning ambitions I explicitly want to address in this project:

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

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Electrical energy consumption doubling every 10 years. We should consume less but we have more electrified products now(electric cars: Tesla)

Higher bills due to increased energy consumption both electricity and natural gas (governmental regulations)

High expectation of innovations but, they don't offer the same level of thermal comfort as conventional thermal systems. We are **used to** our (increasing) comfort.

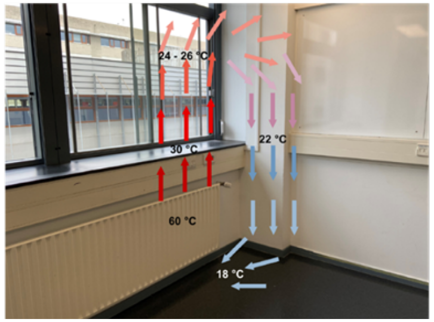
Rethinking conventional thermal systems and scenarios and focus more on Personal

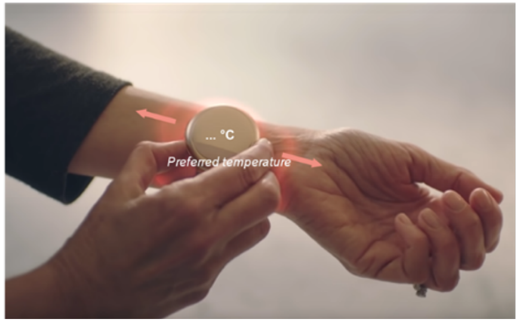
In 2015, 196 parties, including the Netherlands adopted the Paris agreement aiming to limit global warming(United Nations, 2015). The agreement helped to define laws and strategies for a better future. The Dutch government (Ministerie van Algemene Zaken, 2021) decided to stop extracting gas from 2022 due to earthquakes in the north of the Netherlands. The Netherlands is already taking steps to phase out both natural gas and it's CO^2 emissions. Households are mostly making use of natural gas for heating, warming water and cooking. Modern households however are making use of induction heating for cooking and electrical heating systems for warm water. Gas is mostly being used to heat up rooms. With the energy transition to sustainable renewable resources these gas systems will be replaced by heating pumps and other sustainable systems like solar heating etc. Also hydrogen gas is becoming an interesting field. These developments are inevitable

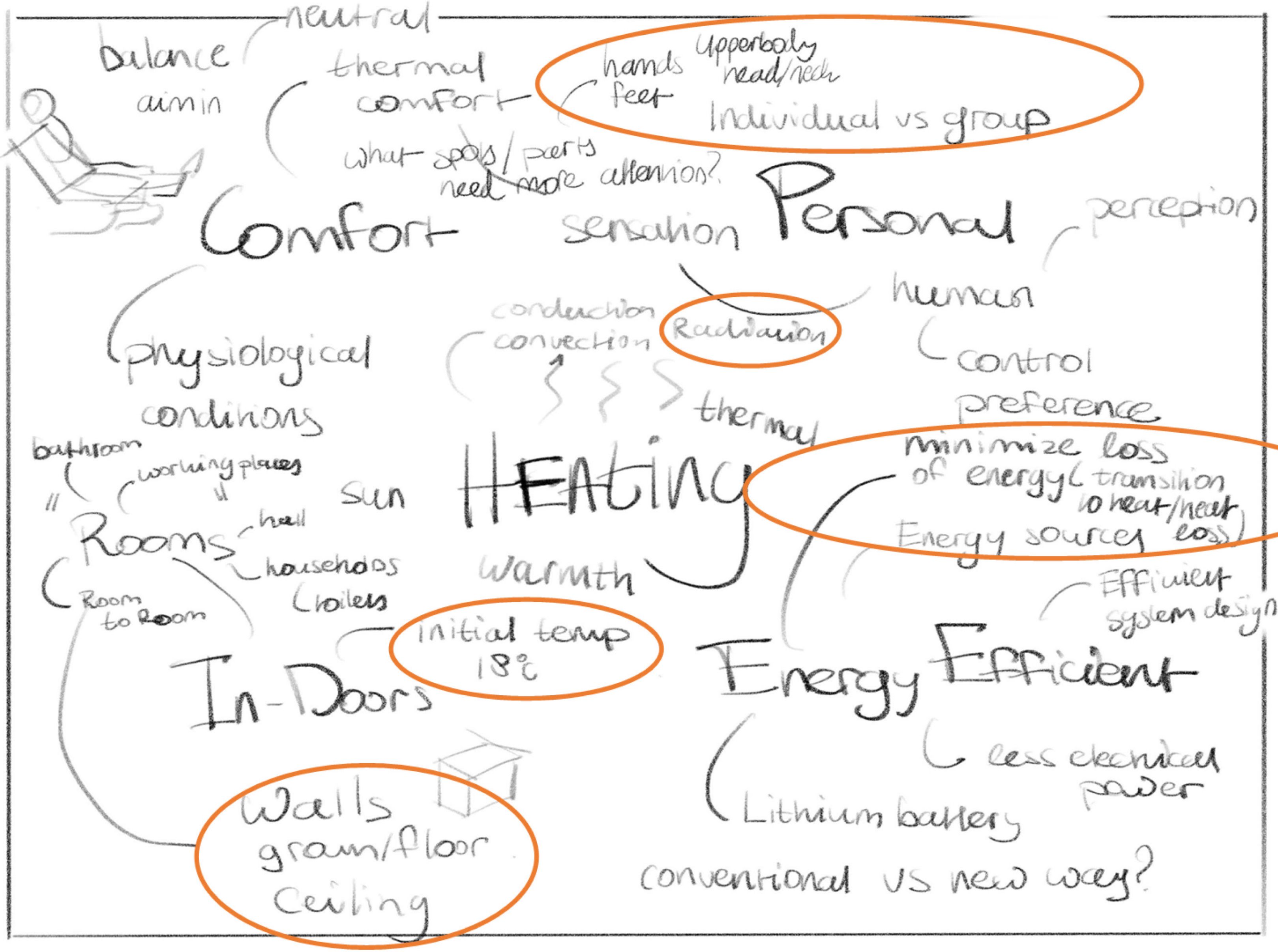
Design Vision

"To design a product that enables a PTC experience available in-doors and at the same time be more energy efficient."

The ideal solution space could therefore be a combination of **central space heating**, **specific location heating** and **body heating.**






neutral
balance
aim in
thermal
comfort
hands
feet
upperbody
head/neck
Individual vs group
what spots/parts need more attention?
Comfort
sensation
Personal
perception
human
control
preference
physiological
conditions
conduction
convection
Radiation
thermal
HEATING
minimize loss of energy (transition to heat/heat loss)
Energy sources
Efficient system design
bathroom
working places
Rooms
hall
households
boilers
sun
warmth
Room to Room
initial temp
18°C
In-Doors
Energy Efficient
less electrical power
Walls
ground/floor
ceiling
Lithium battery
conventional vs new way?

Environmental conditions

1. The indoor temperature should be around 18 degrees celcius.
1. The ideal relative humidity for health and comfort is somewhere between 30-50%.
2. 3. Airflow velocity lower than 1–2 m/s.

Human thermal comfort

1. The product should be easily and intuitively adjustable to thermal needs and preferences.
2. The product should be focused on body parts through which most heat is lost: head, hands and feet. (however it is still optional for the user to be flexible and control where to aim.)
3. The product should be able to make the user conscious of the product 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 having to shiver and 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 should use electrical power or chemical power for heating. In the future there might be more 'green' ways of producing electricity thus a drop in electricity prices.
2. The product should have higher energy efficiency compared to conventional thermal and already existing solutions
3. The product should take into account safety factors when using heating sources
4. The product should provide a power range of 150 - 300 W. Comparable with a wearable/mobile device.

Heating source

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4. The product should provide a power range of 150 - 300 W. Comparable with a wearable/mobile device.

1. The product should provide at least a delta of 5 degrees increase compared to in-door temperature. One assumption is that most houses will use a heat pump, the product should be an added value product considering most heat pumps are efficient and inexpensive when operating on a constant temperature.

Appendix B

PMV - Model and paradoxes

The global norms express that the PMV ought to be kept 0 with a resilience of ±0.5 to guarantee an agreeable indoor climate. This implies that the most agreeable warm sensation ought to be unbiased. Anyway studies show that thermo neutrality does not necessarily correspond to the desired or preferred thermal sensation (Hoof et al., 2010).For example, when it is exceptionally warm outside, individuals lean toward a to some degree cool condition went against to thermo-neutrality. Whenever it is freezing outside, individuals favor fairly warm circumstances. Simultaneously there are concentrates on that show disparities among real and anticipated impartial temperatures (Charles, 2003). There are theories for versatile warm solace models that foresee that logical elements and past warm history changes the inhabitant's warm assumptions and inclinations. Individuals in warm environment zones would favor higher indoor temperatures than individuals living in cool environment zones, which is as opposed to the presumptions hidden solace principles in view of the PMV-model.

There are a lot of individual differences that the PMV-model does not account for, but there are also a lot of studies that show that the PMV-model is valid for certain situations. The six variables are proven to have a big influence on the thermal sensation and therefore it is important to understand these six variables when designing an individual comfort system.

Central Heating Systems(HVAC)

Definition

Central heating systems are part of Heating Ventilation and Air Conditioning(HVAC) is the technology of indoor and vehicular environmental comfort. Its goal is to provide thermal comfort and acceptable indoor air quality. HVAC system design is a subdiscipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics and heat transfer.

HVAC is an important part of residential structures such as single family homes, apartment buildings, hotels and senior living facilities, medium to large industrial and office buildings such as skyscrapers and hospitals, vehicles such as cars, trains, airplanes, ships and submarines, and in marine environments, where safe and healthy building conditions are regulated with respect to temperature and humidity, using fresh air from outdoors.

An overview of heat sources are presented below(Figure 7). Because of the energy transition more Dutch households are deciding to go for sustainable solutions such as electrical heat pump systems. Also hybrid systems are becomming more affordable.

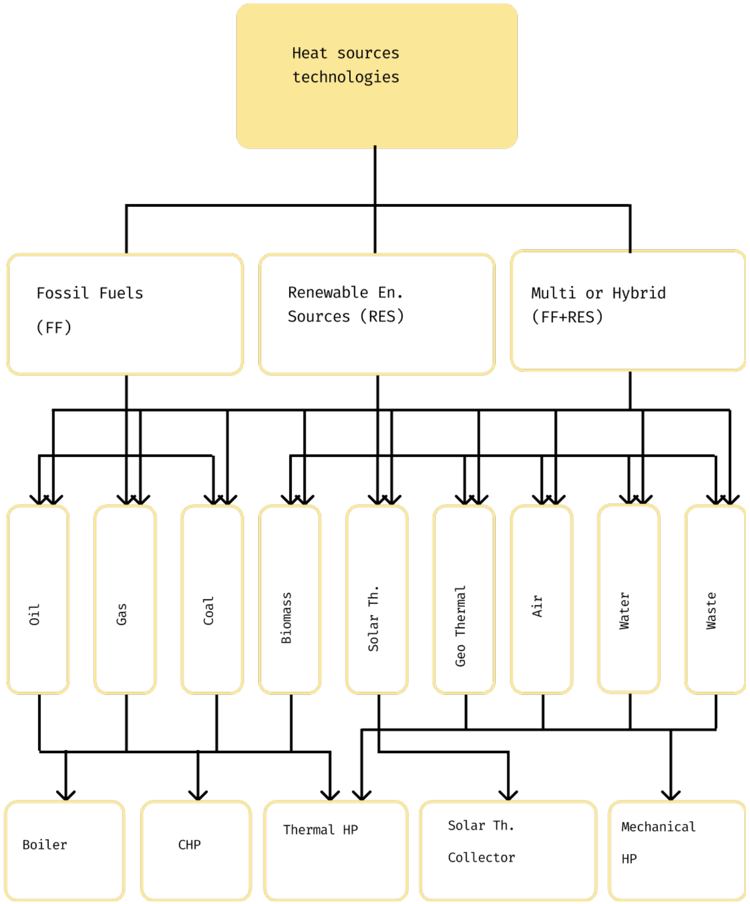


Figure 7: Adapted version of Heat pump placement, connection and operational modes in European district heating, Available from: https://www.researchgate.net/figure/Overview-of-heat-sources-and-technologies-used-in-European-district-heating-systems_fig4_330986269 [accessed 5 sep, 2021]

Heat Pump (HP)

A heat pump is an economical alternative to traditional boilers. The technology even produces up to 75% of the heat you need completely free of charge. The remaining 25% comes from earth or electricity. A heat pump is comparable in size to a classic floor boiler. Also available in hybrid versions in which a boiler and heat pump are combined. Always use the most economical function. Operates on a low temperature regime. That requires a well-insulated home and a heat emission system that works at a low temperature. A heat pump extracts heat from a heat source (soil, air, groundwater) using collectors. A coolant transports this energy to a compressor. The advantage of the coolant is that it reaches its boiling point and evaporates at a low temperature. The vapors in the compressor are compressed until they have reached a higher temperature than the air or water used to heat the house. The compressor is the only part of the heat pump that consumes that energy.

Going from Natural gas based boilers to electrical heat pump systems. A short overview of how they work.

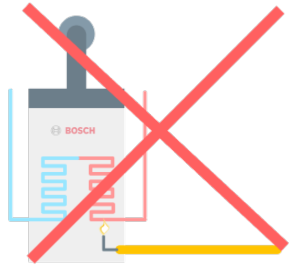
This heated vapor then ends up in a condenser. Here the vapor gives off its heat to the heating system of the home.

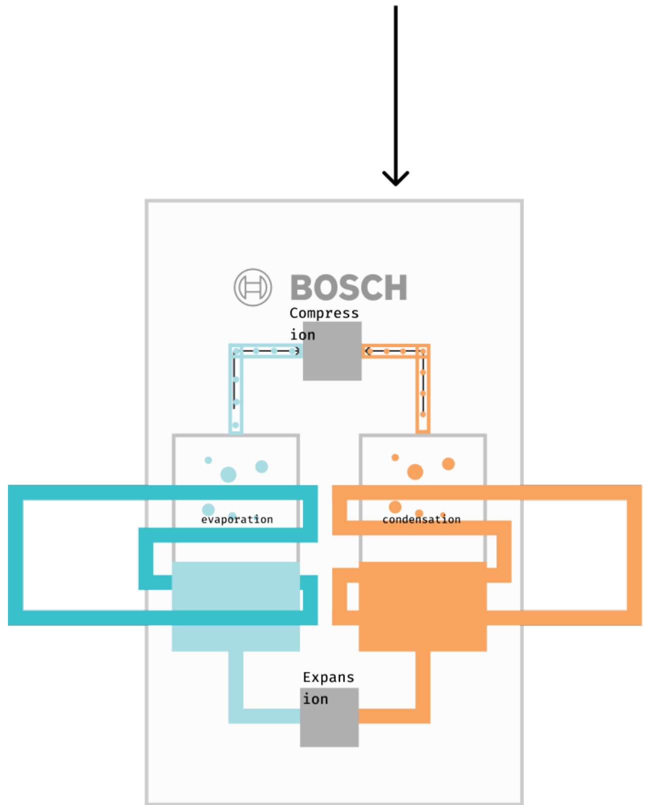
A heat pump extracts heat from a heat source (soil, air or groundwater) using collectors. A coolant transports this energy to a compressor. The advantage of the coolant is that it reaches its boiling point and evaporates at a low temperature.

2. In the compressor, these vapors are compressed until they have reached a higher temperature than the air or water used to heat the house. The compressor is the only part of the heat pump that consumes energy (electricity or natural gas)

3. This heated vapor then ends up in a condenser. Here the vapor gives off its heat to the heating system of the home

4. An expansion valve lowers the pressure of the vapor and cools it down again to a liquid. It is then sent outside again to evaporate, after which the whole process can start again

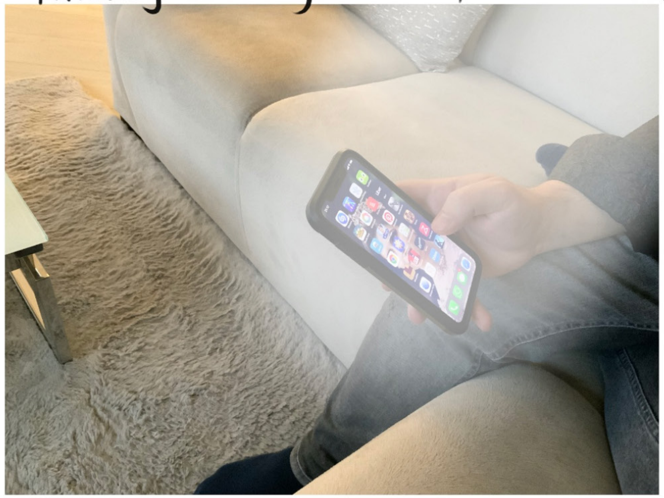




Functionalities future product

Spot heating from Ceiling

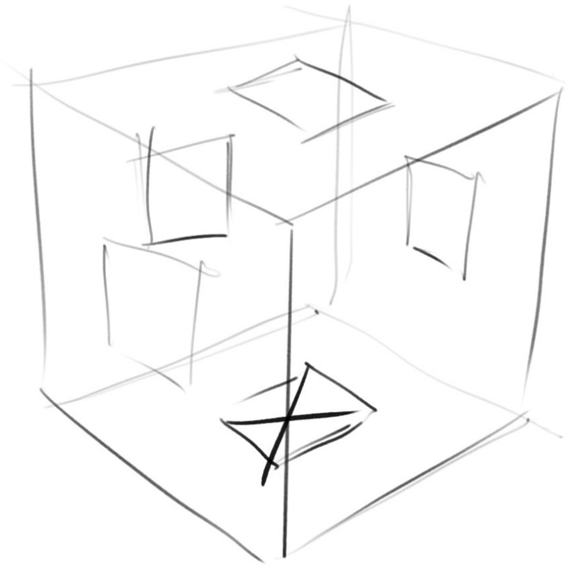
Aiming at body: hands, feet and etc.



- able to narrow down the heating area (specific)
- Rotational motion to aim directly at person
- increase/decrease intensity

An interactive Pannel

- Rotate
- move
- aim
- lenzen feer



1. Performance

Highly depended of working principle, laws of thermodynamics(heat transfer) and total system.

Safety

How safe are these technologies for humans and are there any safe

Complexity

Joule Heating

Explanation:
Joule heating is the process by which the passage of an electric current through a conductor produces heat.

Infrared Radiation

Explanation:
Three components: an emitter. a heat exchanger(copper) and a fan that blows air to spread heated air.

IR Incandescent light bulb

Explanation:
It is an (emitting) heat source that uses the principles of radiant heat to transfer radiant energy to an object.

Micro Waves

Explanation:
A microwave (oven) passes microwave radiation at a frequency near 2.45 GHz through food.

Solar Electricity

Explanation:
Solar power is energy from the sun that is converted into electrical energy.

Kinetic Friction

Explanation:
When surfaces in contact move relative to each other, the friction between the two surfaces converts kinetic energy into thermal energy.

Performance

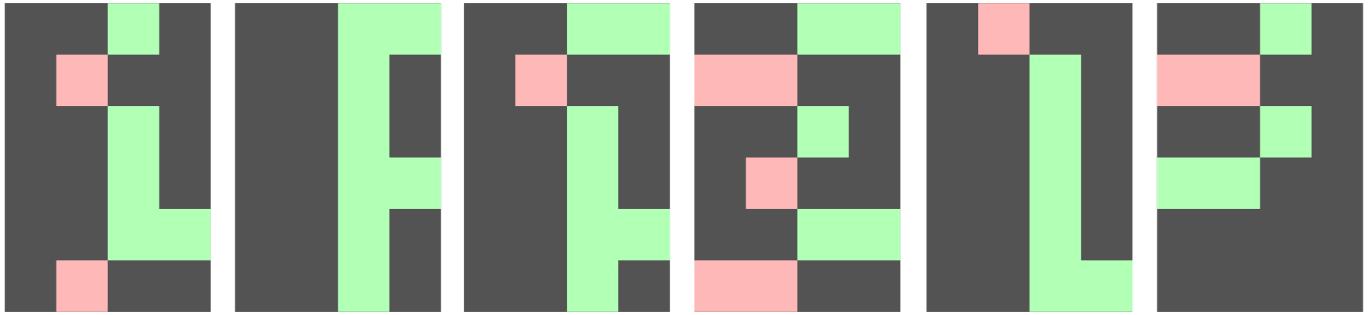
Safety

Complexity

Energy Efficiency/Power Consumption

Availability

Costs



Energy efficiency/Power Consumption

Most central heating systems are given a so-called Energy Label. Unfortunately personal heaters don't have an energy label.

Availability

To what extent are theses technologies available

Costs

Cheap/expensive purchase costs compared to energy costs

Radiant Heaters

Explanation:
Imitates the sun. The heat is emitted only when the rays hit a surface.

Chemical Energy

Explanation:
Disposable chemical pads employ a one-time exothermic chemical reaction.

Solar Heating

Explanation:
Solar heating systems use heat from the sun to warm central water systems for radiators.

Body Heat

Explanation:
The human body loses heat mostly due to radiation(65%). Making contact can provide thermal comfort

Thermal Mass

Explanation:
It is an (emitting) heat source that uses the principles of radiant heat to transfer radiant energy to an object.

Induction heaters

Explanation:
Heating by passing through an induction coil that creates an electromagnetic field.

Performance

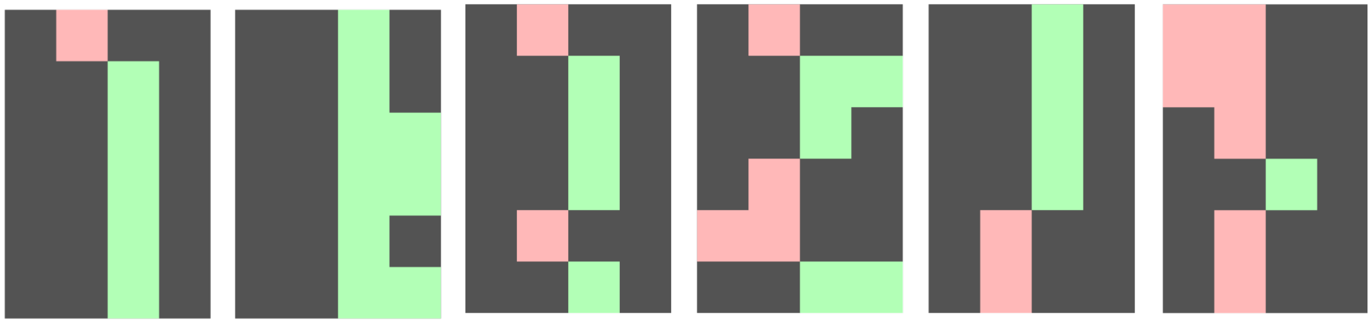
Safety

Complexity

Energy Efficiency/Power Consumption

Availability

Costs



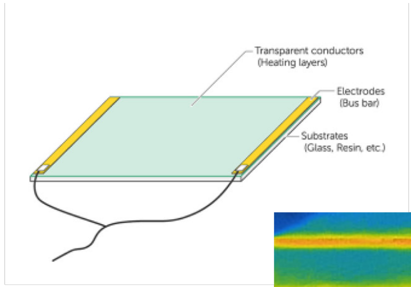
Appendix C

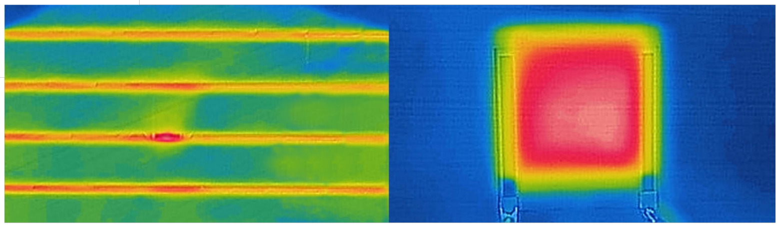
Transparant heating

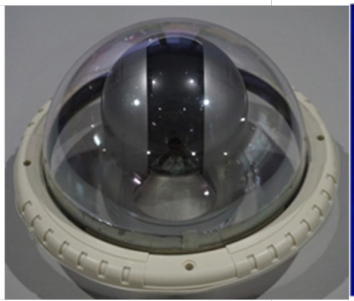
Transparent heaters make use of Geomatec's thin-film technology and are mostly used to prevent dew condensation and accumulation of snowfall and frost on objects that require high transparency, such as cameras and windows. They are perfect for environments that require temperature controlled surfaces.

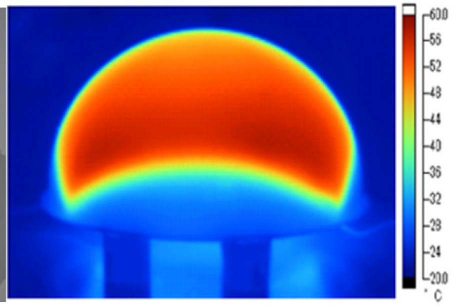
Maintaining consistent temperature across the entire surface
Applicable to not only flat surfaces but a variety of other forms, including curved and semi-circular surfaces
Freely customizable to meet conditions such as maximum generated temperatures of 350.

Applying it to room furniture, stand-alone design that blends into the room as a design. Since most heaters have noticeable aesthetics a transparant design gives a rather futuristic aesthetic to design. Onyl downside of the idea is that the user needs to make physical contact with the film. By applying the transparent conductive films and ITO films that are Geomatec’s specialty to substrate materials like glass and attaching metal electrodes to conduct electricity, it is possible to create special materials that are transparent and yet generate heat.





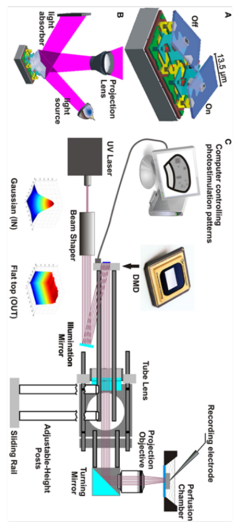


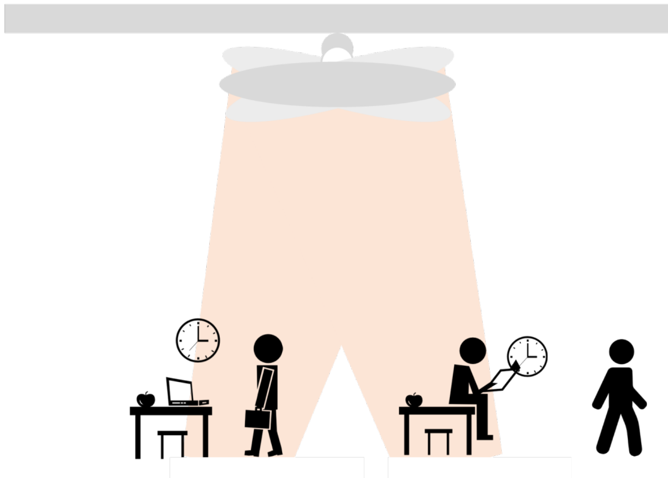


Heat projector mechanism

This idea is comming from the working principle of an overhead projector. An overhead projector(figure ..) uses light to project an (enlarged) image on a screen. Initially the displayed image is comming from a piece of paper laying on top of projector. Imagine replacing the light source by an infrared heating light source. Secondly removing the top part(where the piece of paper lays on) and adding an interactive dimmer to the device. By decreasing/increasing the distance of the heating source the projectected area(screen/image size) can be varried. Secondly the dimmer can act as a way to lower/higher the set temperature.

The heat projector can heat a person on demand and can aim at body parts: hands, arms, chest and back. Increasing the surface area to preheat a couch or a larger area. The projector turns off automatically when the user is leaving the 'heating' spot.
Nowadays these projector systems are more advanced. In the television/media and automotive industry(head lights) DMD's (digital micor mirror device)





Foldable structures applied on flexible radiated structures

Flexibility and controllability are both factors that are part of the design input. The definition of flexibility: the ability to be easily modified. Controllability means the ability to be controlled or managed. How can a design(shape and function) comply with flexilibity and controllability? There are ofcourse many possibilities to comply and adress both of these factors in product design. One particular design direction had always interested me and has already have many applications in engineering: origami, art of paper folding, which is often associated with Japanese culture. The artform is most known to fold and create planer sculpted figures like a crane(Figure 9)

Most known application on the engineering field is in space engineering: organizing luggage for space travel, increasing flexibility(product shape) of spatial structures, and improving the accuracy of robotic motion(product function). Even with the art's history, major engineering applications have come within the past 40-50 years.

Some terms that are common in origami must be introduced: A crease is a fold, either convex (mountain) or concave (valley). Collectively, all the creases make up the crease pattern. The folded state is the end result of some folding motion. In Figure 9 a Miura-Ori crease pattern is shown. Based on this crease pattern a space satellite has been made by nasa.

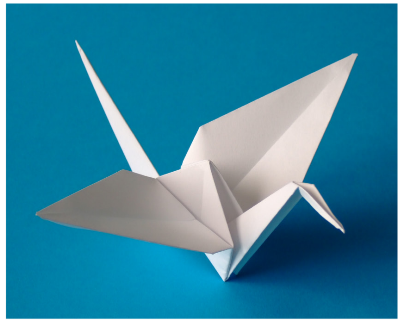
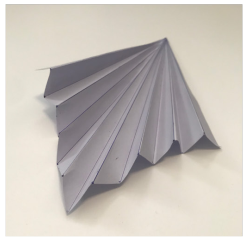
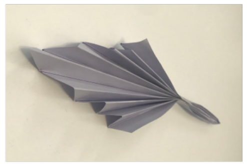
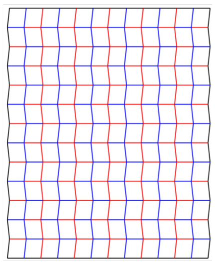


figure: Folding a flat piece of paper into a 3D shape: crane.







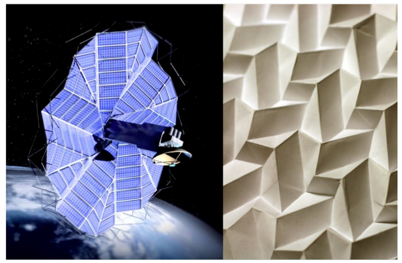


figure: The space satellite with the solar panel that folds. It uses the Miura-Ori base. (Courtesy: National Science Foundation, source: www.nsf.gov)

Figure 9: Folding a flat piece of paper into a 3D shape. Miura-Ori crease pattern. Based on this crease pattern a space satellite has been designed by NASA

Appendix D

History of Infrared Heating

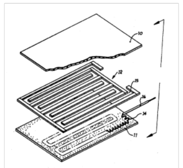
During World War II infrared heating became more widely used and recognized. The main applications were in the metal finishing fields, particularly in the curing and drying of paints and lacquers on military equipment. Banks of lamp bulbs were used very successfully; though by today's standards the power intensities were very low, the technique offered much faster drying times than the fuel convection ovens of the time. After World War II the adoption of infrared heating techniques continued but on a much slower basis. In the mid 1950s the motor vehicle industry began to show interest in the capabilities of infrared for paint curing and a number of production line infrared tunnels came into use.

The passageway is constructed of strips of heat insulating material composed of fibrous aluminum oxide and silicon dioxide and having the consistency of a feltlike cloth and being capable of withstanding temperatures up to up to 1260 °C Such a material is sold under the trademark "Fiberfrax' by Carborundum Co.

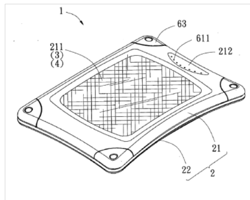
Patented Feb. 16, 1971
73) Assignee Infra-Red Systems, Inc. Carborundum Co.

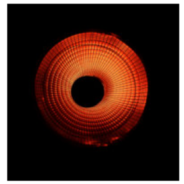











White, Jack R. Herschel and the Puzzle of Infrared. Tech. 3rd ed. Vol. 100. N.p.: n.p., n.d. Research Port. Web. 16 Apr. 2013.

Arnquist, W. "Survey of Early Infrared Developments." Proceedings of the IRE 47.9 (1959): 1420-430. Print.

Technology Guidebook for Electric Infrared Process Heating, Cincinnati: Infrared Equipment Association,1993. Battelle Columbus Division, Electric

Belling & Co

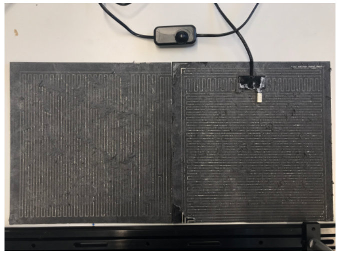
Philips Infrared heat lamp
type HP-3603 150W / 250V

1900 **1930** **1950** **1966** **1969-1970** **2000** **2010** **2020**

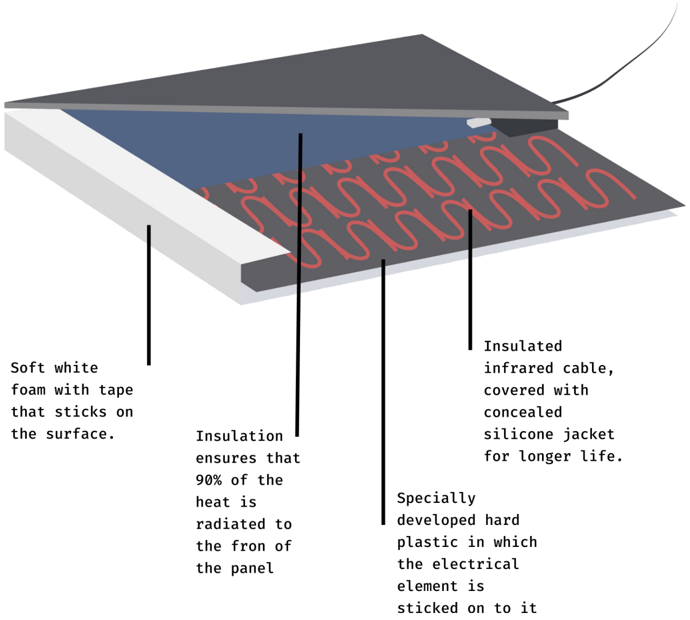
IR Panel Teardown

An infrared pannel is decomposed to see what kind of functional and interactive parts there are. The infrared cable/wire is the most functional part and is divided all over the surface area. The warmth is felt at a relatively close range: 0 - 30 cm

The infrared pannel is controlled via a cable dimmer. The user must physically interact with the device. The user needs to be close and turn/tiwst to aim in the right direction so that the pannel reaches it warmth to the user.



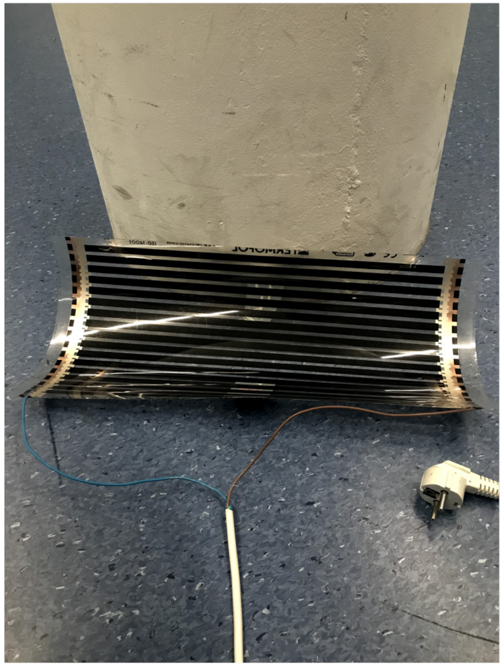


IR Heating film testing

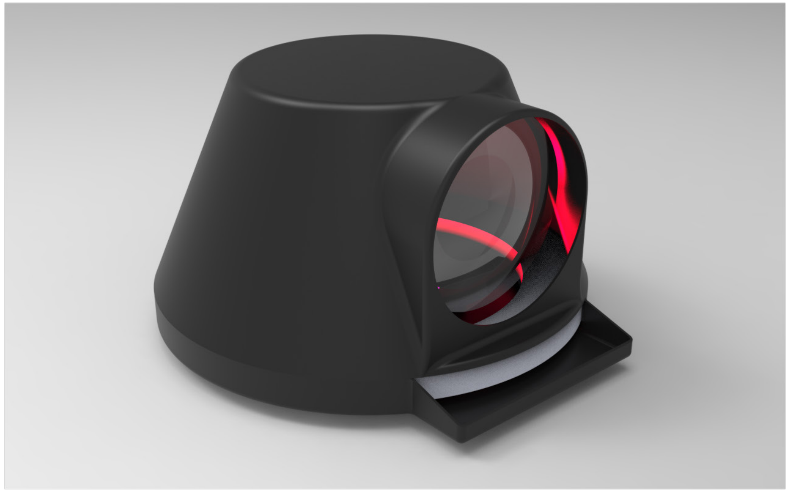
These type of foils are normally used for putting it under carpet or laminate flooring.

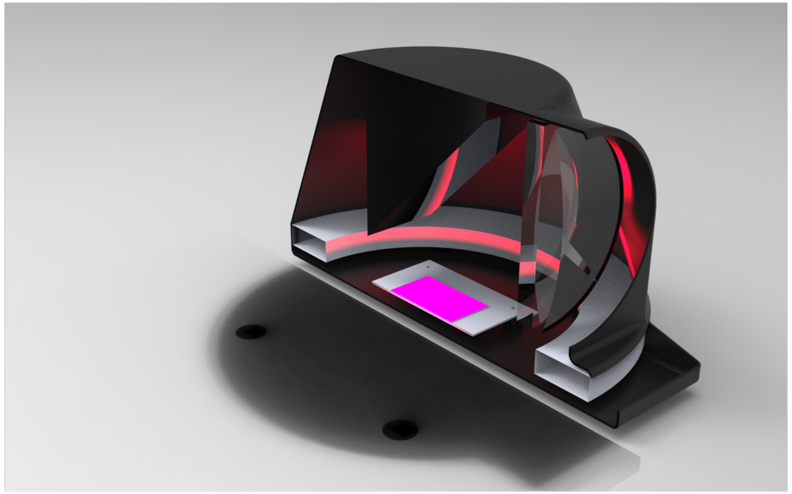
The heating film (250 mm x 500 mm x 0.1 mm)consists 17 nanotubes(10 mm x 42.9 mm), the whole sheet consumes 0.13 A. The voltage is 228.7 V meaning the whole power drawn from the sheet is (P = V x I) 29.7 W resulting in a measured core temperature of 40 °C. The resistance measured along each tube is approximately 103 Ω.

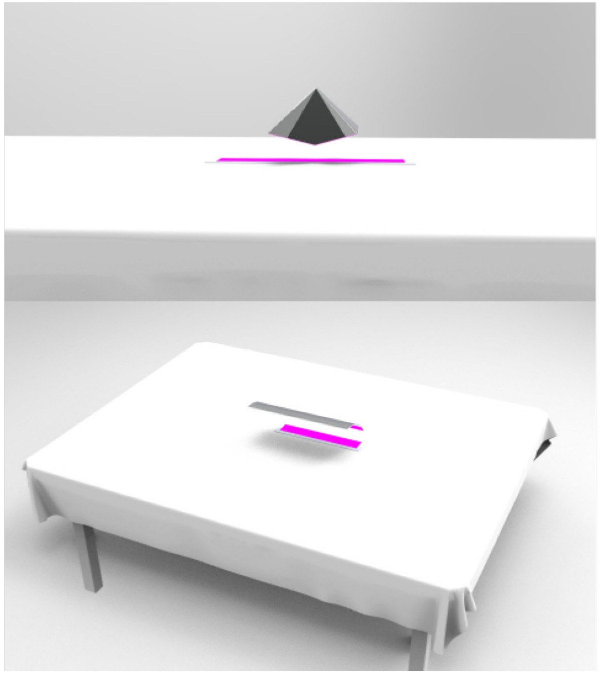


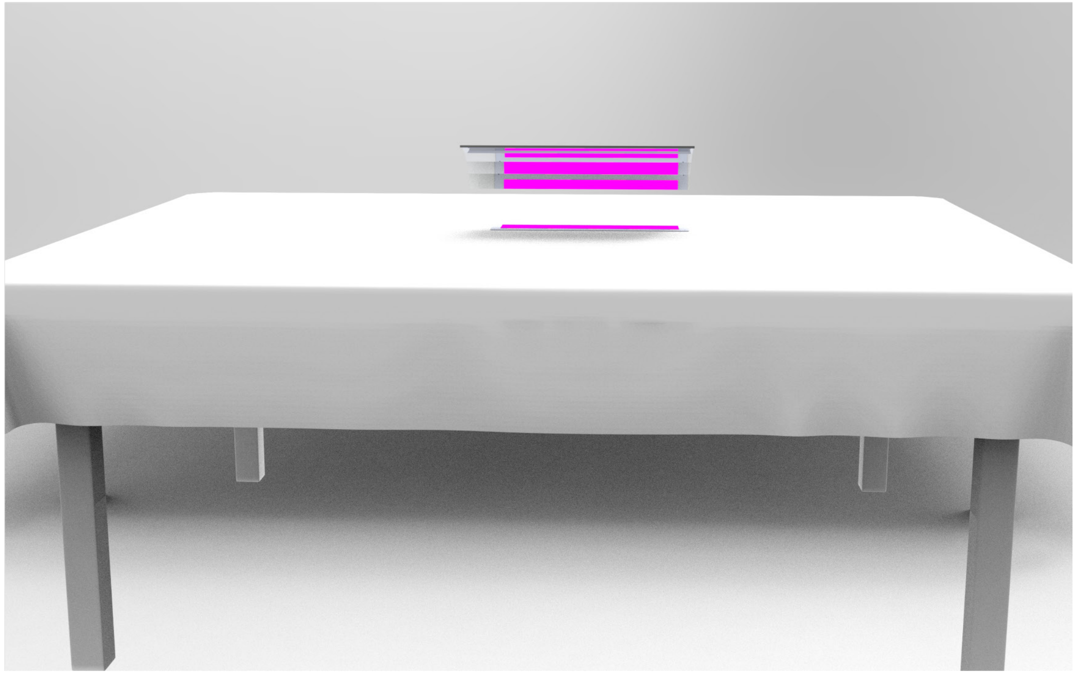
The heating film, with current sheet measurements and thickness is only able to provide comfort by making direct contact or being literally close to it. Measured from current air temperature(23 degrees celcisu) the heat is only felt at a distance approximately 1 - 3 cm.

The surface of aluminum has the ability to reflect 95% of the infrared rays which strike it. Since aluminum foil has such a low mass to air ratio, very little conduction can take place, particularly when only 5% of the rays are absorbed.







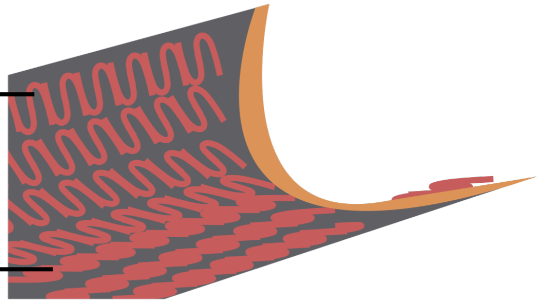


Heating film characteristics and design parameters

The flexible and transparent heating film is composed of polymer-graphite composites: poly(methyl methacrylate) and polybutene composites containing graphite. These films are stacked graphene films using a roll-to-roll method and prepared. Based on a study on the Heating Characteristics of Films Prepared with Polymer-Graphite Composites(Kim, 2019), heating films exhibited stable heating performance under continuous use condition of 200°C or less. The sheet resistance of the film decreased with the increase of the film thickness and the graphite content added to the film. By decreasing the heet resistance a higher temperature range is assured.

Carbon materials such as graphite, carbon nanotube, carbon fiber, and graphene have high conductivity and excellent mechanical properties and are applied in the fields where lightweight and high-performance composite materials are required.

In particular, these films are mechanically stable against large bending deformations, which is suitable for automobile defogging/deicing systems and heatable smart windows.



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Korea (NRF) funded by the Ministry of Education
(no. 2017R1D1A3B03034728). This work was also supported
by the Korea Basic Science Institute (KBSI) National
Research Facilities and Equipment Center (NFEC) grant
funded by the Korean government (Ministry of Education)(no. 2019R1A6C1010045).

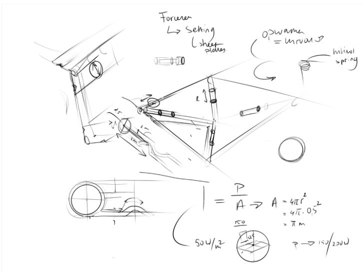
Testing with folding

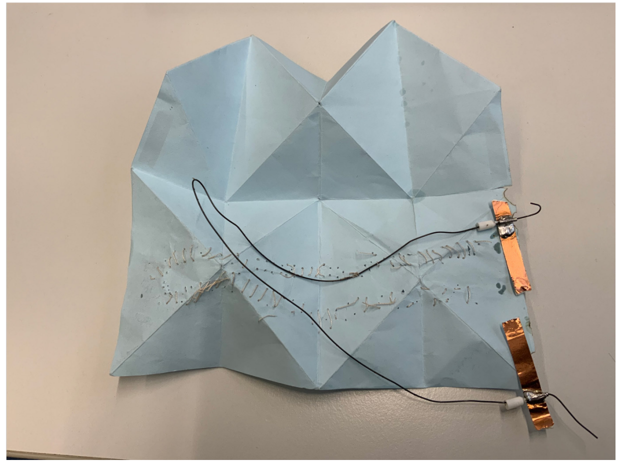
The purpose of this test to get an idea on what's happening with physical fold lines when having a "high" number of folding-cycles. The initial test was done with paper. The test was done both on thin paper

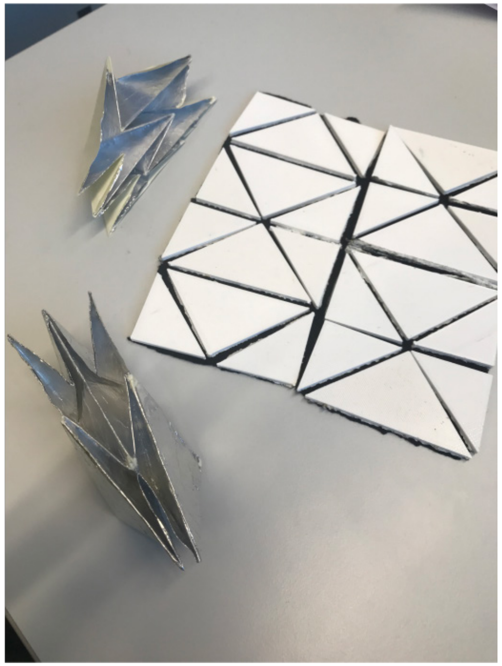
Origami

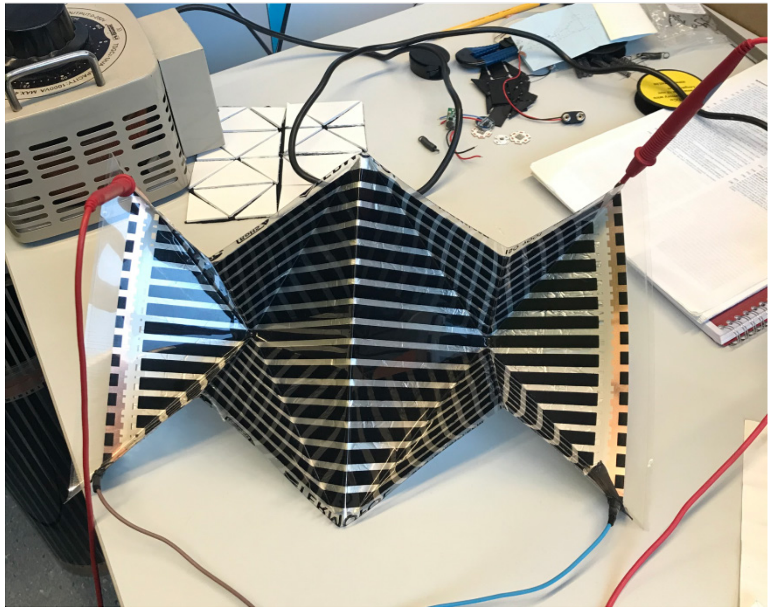
Experiments in lightweight and versatile paper actuation using muscle wire, a shape memory alloy (SMA) that contracts when heated with electric current.

Qi, Jie and Buechley, Leah. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12). ACM, New York, NY, USA, 749–752.









Criteria for Concept selecting

Criteria (weight) :
1. Viability (ability to work successfully)
2. Customizability (the ability to customize to users needs)
3. Feasibility (the state or degree of being easily or conveniently done)
4. Durability (the ability to withstand
5. Environment / Material use
6. Cost (estimation)
7. Innovativeness

Reducing the indoor-temperature leads to a yearly cost saving 20.4% - 31.7% (€115 - 156.72) depending on the type of household, insulation and ventilation type.

Origami engineering ⟶ Fold-able for primarily ease of use, controllable(user), Flexibility for more use cases,

Product Application

Safety design(electronics and heat)

Manage expectations ⟶ surface temperature vs feeling temperature

Motion detection ⟶ User leaves product product turns automatically off.

Visualisation core product function ⟶ Radiation sheet

The COP (Coefficient Of Performance) indicates the efficiency of the heat pump: the ratio between the amount of energy that the heat pump releases and the amount of energy that the heat pump absorbs.
The SCOP also called SPF gives the Coefficient per year over 4 seasons.
With an SPF/COP of 1, the heat pump gives off as much heat as it uses up in energy. Electric heat pumps for heating today have a COP between 3.5 and 5: the efficiency is therefore between 350 and 500 percent. The COP for hot water is lower (2 to 3.5) because a higher temperature is required (58 degrees). The return for this is therefore 200 to 350 percent.

Appendix E

1.4 Optic aiming for IR heating

The purpose of this experiment is to discover if an optic device(aiming mechanism) is effective for developing a personal heater with infrared heating as a heat source. 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 folowing 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 manipulateable without losing thermal properties.
3. What are the temperatures over the distance when a Fresnel lens is used?

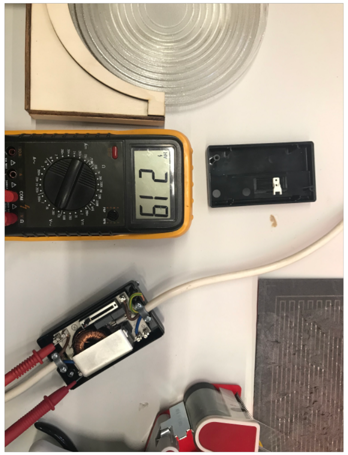
Additional questions:

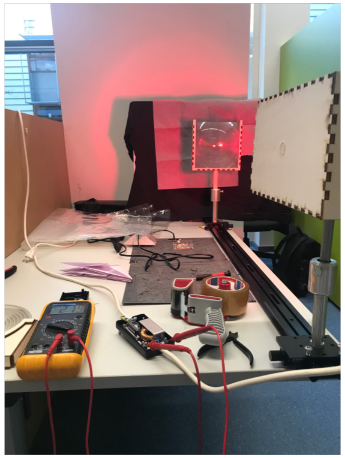
1. What is the thermal absorption rate distributed over the distance when operating the IR bulb?
2. How much electrical power goes to IR light and heat?

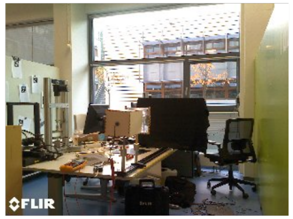
In order to execute this experiment an optics experimental setup has been build at the applied labs at the faculty of IDE in Delft. The additional questions help to decide upon energy efficiency and feasibility.

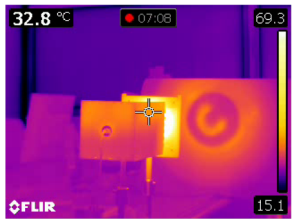
Materials:

1. A reflective box containing a E27 fitting and a dimmer
2. 250 Watt IR Light bulb
3. AC Power source(230 V)
4. Fresnel Lens(FL) attached to a mount
   a. Silicon Fresnel Lens(**SFL**)
   b. Glass Fresnel Lens(**GFL**)
5. Black piece of cotton (square)
6. Skin-like silicone material (square)
7. Pannel for mounting 5 and 6
8. Flir Exx series thermal camera for creating a thermal image/video
9. Rails system to mount the heating source, the lens and the object
10. Multimeter









Setup

The experiment setup contains an optic rail with at the beginning a holder for the infrared bulb, a lens(in a holder) at the middle and at the end an object pannel.

The infrared bulb is atached to an E27 fitting enclosed in a (plywood) with aluminium reflective tape to ensure all the heat is directed towards the lens. The E27 fitting is soldered to a cord dimmer and connected to a wall outlet(230 V).

Two lenses are used: both of them are fresnel lenses. Appendix E contains more information about fresnel lenses. In short fresnel lenses are used for **weight reduction** since the concentric rings are used to increase/decrease the effect of converging/diverging. Most optic systems such as a projector make use of fresnel lenses since they are able to focus an **omni-directional light bulb to a specific surface area(evenly light distribution)**. The left one is made from glass material and the other one is made of silicon. The glass lens has larger concentric rings in comparison with the silicon lens: the silicon lens has a stronger convergent effect.

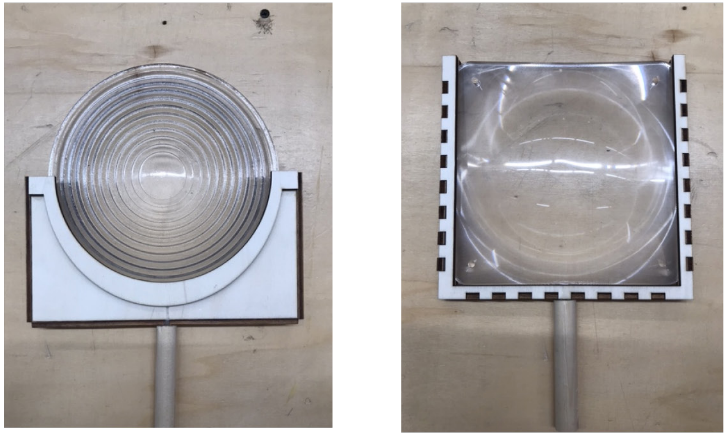


Figure : On the left, the glass fresnel lens with larger concentric rings. On the right a silicon fresnel lens with smaller but a higher quantity of concentric rings. The silicon lens has a stronger convergent effect.

Variables of interest

In order to answer the research questions, the variables of interest are defined. Increase of **temperature(dT,°C)** is the most important variable since we are dealing with an heating solution. This variable is highly depended of the **power source(P, W)** and **time(t,s)**. At last the temperature over the **distance(s, m)/temperature gradient** is really important. The distance is depended on where the heat is projected on(object pannel distance, cm) and the surface **area(A, cm²)**. The heated surface area is varied by changing the lens location, **o(object distance)** vs. **i(image distance)**. The o and the i are part of the optic formula of **f(focal length)** and suggests how strong(Optical power) the lens is. In this experiment the optical image is **not** of importance. The area of heat is of importance since the personal heater focusses on a variety of difference surface areas. A thermal camera is sufficient for conducting this test. Figure .. a setup is drawn to show the initial process for conducting this experiment and to define the variables.

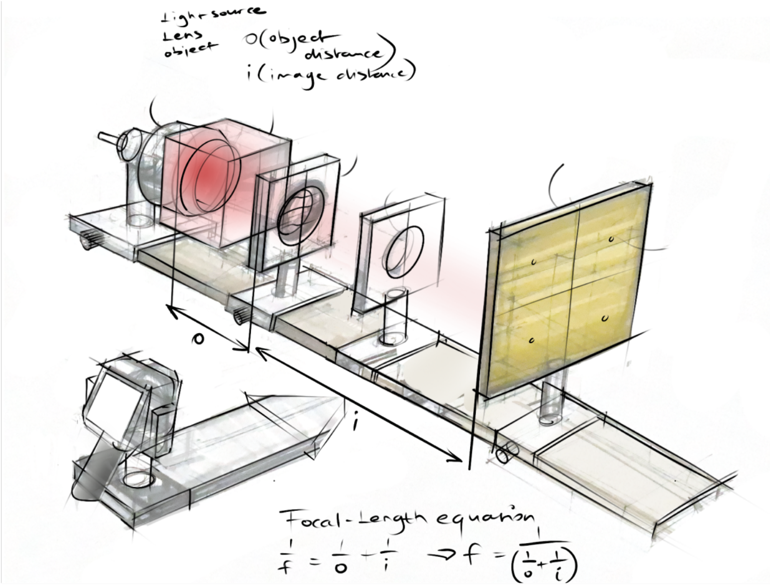


Figure : A handdrawn testsetup for variable exploration. Both the formula as the variabbles are given(handdrawn).

Measurements

The Flir Exx series thermal camera is positioned on a fixed surface with a mount. The IR bulb, Fresnel lens and the object should be fixed. The IR bulb is turned on for measuring surface area on the object then turned off. Initial conditions are written down at the start. Then the camera is turned on. The IR bulb is turned on. Each measurements is going to take **600 s(10 minutes)** to measure a precise and clear **temperature increase at the source, lens and object(Figure ..).** The object is kept constant for full power 250 watt(100%) 187,5 Watt(75%) 125 watt(50%) . Only two surface area's are measured: One surface area is aimed at a typical P95 hand's area(DINED). And the other one P95 frontal torso area.

Initial and Environmental Conditions

Both the initial conditions and environmental conditions are setup and updated throughout the measurements. The Flir Exx software is used to analyze the temperature gradient. A single test has been done to calibrate the color gradient with respect to minimum and maximum temepratures.

o(object distance) = 248 mm

I(images distance) = 99 mm

F(focal length) (mm): 55.88 mm

Dimension SFL: 182.5 mm x 182.5

Dimensions GFL:

Area of heated surface = r = 270 mm

P = 250 W ⟶ (I = 1,136A U = 220V)

Air speed = 0.3 m/s

Air temperature = 23 °C

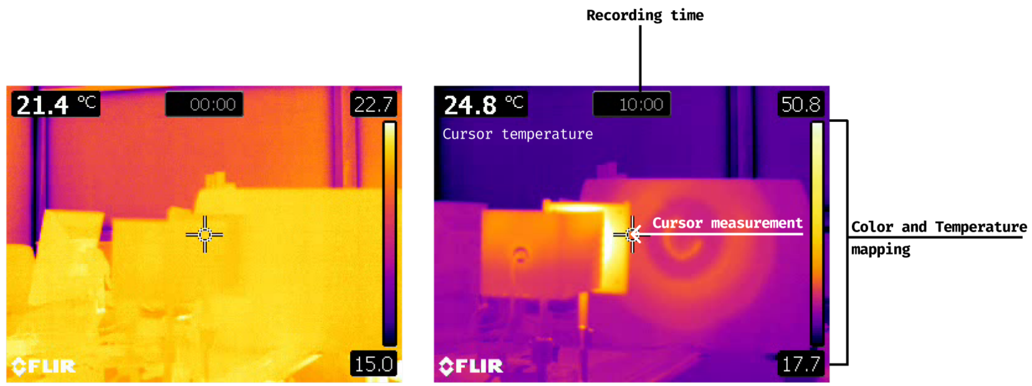
Humdity = 35 %

Since a personal heating solution should focus on human body measurements, two surface area's are defined(p95):

Hand Area(HA) = 186 mm x 97mm = 0,018 m^2

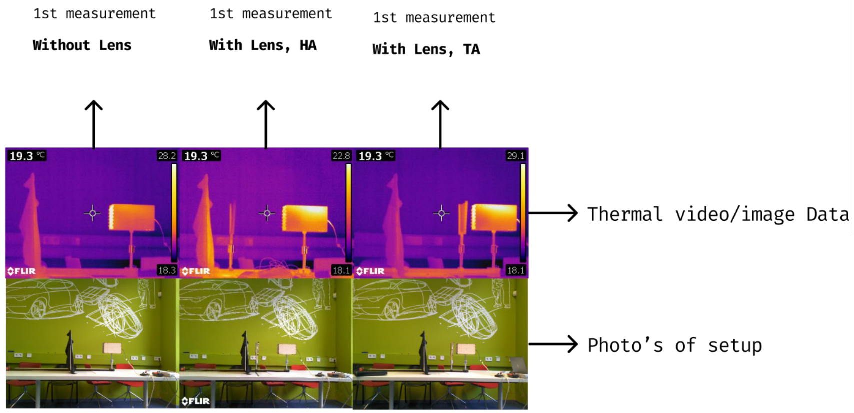
Torso Area(TA) = 396 mm x 601mm = 0,237 m^2

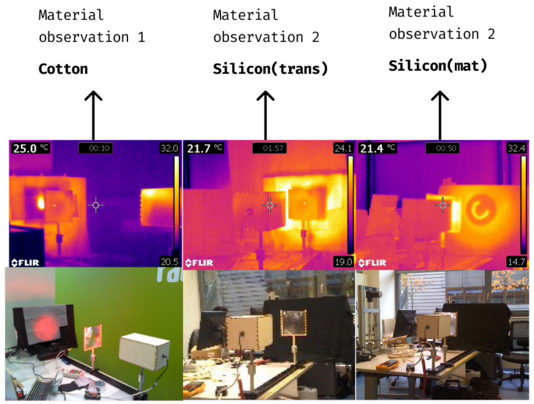
These surface areas are reached by increasing/decreasing the o and the i(changing lens positions)

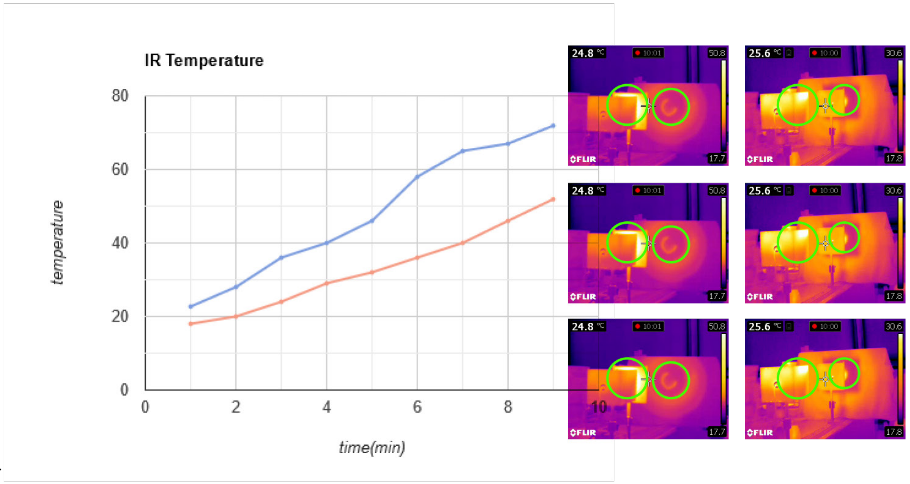


Results

The total data package is presented in the appendix and as a zipped file. The data package contains, a thermal video clip and an image screenshot. The data is analyzed through the software and imported into excel for creating multiple diagrams for each measurements. A final diagram is presented here.

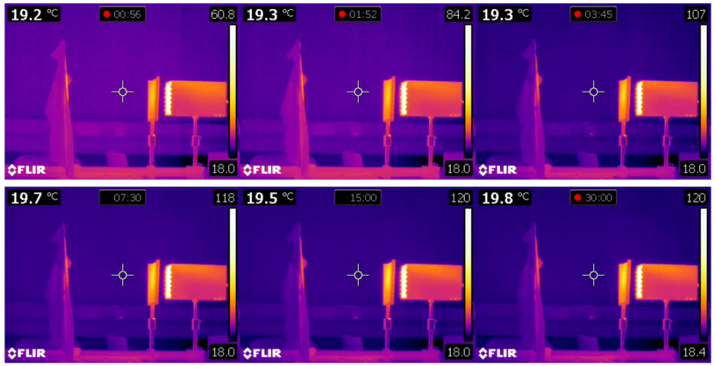


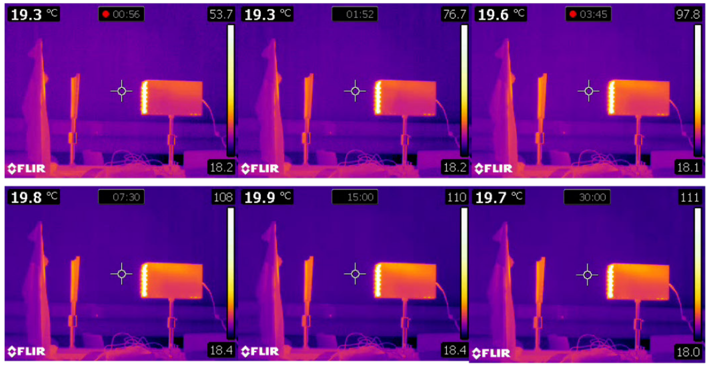


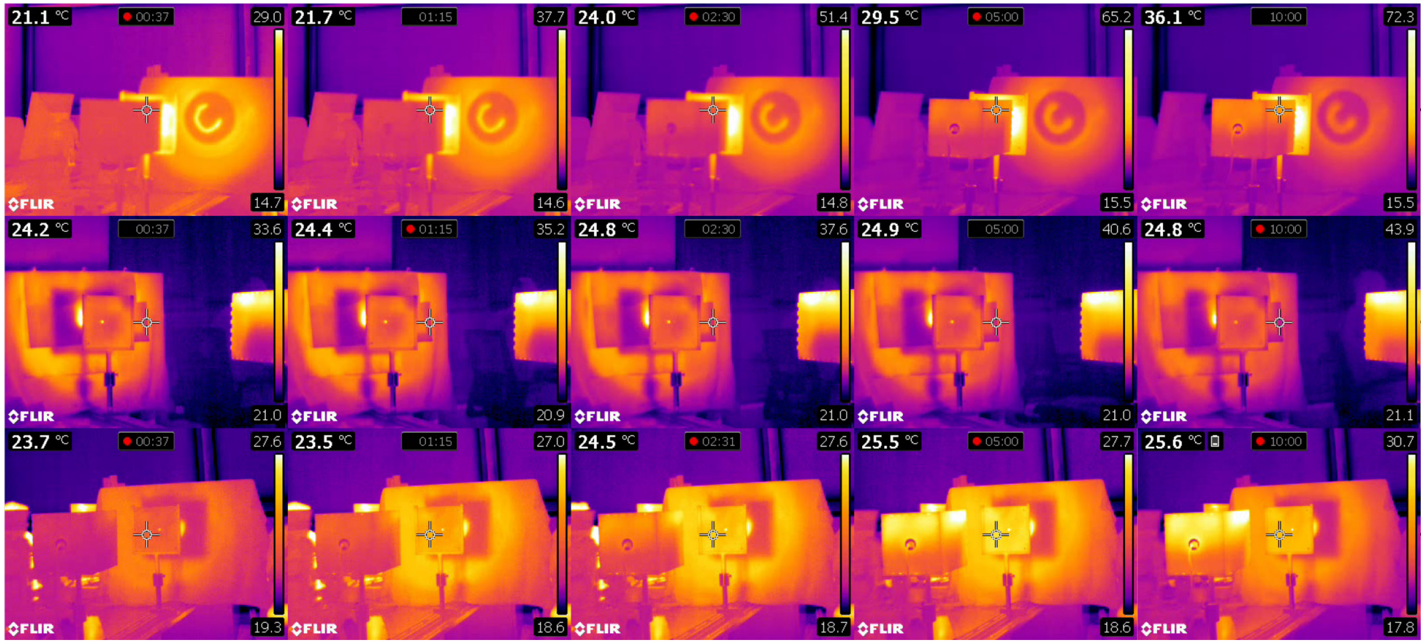


The data diagram shows that the silicon fresnel lens has a significant impact on both increasing and decreasing the area of heat. The glass fresnel lens has a little or no effect and that has to do with the small optical power of the lens. However at the temperature of **50°C** the silicon lens starts to react by expanding leading to bending of the lens in the holder. The glass lens doesn't expand at all. With a larger i(HA) the dT = **5,1°C – 6,4°C** in comparison to a smaller i(TA). The surface area heats **55% – 65%** faster for a larger i(HA) in comparison with a smaller i(TA). At a P = 250 watt the temperature distribution is **72.1 °C – 33,2 °C,** with the highest temperature close to the source and the lowest at i = 990 mm(TA). T = 36,2 °C is found on the outer surface area on the object pannel. On the inner part of the surface area the temperature is in between **33,2 °C – 40,3 °C.** With the gradient map a temperature

Measurement Analysis	Measurement Analysis	Measurement Analysis	Measurement Analysis
Torso Area	Torso Area	Hand Area	Hand Area
P = 250 W	P = 250 W	P = 250 W	P = 250 W
Δs = 50 cm	Δs = 30 cm	Δs = 50 cm	Δs = 30 cm







→ **Cotton(1mm)**

→ **Silicon transparant(1mm)**

→ **Silicon matt(1mm)**

Thermocouple measurements of NIR heating.

At **t = 1800 s(30 minutes)** atemperature distrubtion table has been made with the FLIR XX series software. Environmental conditions: **v = 0.3 m/s, T = 23 °C , RH. = 35 %**

At t = 1800 s (30 minutes) it is expected to have a more steady temperature distrubtion from source, air and object. The object is neglected, since the object will absorp heat which will have effect on measurement.

The software can analyze the temperature increase/decrease over time when aiming at the heat source. In the thermal clips I've marked areas In which there is a Δs of 10 mm from source to object. With these markings I've analyzed and pinpointed temperatures.

s (mm)	**P = 250 W NIR Bulb T(°C)**	**P = 30 W FIR Foil T(°C)**
0	72.1 °C	45 °C
10	71.9 °C	30.3 °C
20	70.6 °C	28.7 °C
30	70.2 °C	27.2 °C
40	69.8 °C	24.2 °C
50	69.5 °C	23.2 °C
60	68.9 °C	23.2 °C
70	68.5 °C	23.2 °C
80	68.4 °C	23.2 °C
90	67.2 °C	23.2 °C
100	65.7 °C	23.2 °C
110	63.4 °C	23.2 °C
120	63.8 °C	23.2 °C
130	62.7 °C	23.2 °C
140	61.6 °C	23.2 °C
150	60.9 °C	23.2 °C
160	59.8 °C	23.2 °C
170	58.7 °C	23.2 °C
180	57.4 °C	23.2 °C
190	56.4 °C	23.2 °C
200	55.4 °C	23.2 °C
210	54.4 °C	23.2 °C
220	53.4 °C	23.2 °C

Distance (mm)	**P = 250 W NIR Bulb T(°C)**	**P = 30 W FIR Foil T(°C)**
230	52.1 °C	23.2 °C
240	51.3 °C	23.2 °C
250	50.2 °C	23.2 °C
260	49.5 °C	23.2 °C
270	52.5 °C	23.2 °C
280	50.5 °C	23.2 °C
290	48.5 °C	23.2 °C
300	46.5 °C	23.2 °C
310	44.5 °C	23.2 °C
320	42.5 °C	23.2 °C
330	40.5 °C	23.2 °C
340	38.5 °C	23.2 °C
350	37.5 °C	23.2 °C
360	36.1°C	23.2 °C
370	35.5 °C	23.2 °C
380	34.7 °C	23.2 °C
390	33.9 °C	23.2 °C
400	33.3 °C	23.2 °C
410	32.7 °C	23.2 °C
420	32.1 °C	23.2 °C
430	31.9 °C	23.2 °C
440	31.1 °C	23.2 °C
450	30.9 °C	23.2 °C

Distance (mm)	**P = 250 W NIR Bulb T(°C)**	**P = 30 W FIR Foil T(°C)**
460	30.5 °C	23.2 °C
470	30.1 °C	23.2 °C
480	29.8 °C	23.2 °C
490	29.2 °C	23.2 °C
500	28.9 °C	23.2 °C

It is expected that lens(material), object and the human skin will react to NIR heating. With literature research there is an important

The following materials are of interest:

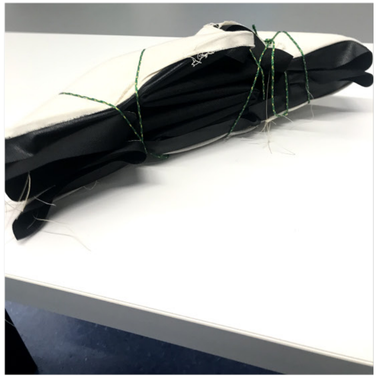
Lens material: glass vs silicon. What will happen with the lens at fixed position for a long time. The temperature at 300 - 600 - 1200 and 1800 are compaired for each distances.
Clothing material vs human skin(silicon sheets). Since the aim is to warm people heat exposure is important to analyse.
What will happen to clothing and what will happen to skin?

Three material observations

Black colored nylon 30% and cotton 70% piece of cloth.
Transparant/skin colored Silicon skin like surface material
Multiple silicon sheets with various visual properties.

All tests are conducted with one lens and one position set-up. The test took 1 hour for each piece of sheet material. After 1 hour the IR bulb was turned off. The temperature at that time(t=0) is measured and the temperature decrease over t is also measured. All these measurements are collected into a single file datasheet.

Based on the measurements, the black colored material was staying at a temperature of 40 degrees celcius significantly longer than(more than 10 minutes) after shutting off the IR light bulb. The color or material properties didn't change because of the color of the near IR spectrum. The skin colored material had a temperatre of 34 degrees celcius after shutting down the bulb. Compared to the black sheet it had a lower effect



b) Theory and Calculations

Requirements

Requirement: The product should be able to provide additional heat within the range of 30-50 cm.

Requirement: The product's powerconsumption should be in the range of P = 100 watt - 200 watt. The Irradiance has a range of E = 50 $W \cdot m^{-2}$ - 80 $W \cdot m^{-2}$

Inverse Square Law

If at a distance of one meter from a point source an object receives 1 W/m2 of radiative energy, then at a distance of 2 meters the same object will receive 0.25 W/m2 of energy. That's true for a monochromatic point source as well as for a blackbody, and comes exclusively from geometry.

In science, an inverse-square law is any scientific law stating that a specified physical quantity is inversely proportional to the square of the distance from the source of that physical quantity. The fundamental cause for this can be understood as geometric dilution corresponding to point-source radiation into three-dimensional space.

Many concepts in physics can be explained by the inverse square law. In this project the focus will be on infrared radiation. The radiation intensity from a point-like source(omnidirectional) with unlimited range, which effects in all directions, in a specific distance r is equal to the quotient of the power to the surface of an imaginary sphere with radiant r. I is the intensity in r distance, that corresponds to a surface A. At a 2r distance the same amount of energy pass through the surface 4A. So the intensity becomes I/4 etc.

Requirement: The product should be able to provide additional heat within the range of 30-50 cm.

Requirement: The product's power consumption should be in the range of P = 100 watt - 200 watt. The Irradiance has a range of E = 50 W·m-2 - 80 W·m-2

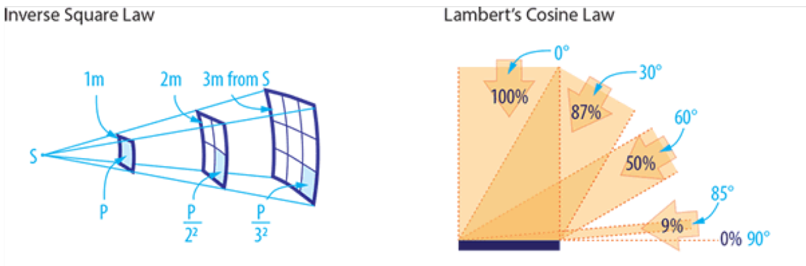
Stefan-Boltzmann Law

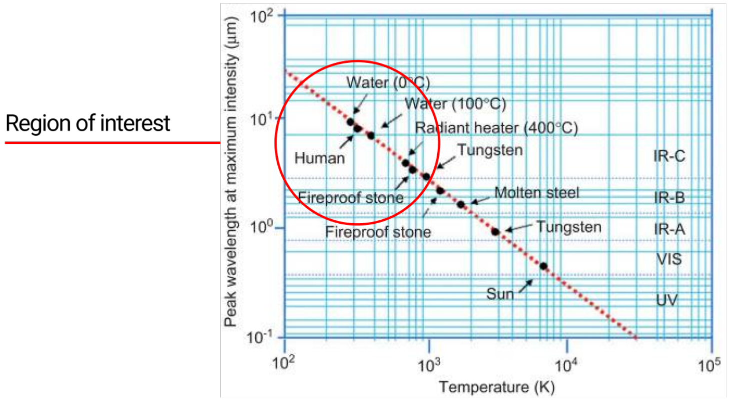
c.3 Inverse Square Law and Lambert's Cosine Law

The inverse-square law is any scientific law stating that a specified physical quantity is inversely proportional to the square of the distance from the source of that physical quantity. The fundamental cause for this can be understood as geometric dilution corresponding to **point-source radiation** into three-dimensional space. Since the power range is going to be between 300 - 100 W

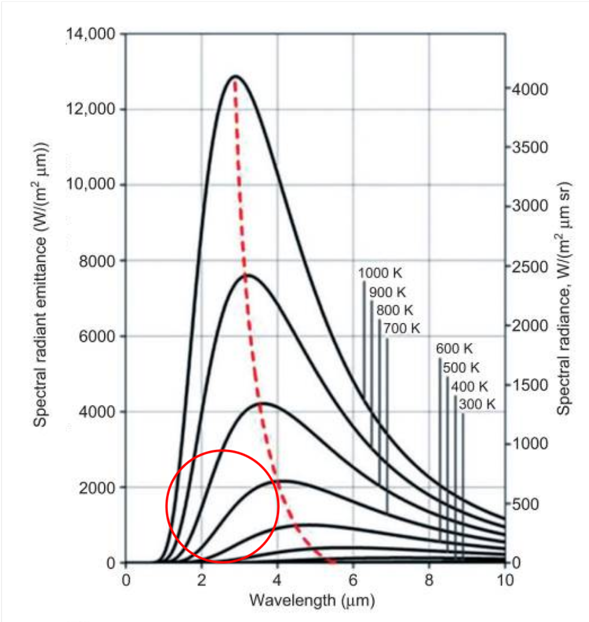
$$I = \frac{P}{A} = \frac{P}{4\pi r^2}.$$

Inverse Square Law

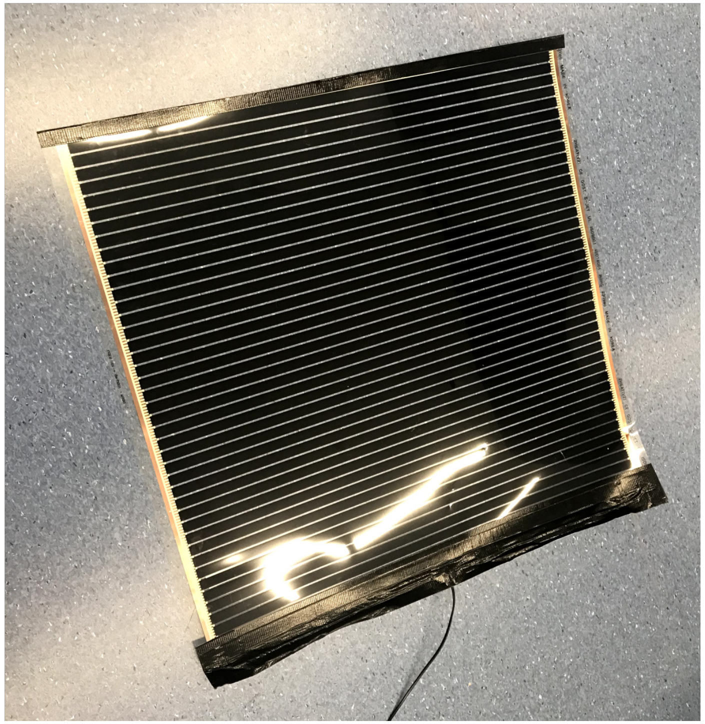


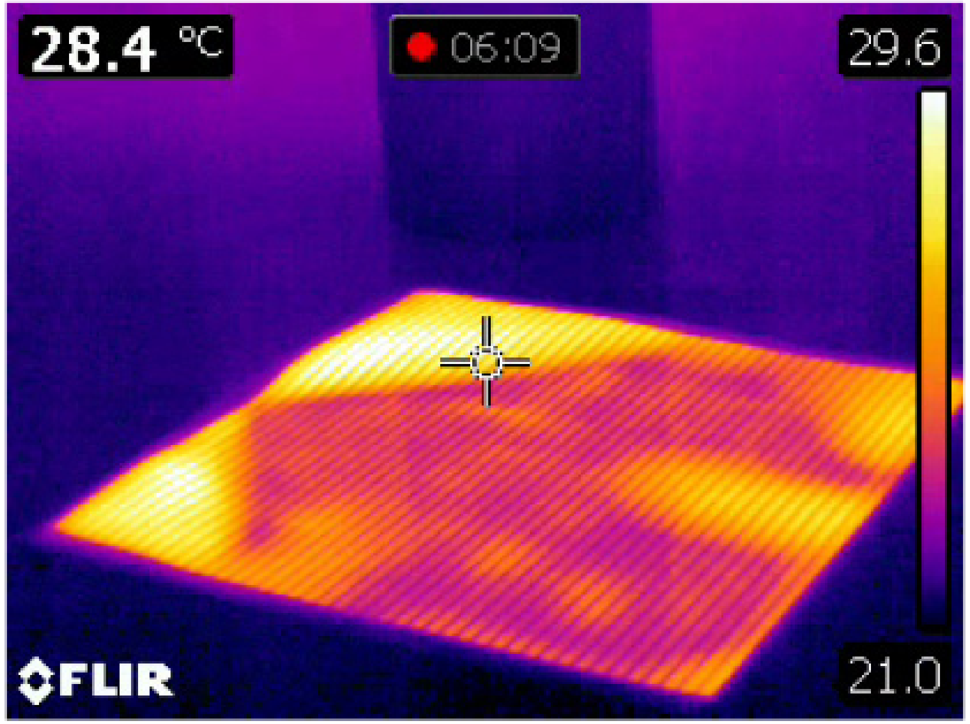


Planck's law. Dependence of spectral radiant emittance (ωλ) for perfect blackbodies as a function of wavelength (λ).



Wien's displacement law. The wavelength of maximal radiant exitance (λmax) as a function of the absolute temperature (T) for a perfect black body (dashed line) and different bodies.




28.4 °C
06:09
29.6
21.0
FLIR

c) Product Architecture

Core technology

- IR radiating elements
- Two sheets sandwiching the infrared radiating elements
- One sheet is IR radiant refelective
- Terminals and cable for power.

Temperature control

- Cable dimmer
- Temperature input/Increase/Decrease

Aiming

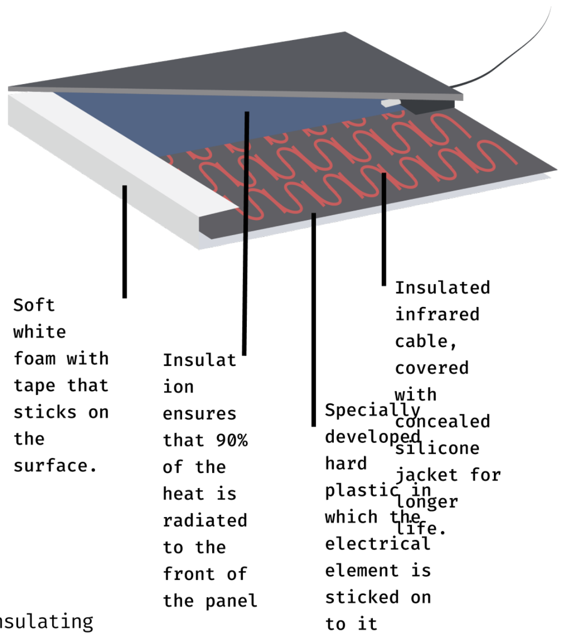
- Automatized
  - Mechanical parts not prefered, weardown/ tear etc.
  - Nitinol for unfolding when heating up. Cooling down results to folding.
- Manual
  - User folds/unfolds as prefered arrangements.
  - Tabletop fold(recht opstaand)
  - Tabletop fold(laying back) multiple directions

Ease of use

1. Physical/Software
   a. Cable dimmer
   b. On/off
   c. Timer
   d. Motion sensor
   e. Display
      i. Current temp from heater
      ii. Environmental temp

System Architecture

1. A continuous infrared radiating element disposed in a passageway(zigzag maze) sheets and securing them adhesively.
2. Two Sheets that sandwich the infrared passageway
   a. One of them is reflective material, preferably aluminum or other suitable light-reflecting materials that l covers the outer surface of one of the sheets, so that radiant energy is emitted only from one side of the sheet.
3. Terminals(phase and 0 cable)extending outwardly of the heater.
4. Controlls: Terminals are connected to a cable dimmer or controllable system.
5. Visual feedback trough LED



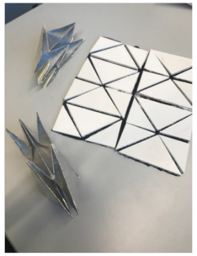
The passageway is constructed of strips of heat insulating material composed of fibrous aluminum oxide and silicon dioxide and having the consistency of a feltlike cloth and being capable of withstanding temperatures up to up to 1260 °C

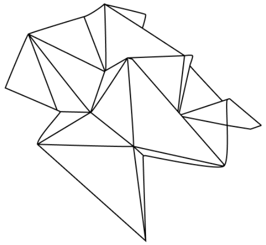
Such a material is sold under the trademark "Fiberfrax' by Carborundum Co.

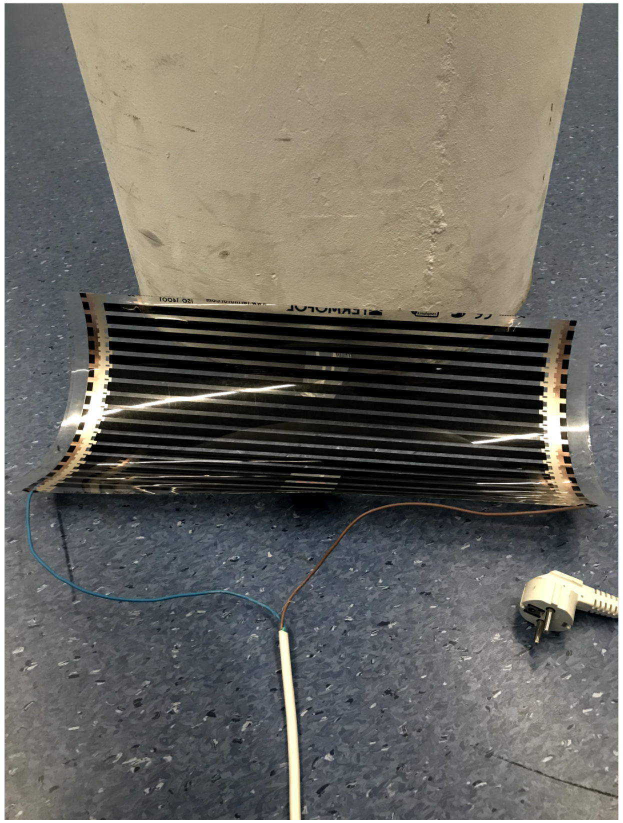
Patented Feb. 16, 1971

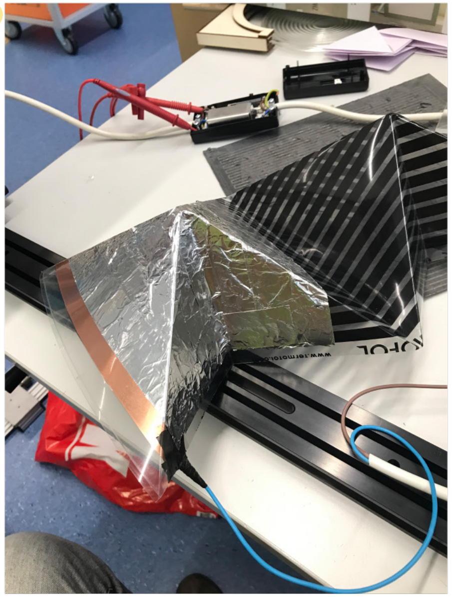
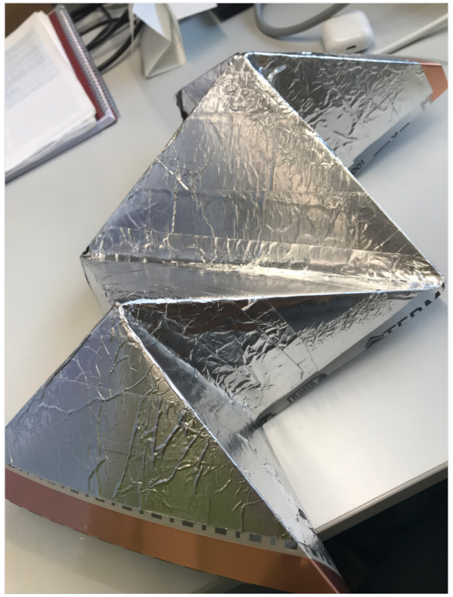
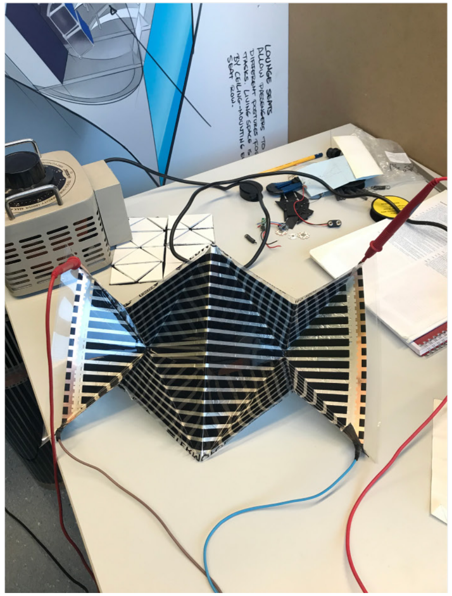
73) Assignee Infra-Red Systems, Inc. Carborundum Co.

Appendix F



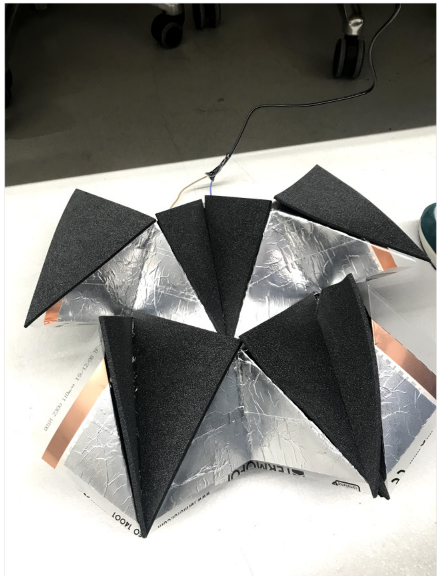
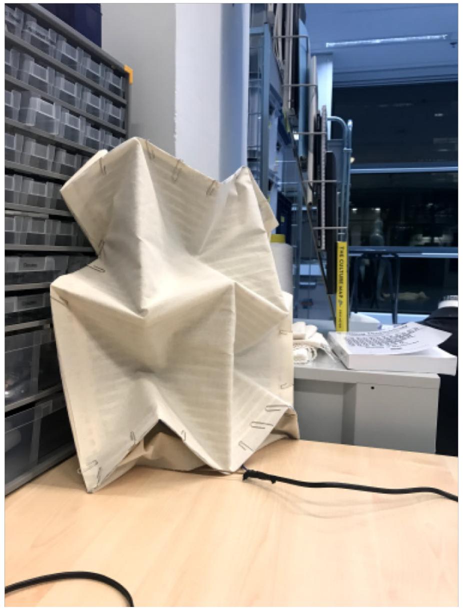




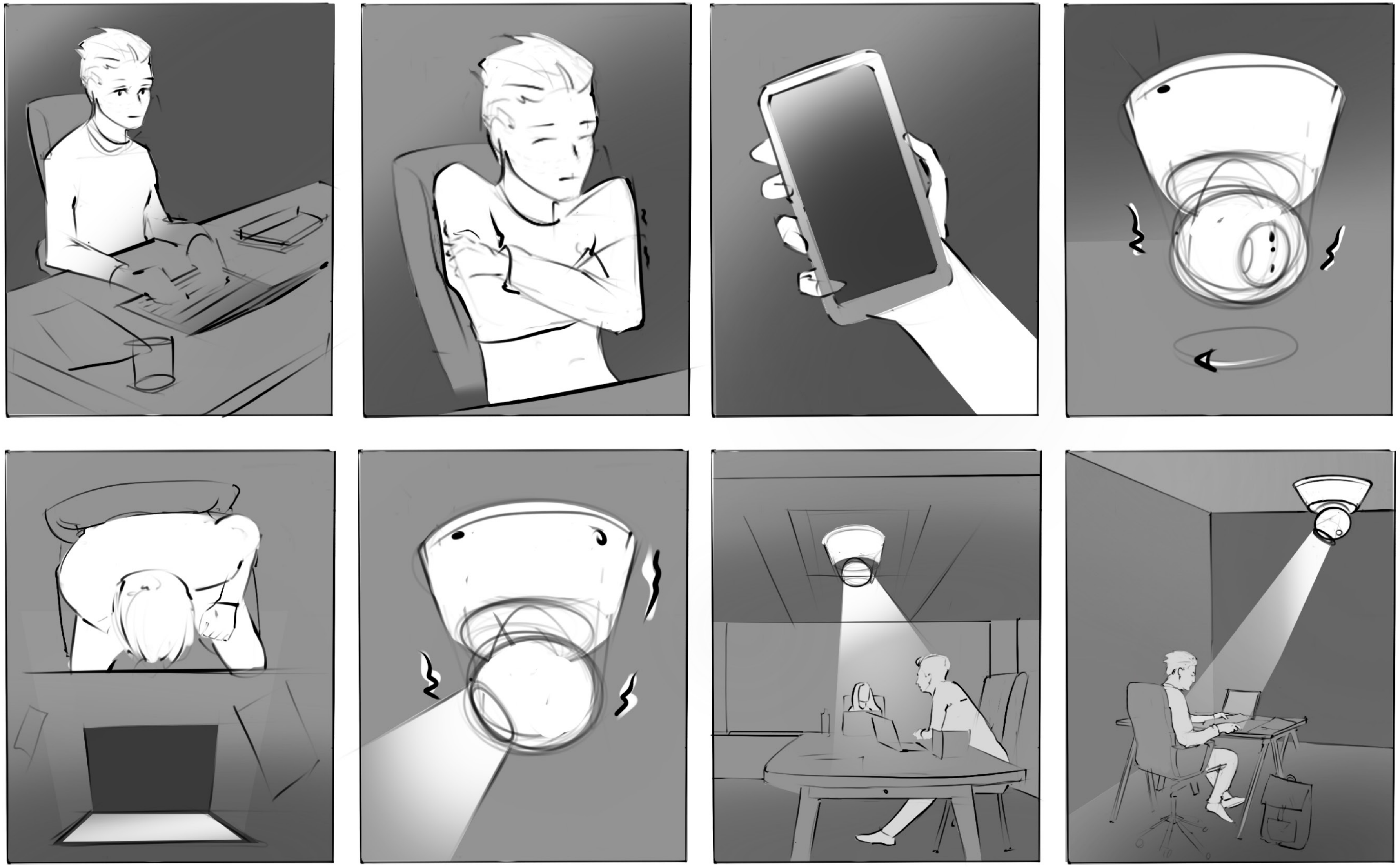


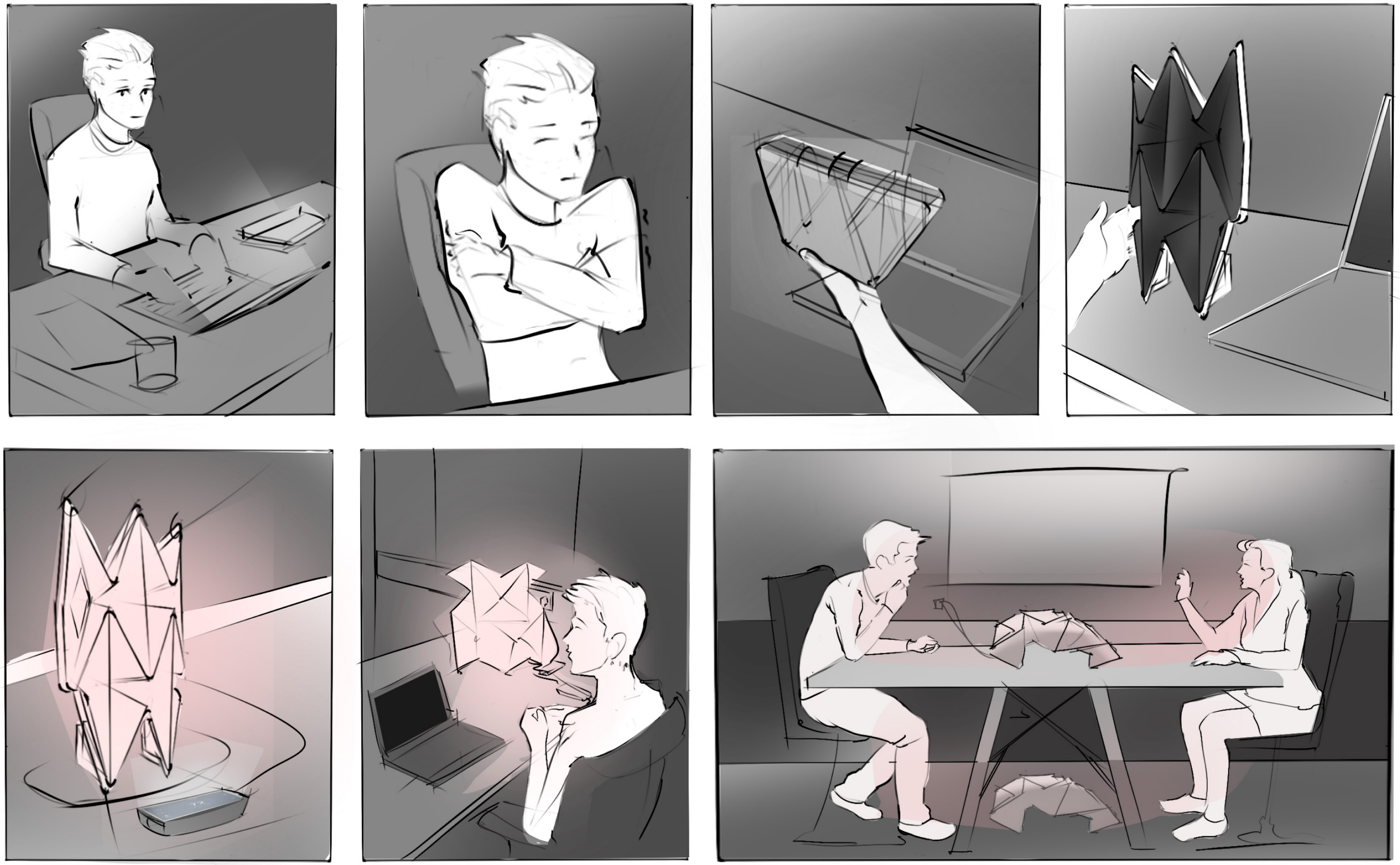


Do not turn dials


ZWAAR
URKOPP ADLER



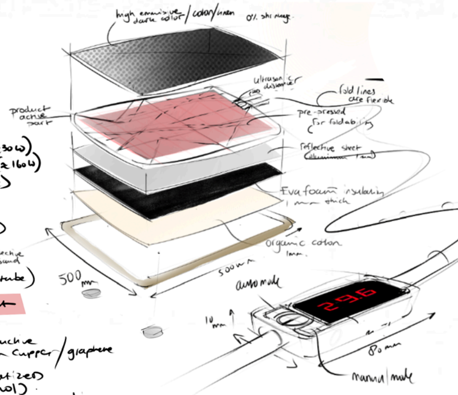


1 Solution architecture

- How does the solution architecture look like?
- Make a sketch of the solution architecture (components & how they interlink)
- What do you think will be the biggest challenge?

Challenges

1. Heating performance
   - increase thickness
     current prototype : 0.1mm (≈30W)
     to 0.5-1mm → 5x (10x) (≈160W)
     – Arguments paper (possible)
2. Manufacturing
   - Foldable sheet (Pre-fold/cutout)
     – press sheet — wears over time
     – crease lines — small resistance
     – cuts (cutout for carbon/nanotube)
3. Weardown of Fold in-out
   1. Pre-fold film
   2. Cutout sheet
   3. use flexible paths — conductive woven cupper / graphene
   4. Hinge design — automatized (nitinol) (heat expanding



2 Solution performance

- What are the expected applications and attributes of the product?
- What does it deliver with regards to performance? (KwH, lifetime, robustness etc.)
- What is innovative about the product compared to alternative solutions?

Expected Applications

1. Directed FIR Heating
   - product configurations
     → 3 scenarios
     → compact for easy store / take and go
   - Folding planes
     - Top — Table top: • chest • neck
     - Bottom — • ABS • hands
   - magnets
     - Fix for two ways configurations
     - easy folding for bag

Performance

Power consumption — Heating + Control
- P = 160 W ± 5W

Temperature
- 80 C - 75°C - 70°C (@ 18°C AIR temp)

✱ within 50 - 30 cm user-product distance

Robustness:
- Flexibility of product — times(x) Fold in in/out, material
  – Design with hinges
  – Design with flexible fold lines

Expected lifespan:
- 2 - 5 year
  – based on competitive products.

Innovative Factor

Folding planes
- allowing multiple config
- 1/2 person heating (social!)
- easy take'n go + store.

3 Technical fit

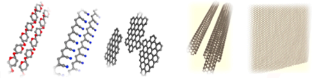
- Are the technologies currently available in your company?
- If not: is the specific technology currently available in the world? If so, where?

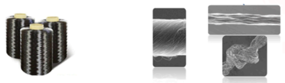
Technology Availability

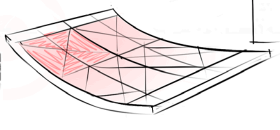
CNT (carbon nanotube) — SWCNT / ~~MWCNT~~
Graphene (fibre)
Carbon fibre

These technologies are available and are being used: highly heat conductive — Sportswear, FIR heaters, FIR pads, wall/floor/ceiling heating panels

Available in — company listing
korea and china → manufacturing FIR film for floor heating







4 Evidence

- How can we achieve the main commercial claim(s)?
- What is the possible downside of the chosen solution architecture for the target user?
- How technically feasibile do you think this product is on a scale from 1 (low) - 5 (high)? Why?

Commercial Claim Achievement

Commercial claim: Energy efficient foldable (aiming compact) FIR Heating.

1. Focus primarly on: Biggest challenge

Downside chosen Architecture

1. heat loss of planes that are not directed
   – miss use scenario.
2. Fixed scenario's vs freedom.
   a set of configurations possible for heating.
3. Ori's temperature range (65° - 55°)
   - Safety → Touch physically.
   - Ori's comfort achieved only when enclosed environment has:
     Air temp:
     Humidity:
     Airspeed:

Feasibility

4 — The challenges need to be solved to have the claimed performance.

5 IP position

- What is your freedom to operate?
- What is the estimated protectability of your solution?
- Is the consumer benefit protected or just the solution?

Freedom

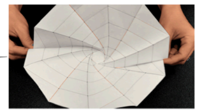
1. the technology is used within multiple brands Stoov. sit and heat car manufacturers.etc.
   - the folding technique is based on the waterbomb tesselation which is also used in space engineering and other fields.

the solution will be protected

Designrights

- origami folding shape
- Sheet design
  – FIR
  – thickness 0.5

Solar panel



6 Estimated cost price

- What are the costs of the solution?
- What are the most expensive features and/or main cost drivers of your solution?

Costs Model

→ Assuming FIR FILM inhouse (€7,10)

FIR

Manufacturing and assembly → €25,56

Overheadfactor costs: company → 15%, sell → 5%

Profitfactor → 30%

Totalfactor → 57% → 14.56 +

€40,12 → price product finished

Margin wholesale etc → 30%. 12.03 +

Storefactor (25%-100%) €52.15

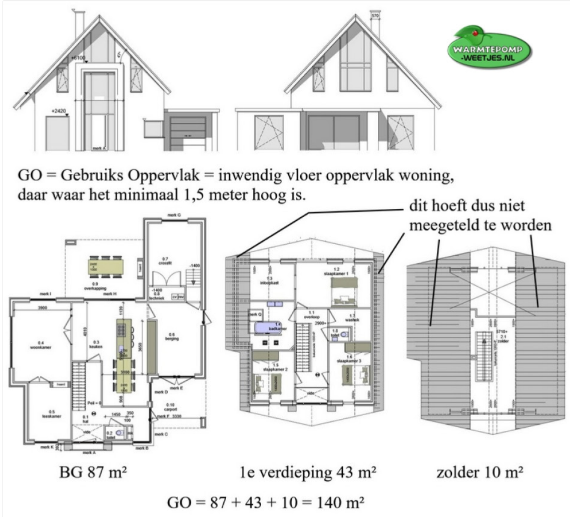
€52.15 (100%) → BTW (21) → €82,03

€15.65 (30%) → BTW (21) → €126,20

Appendix G

Indicatietabel hoekwoning vollast draaiuren per maand / jaar en richtgetal vermogen in Watt per m2 Gebruiks Oppervlak

		1995-1974	1975-1980	1981-1989	1900-1999	2000-2010	2011-2015	2016-2017	2018-2019	2020 -
						EPC 0,8	EPC 0,6 - Rc5	EPC 0,4 - Rc6	EPC 0,2 - Rc 7	BENG
		W/m² GO	W/m² GO	W/m² GO	W/m² GO	W/m² GO	W/m² GO	W/m² GO	W/m² GO	W/m² GO
Ventilatie	mechanisch	100	90	85	80	70	50	45	40	35
	CO2 gestuurd	x	85	80	75	65	45	40	35	30
	wtw	x	80	75	70	60	40	35	30	25
aanpassing	*tussenwoning*	*-10*	*-8*	*-7*	*-6*	*-6*	*-6*	*-5*	*-4*	*-2*
kengetal	*vrijstaand*	*+10*	*+6*	*+5*	*+4*	*+4*	*+4*	*+3*	*+2*	*+1*
	Januari	450	382	338	296	258	222	189	160	151
	Februari	444	377	334	292	254	219	187	157	149
	Maart	357	303	268	235	204	176	150	126	120
	April	266	226	200	175	152	131	112	94	90
	Mei	148	126	111	97	85	73	62	52	50
	Juni	72	62	55	48	42	36	31	26	24
	Juli	3	3	2	2	2	1	1	1	1
	Augustus	15	13	11	10	9	7	6	5	5
	September	105	89	79	69	60	52	44	37	35
	Oktober	220	187	166	145	126	109	93	78	74
	November	342	290	257	225	196	169	144	121	115
	December	432	367	325	284	247	213	182	153	145
	Totaal VL uur	2854	2422	2146	1878	1634	1409	1201	1012	961



Tabel Betafactor afgeleid van ISSO publicatie 72

Beta factor	is % van vollast opstel-vermogen	geeft een dekkingsgraad van totaal warmtebehoefte	bij-verwarming nodig voor % van de vraag	Vermenigvuldig factor voor draaiuren met lager opstel vermogen
0,2	20	59%	41%	2,95
0,3	30	88%	12%	2,933
0,4	40	91%	9%	2,275
0,5	50	92%	8%	1,84
0,6	60	94%	6%	1,5666
0,7	70	95%	5%	1,3571
0,8	80	97%	3%	1,2125
0,9	90	98%	2%	1,0887
1	100	100%	0%	1

General calculation heating households

Heat is currently expressed in kW. To achieve a temperature of **18° Celsius**, you need at least **70 watts per square metre,** assuming a ceiling height of 1.5 metres. Each degree more or less equals **5%.**

If you have a stand alone house, **add 10%;** If your home is poorly insulated, **add 15%.**

A calculation example:

If you want to heat a house of **140 m²** at **20°**, you need:

1. 140 x 70 (Watts) = 9.8 kW
2. 20° means 2 x 5% = 10% extra
3. 1,1 x 9.8 = 10.78 kW
4. 1,15 x 9.8 = 11.27 kW
5. 1,20 x 9.8 = 11.76 kW

Different energy consumption scenario: How much does the monthly bill increase if one wants his house at an air temperature of 20 instead of 18 degrees?

For 20 degrees it is 10.78 kW and for 22 degrees it is 11.76 kW meaning approximately **1 kW** difference for 2 degrees celcius.

Energy resources	Energy content in MJ (and kWh)
Natural gas per m³	35.17 MJ (= 9.7 kWh) at above value / using condensation energy
Elektra per kWh	3,6 MJ (= 1 kWh)

Natural gas has an energy content which is almost 10 times higher (per m³) compaired to Elektra.

Assumptions

Suppose a house with an active surface area* of the house of 140 m2. Active surface area is defined as the area indoors where the minimal height = 1.5 m. The indication tabel suggests that there are houses with different types of ventilation. In the example they are foucssing on a house build in 2016 with “mechanical ventilation”. Keep in mind these examples are focussed on **Dutch houses**. In this calculation example a house with Rc-6 (EPC0,4) (2016-2017) is taken into account where a fixed number is given of **45 Watt/m2**. We then see that statistics show that a heat pump in the Netherlands, with type Rc 6 (EPC0.4); 1201 full load hours per year run in a monovalent situation and a heat pump with a full load capacity of 6.3 kW. At 100% deployment and a transmission of 6.3 kW, the power output required by the installation. Of the 3 European zones, the Netherlands is in the '**Average Climate**'

We see an efficiency for heating (supply 35 / underfloor heating) of 200 % To find the year COP (SCOP) also called SPF for both, we have to divide it by 40 (European determined efficiency of a power plant). We then get an SPF for heating of **200 : 40 = 5.** Our expected electricity consumption is therefore: **1513.2** for only heating. The full model can be found at page 44.

Expert suggests that SCOP divide it over the 57% for a reasonable efficiency scale. **200:57 = 3.5**

Electrical Price

The costs per kWh consumed are around €0.24, including 21% VAT. A kilowatt hour (kWh) of electricity costs a 'bare' consumer about €0.09 including VAT. This price varies per supplier. In addition, there are fixed rates for energy tax + storage of sustainable energy, approximately €0.15 per kWh.

HP selection model, the energetic value and cost comparison

The purpose of using the model to calculate both the power consumption and the yearly costs is to get a glimps of how much an (energy efficient) personal heater would **save costs** and mostly to present the **financial return** when decreasing the in-door temperature(thermostat setting) to 18 °C. The financial return could serve as a way to invest in an energy efficent heater such as the Ori. Below the calculation is based on a division factor of **5.**

2000-2010

1. 140 m2 x 70 W/m2 = 9800 W = 9.8 kW.
2. 1634 hours x 9.8 kW = 16013 kWh
3. 16013 : 5 = 3203 kWh
4. 3203 kWh x 0.24 = **€768.72/y**

2016-2017

1. 140 m2 x 45 W/m2 = 6300 W = 6.3 kW.
2. 1201 hours x 6.3 kW = 7566 kWh
3. 7.566 : 5 = 1513.2 kWh
4. 1513.3 kWh x 0.24 = **€363,19/y**

1. 140 m2 x 70 W/m2 = 9800 W = 9.8 kW + **1 kW**
2. 1634 hours x 10.8 kW = 17.647 kWh
3. 17.647 : 5 = 3530 kWh
4. 3530 kWh x 0.24 = **€847.20**
5. €847.20 - €768.72 = **€78.48/y**

An increase of **10.2%** a year

1. 140 m2 x 45 W/m2 = 6300 W = 6.3 kW. + **1 kW**
2. 1201 hours x 7.3 kW = 8767 kWh
3. 8767 : 5 = 1753 kWh
4. 1753 kWh x 0.24 = **€420.72/y**
5. €420.72 - €363,19 = **57.53/y**

An increase of **15.8%** a year

1. 140 m2 x 70 W/m2 = 9800 W = 9.8 kW + **2 kW**
2. 1634 hours x 11.8 kW = 19.281 kWh
3. 19.281 : 5 = 3856 kWh
4. 3856 kWh x 0.24 = **€925.44 euro**
5. 925.44 - €768.72 = **156.72/y**

An increase of **20.4%** a year

1. 140 m2 x 45 W/m2 = 6300 W = 6.3 kW. + **2 kW**
2. 1201 hours x 8.3 kW = 9968.3 kWh
3. 9968.3 : 5 = 1994 kWh
4. 1994 kWh x 0.24 = **€478.56**
5. €478.56 - €363,19 = **115.37/y**

An increase of **31.7%** a year

Figure XX: HP estimation model for power consumption and costs.

Assumptions

With the HP, households model and using the active surface area(GO)*

A = 140 m2

a yearly power consumption estimation can be calculated In the Netherlands relatively new houses are build from 2000 and up. With a fixed ventilation(mechanical) a clear monthly and eventually yearly hourly useage of HP can be taken from the model. Earlier, a quick handcalculation resulted to a

ΔT = 2 °C an overall **P = 1 kW.**

Keeping in mind that is not a strict rule: depends on multiple factors as COP of HP and household insulation that prevents a huge temperature drop. In figure XX

Note

The effect will be much higher if more households are considering to think about their thermostat behaviour. Especially considering the power grid pressure due to electrification.

Below the calculation is based on a division factor of **3.5.**

2000-2010

1. 140 m2 x 70 W/m2 = 9800 W = 9.8 kW.
2. 1634 hours x 9.8 kW = 16013 kWh
3. 16013 : 3.5 = 4575 kWh
4. 4575 kWh x 0.24 = **€1098.03/y**

2016-2017

1. 140 m2 x 45 W/m2 = 6300 W = 6.3 kW.
2. 1201 hours x 6.3 kW = 7566 kWh
3. 7.566 : 3.5 = 2161.7 kWh
4. 2161.7 kWh x 0.24 = **€518,80/y**

---

1. 140 m2 x 70 W/m2 = 9800 W = 9.8 kW + **1 kW**
2. 1634 hours x 10.8 kW = 17.647 kWh
3. 17.647 : 3.5 = 5042 kWh
4. 5042 kWh x 0.24 = **€1210.08**
5. €1210.08 - €1098.03 = **€112.05/y**

An increase of **10.2%** a year

1. 140 m2 x 45 W/m2 = 6300 W = 6.3 kW. + **1 kW**
2. 1201 hours x 7.3 kW = 8767 kWh
3. 8767 : 3.5 = 2505 kWh
4. 2505 kWh x 0.24 = **€601.20/y**
5. €601.20 - €518,80 = **€82.36/y**

An increase of **15.9%** a year

---

1. 140 m2 x 70 W/m2 = 9800 W = 9.8 kW + **2 kW**
2. 1634 hours x 11.8 kW = 19.281 kWh
3. 19.281 : 3.5 = 5509 kWh
4. 5509 kWh x 0.24 = €**1322.16**
5. €1322.16 - €1098.03 = **224.13/y**

An increase of **20.4%** a year

1. 140 m2 x 45 W/m2 = 6300 W = 6.3 kW. + **2 kW**
2. 1201 hours x 8.3 kW = 9968.3 kWh
3. 9968.3 : 3.5 = 2848 kWh
4. 2848 kWh x 0.24 = **€683.54**
5. €**683.54** - €518,80 = **164.74/y**

An increase of **31.8%** a year

Figure XX: HP estimation model for power consumption and costs.

Personal Heaters

Room heaters are focussed on the volume/area of a room. The average heater has a **P = 1500 W.** To compare yearly costs a quick hand-calculation has been executed below:

Power consumption and running costs assumptions

Suppose the heater is being used only on cold days. Cold days is generic however we could assume that the heater is being used on the autumn and winter months. That would be 179 days and suppose using the heater on a daily basis for 8 hours straight.

t = 179 x 8 = 1432 hours.

P_{high} = 1.5 kW, P_{medium} = 1.125 kW and P_{low} = 0.750 kW

E = P_{high} x t = **2148 kWh** ⟶ Costs = 2148 x 0.24 = **€ 515.52/y**

E = P_{medium} x t = **1611 kWh** ⟶ Costs = 1611 x 0.24 = **€ 386.64/y**

E = P_{low} x t = **1074 kWh** ⟶ Costs = 1074 x 0.24 = **€ 257.76/y**

Room heater retail price estimation: €67.85

3 heat settings (low/medium/high)

P = 750, 1125, and 1500 watts

Ori running costs

t = 179 x 8 = 1432 hours.

P_{high} = 0.160 kW, P_{medium} = 0.140 kW and P_{low} = 0.120 kW

E = Phigh x t = 229.12 kWh ⟶ Costs = 229.12 x 0.24 = **€ 54.98/y**

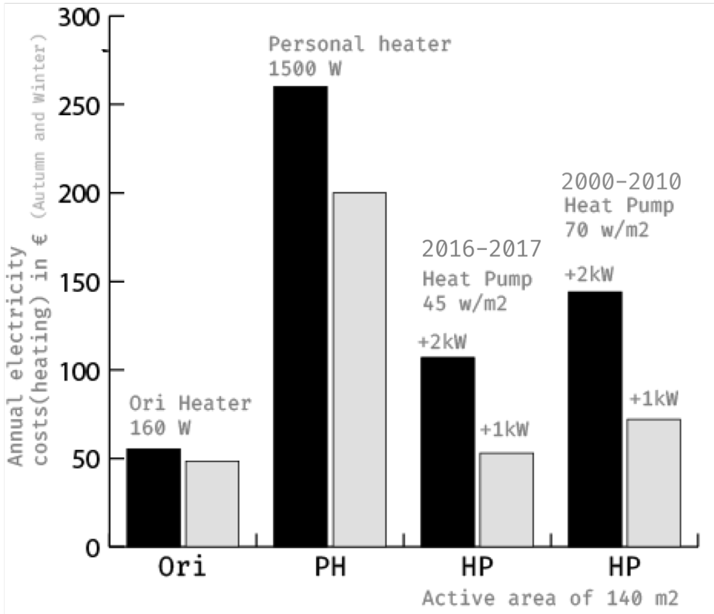
E = Pmedium x t = 200.48 kWh ⟶ Costs = 200.48 x 0.24 = **€ 48.12/y**

E = Plow x t = 171.48 kWh ⟶ Costs = 171.48 x 0.24 = **€ 41.24/y**

Ori retail price estimation: € 126.20

Annual electricity vs heating systems

Below a graph has been constructed to compare HP system at two households(2000-2010 to 2016-2017), personal heater and the Ori. The comparison seems valid; All heating system use electrical energy for heating. Though each system has a different energetic value(heating) due to heat transfer. The HP and the room heater for instance offer heating trough Air and is depended on room area/volume. The ori for instance offer heating trough radiation. To what extent is this graph below valid? And is there a way to make a more realistic comparison? These questions need to be answered but are not within the scope of this project.



The SCOP also called SPF gives the Coefficient per year over 4 seasons.
With an SPF/COP of 1, the heat pump gives off as much heat as it uses up in energy. Electric heat pumps for heating today have a COP between 3.5 and 5: the efficiency is therefore between 350 and 500 percent. The COP for hot water is lower (2 to 3.5) because a higher temperature is required (58 degrees). The return for this is therefore 200 to 350 percent.

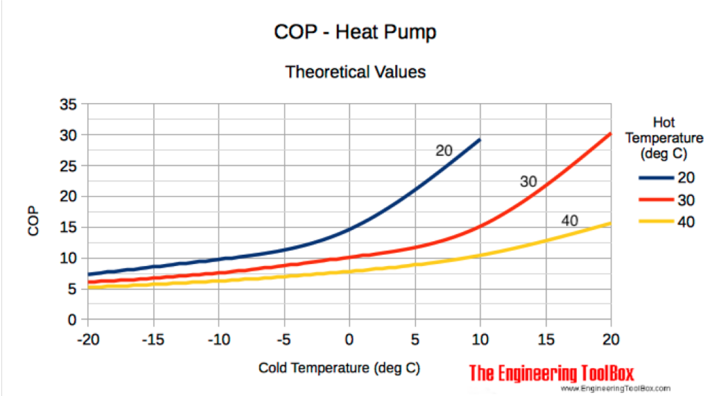
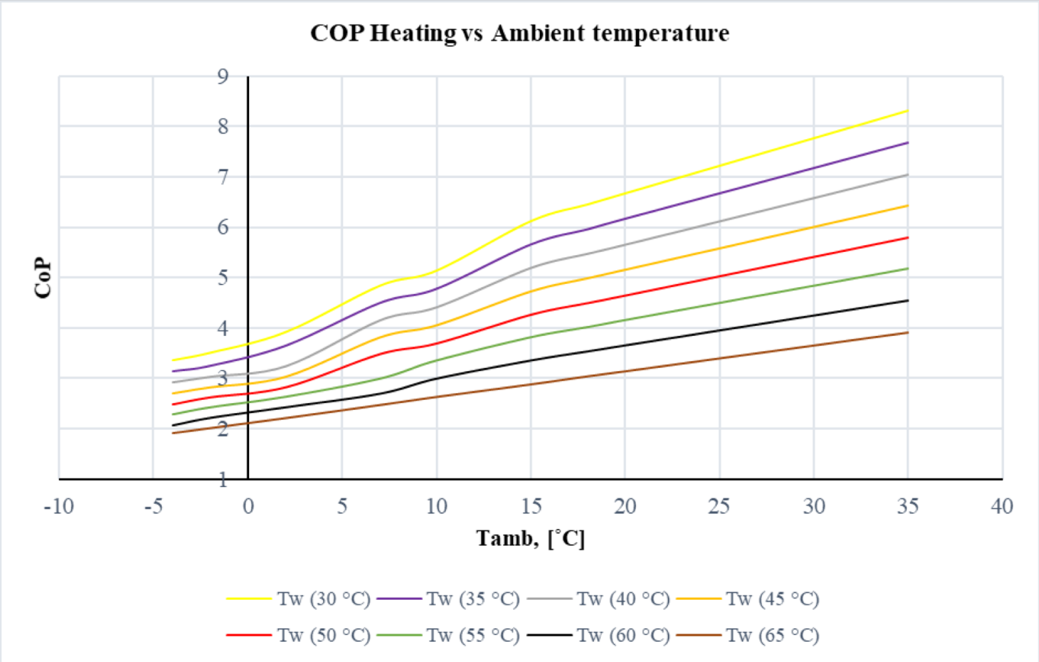


Figure 9: Engineering ToolBox, (2008). Heat Pumps - Performance and Efficiency Ratings. [online] Available at: https://www.engineeringtoolbox.com/heat-pump-efficiency-ratings-d_1117.html



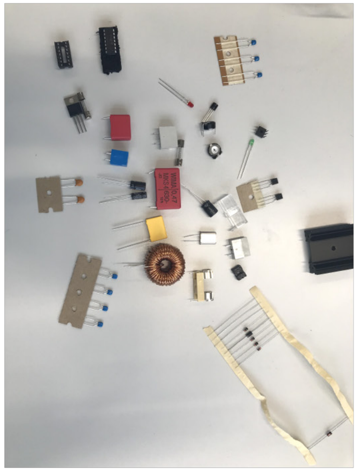
The COP (Coefficient Of Performance) indicates the efficiency of the heat pump: the ratio between the amount of energy that the heat pump releases and the amount of energy that the heat pump absorbs.

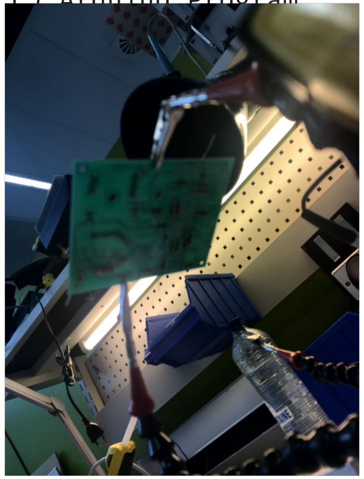
Appendix H

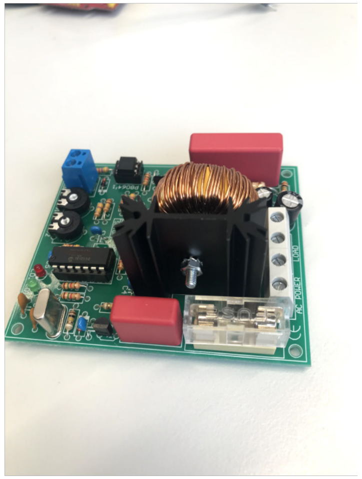
c) Arduino Program

Working

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







```
#include <Wire.h>
#include <math.h>
int a;
float temperature;
int B = 3975;
float resistance;
int PowerPin = 6;
void setup()
{
  Wire.begin();
  Serial.begin(9600);
  pinMode(PowerPin, OUTPUT);
}
int reading = 0;
void loop()
{
  Wire.beginTransmission(112);
  Wire.write(byte(0x00));
  Wire.write(byte(0x51));
  Wire.endTransmission();
  delay(70);
  Wire.beginTransmission(112);
  Wire.write(byte(0x02));
  Wire.endTransmission();
  Wire.requestFrom(112, 2);
  if (2 <= Wire.available())
  {
    reading = Wire.read();
    reading = reading << 8;
    reading |= Wire.read();
    Serial.print(reading);
    Serial.println("cm");
  }
  delay(250);
  a = analogRead(0);
  resistance = (float)(1023 - a) * 10000 / a;
  temperature = 1 / (log(resistance / 10000) / B + 1 / 298.15) - 273.15;
  delay(1000);
```

```
    reading |= Wire.read();
    Serial.print(reading);
    Serial.println("cm");
  }
  delay(250);
  a = analogRead(0);
  resistance = (float)(1023 - a) * 10000 / a;
  temperature = 1 / (log(resistance / 10000) / B + 1 / 298.15) - 273.15;
  delay(1000);
  Serial.print("Current temperature is ");
  Serial.println(temperature);
//wanneer er stroom is --> display(laten zien dat aan is) aan en continu weergave van temperatuur verwarming. Initialiseren
//Initialiseren systeem ledjes van manual en automatic knippert 1 keer.
//Gebruiker: als knopje gedrukt van manual dan automatic uit -->
//Gebruiker: als knopje gedrukt van automatic dan manual uit -->

//manual
//Beveiliging: Automatisch uit wanneer iemand weg is
// Instel temperatuur invoeren/ Omhoog en omlaag knopje correspondeert met vermogen

//automatic
//Beveiliging: Automatisch uit wanneer iemand weg is
//Hieronder verschillende standen die over en weer schakelen.

  if (reading >= 150) {
    analogWrite(PowerPin, 0);
  }
  else if (reading >= 10 && reading <= 20 && temperature == 70) {
    analogWrite(PowerPin, 64);
  }
  else if (reading >= 21 && reading <= 39 && temperature >= 50 && temperature == 70) {
    analogWrite(PowerPin, 128);
  }
  else if (reading >= 40 && reading <= 100 || temperature < 70) {
    analogWrite(PowerPin, 255);
  }

}
```