Design of a stand-alone presence aware infrared heating product for office

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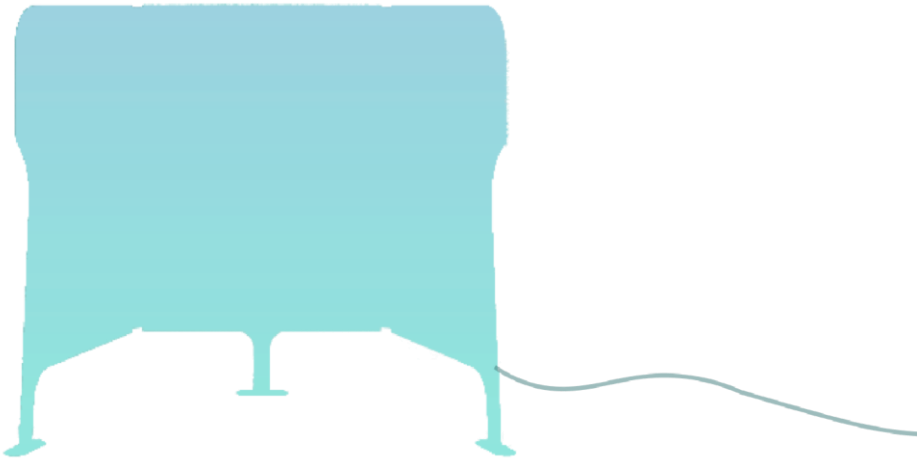

ABSTRACT

Energy saving is becoming a topic that has been widely discussed. By 2050 all ofice buildings according to EU plans should be energy neutral. This implies a large potential for more eficient solutions, such as occupancy-aware local heating. Based on this idea, OficeVitae developed a vertical heating panel for use in ofices using carbon infrared heating ilm. This thesis collaboration between Ofice Vitae, a startup based in Delft that focuses on the vitality of employees in the ofice explored the possibilities of implementing person detection technology into the local heating system.

The project started with the market and the trend analysis to identify the space for the product in the market. Then followed with the context exploration with targeted users through context mapping and interviews to gain insights for requirements from the ofice context and the interaction. The result shows a less obtrusive and simple looking is favored at the ofice, physical interaction is preferred in an ofice environment, the interaction quality is simple and direct with less learning time based on the analysis from insights cards gathered from the interviews. After that, researches of relative topics were accomplished as well, human thermal comfort sensation and the presence detection technology were explored in order to ind the most suitable heating and sensing solutions. The infrared heating ilm selection and analysis of how to ensure the amount of infrared heating is done. Meanwhile, the PIR sensor was selected as the most promising and feasible solution for presence detection.

After setting the design criteria and requirements, through 4 design cycles, from concept generation, technical challenge validation of presence detection, interaction design between product and users, to the inal concept elaboration. During each cycle, extensive user tests were conducted to collect suficient data for further development. Within cycles, the heating strategy, overall ergonomics preference, and the interaction method were deined and elaborated.

The project is inished with a standalone conceptual product that could sense occupancy presence and provide heating accordingly to avoid unnecessary heating in winter. The product is controlled by a reachable, simple, and direct control unit that allows workers to personalise temperature around the working area to have higher control of the workplace while saving energy by lowering the ambient temperature.

Although a working prototype is not built in this project, extensive evaluations and tests with low idelity prototypes validated the feasibility of the inal design. To conclude the research, a list of generic indings, limitations of this project, and recommendations for further development are provided.

ACKNOWLEDGEMENTS

I would like to thank my chair, David Keyson, for providing me this project during my tough time. Your guidance kept me sharp and encouraged me to look back on my indings to identify what are the key problems and ind out the most feasible solution to continue with. And my mentor, Wilfred van Vegte, thank you for helping me spark insights from different perspectives and support me all the time. Then the company mentor from OficeVitae, Marcel Verbraak, and your experience and network lifted the project to another level. for their guidance and support during my project. Your feedbacks provided during each discussion always inspired me and motivated me to push myself.

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Last, thanks to all kind help from participants who were involved in the project, especially thanks to my family and boyfriend Zhi, thank you for all the loving support, I could not have pulled through without you.

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HVAC	Heating, Ventilation and Air Conditioning

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Important are highlighted like this

ART I I TR TI

1. Introduction of the project

This master thesis presents the inal results of the graduation project of the master Integrated Product Design at the Faculty of Industrial Design Engineering at the Delft University of Technology. During this project, an integrated smart heating product was designed for the startup OficeVitae.

1.1 Client introduction - OficeVitae

The main client in this project is OficeVitae, a startup located in Delft Bouwcampusas the igure 1 shows. The main vision of OficeVitae is "Vitality at work" as the igure 2 shows.[1] They measure all relevant comfort and vitality factors in the building and around its users. Then visualize and analyse all this data and from these insights, they come up with meaningful recommendations on how to improve Vitality at work.

After several years of research and development, OficeVitae ventured into the infrared heating industry. Mainly investigating how local heating and infrared heating solutions can contribute to energy savings and increased occupant comfort levels. And they have tested infrared heating solutions at Province of the south holland, University College London, and other buildings.

Among different solutions, the earlier infrared heating panel concept was released for the pilot test in several months ago as the igure 3 shows[2]. In this graduation project, OficeVitae wants an integrated solution of a new panel design with a personalised temperature control unit and the smart feature of detecting human presence in the ofice. After this project, the prototype could contribute to the later winter pilot test in December 2020. And hopefully, the irst inal products will be produced in the nearby future.

Figure 1: OficeVitae ofice

Figure 2: Key aspects around vision

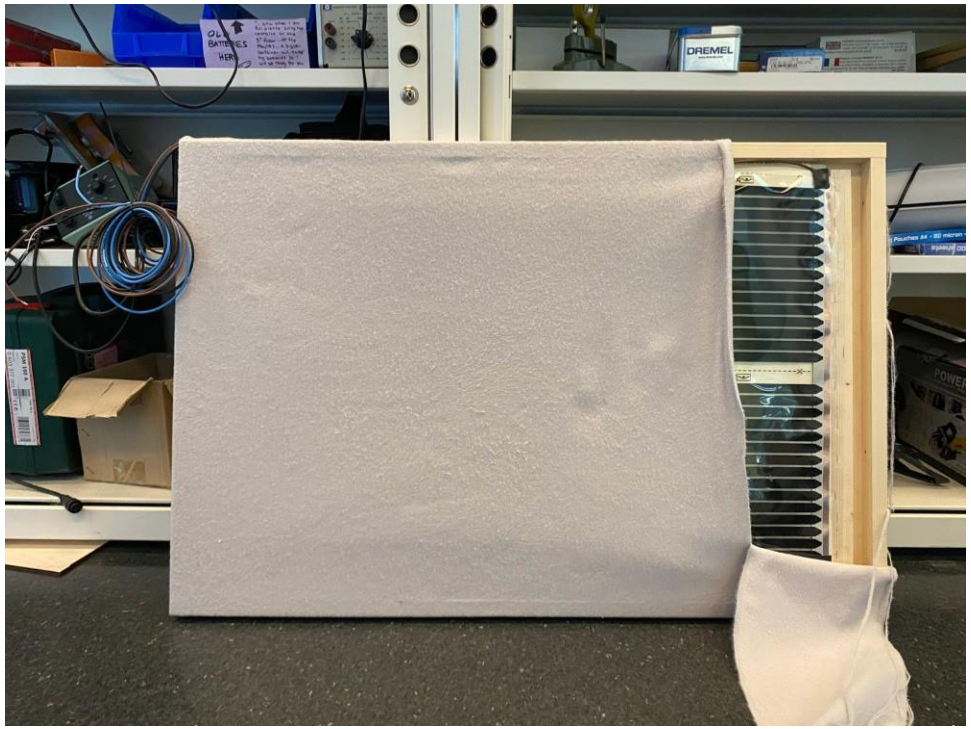

Figure 3: The starting heating panel idea from OficeVitae

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1.2 Background

A Pilot study: "User-Centric Building Interaction (UCBI)" also carried out in the Provinciehuis Overijssel by OficeVitae as the igure 4 shows. It is an objective pilot study: to investigate whether energy savings and/or a reduction of the CO2 footprint can be achieved by applying infrared heating panels (under the desks) that can be operated locally (per workplace). The panel is controlled by a ipping button placed on the desk as the igure 5 shows. Data is uploaded and stored through the LoRa network and antenna system provided by Karbonik[3].

The results were positive. Based on the calculation, energy costs could potentially be reduced effectively by applying local infrared heating.[4] More important is that there is no real difference in comfort between the local heating zone with a lower ambient temperature compared to the control zones.

From the inal result report, OficeVitae also validated that the overall quality of comfort is slightly higher in the areas with local heating. The sense of control is also higher, which can be attributed to individual control of heating afforded by the infrared heating panels. With the early pilot test, the basic energy-saving principle and infrared heating ilm technology are reliable and trustable.

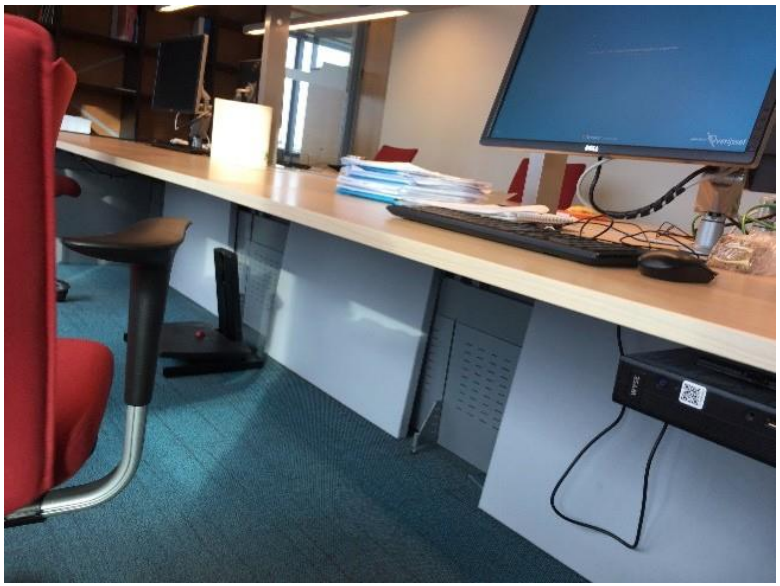


Figure 4: Pilot test with the heating panel

Figure 4: Pilot test environment set up

1.3 Problem deinition

Figure 5: the current product inner structure, fabric cover ixed with stampers

Figure 6: a thermistor for panel temperature monitor

Figure 7: the ipping on and off control unit

As igure 5 shows above, the initial prototype of the heating panel is 58cm per 85cm (without stands), it has a 100% wooden structure, covered by ireproof textiles for safety reasons. The wattage of the current infrared heating ilm is around 170w (the manufactured heating ilm provided by Karbonic). This panel has a surface temperature higher than 70 degrees celsius when turning the power on. There is a temperature sensor placed in the center of the panel for safety reasons as the igure 6 shows.

It is obvious that the overall design of the prototype is rough and at a low level, such as wires on the ground, uffy fabric, wooden structure, etc. Secondly, the control unit is at a low level as well, the user is only able to turn it on or off, the employee is not able to personalise the local temperature. Another insight of the current control unit concluded from the previous pilot test is that the manual ipping control as the igure 7 shows which might cause unconsciously energy waste due to people's carelessness, such as forgetting to turn off the energy switch when people leave seats for meetings or leave the ofice.

In short, the major problems of the earlier prototype are:

1. The personal control unit design needs to be investigated and developed.
2. The smart feature of detecting human presence needs to be implemented.

Thus, the challenge is not only about implementing sensing technologies into the heating product but also about how to design the control interaction between oficce employees and the smart heater in the ofice.

1.4 Initial assignment

The initial design assignment is formulated as following:

To develop a standalone portable unit with embedded electronics, presence aware sensors, and a physical user interface to enable personalise temperature control.

The expected outcome of the project would be a design concept along with a functionally working prototype (product/product-system) in low energy consumption, which can sense the human presence of the local working space. The product can be easily used by the employee in an open ofice environment.

1.5 Research questions

Based on the problem deinition and the initial assignment, research on the following 3 topics should be answered:

1. What is local infrared heating in the open ofice context?
    a. What is the context?
    b. What are current local infrared heating solutions?
    c. Who are stakeholders?
    d. What should OficeVitae target on as a Startup in the infrared heating market?
    e. What kind of infrared heating product is needed in the ofice context?
    f. What kind of local infrared heating is needed?
2. How to implement the presence aware smartness?
    a. What is infrared heating?
    b. What are the available sensing technologies currently?
    c. What kind of automated occupancy sensing is needed in the ofice context?
3. What kind of interaction should be designed for employees while using the smart heater at their local working place?

1.6 Approach

The igure 7 shows the design approach. During the research phase, The Design Thinking and Lean Startup has been used in the project. This approach combines two exible models to reduce the risk of failing. With this methodology, the designer starts from the original design brief, then explores potential design opportunities while empathising with users to deine related design principles and criteria. After that, ideas will be generated and transformed into design directions and concepts and move to the next cycle.

The project explores complex issues about local heating in the ofice through 4 design cycles. Each cycle is set from building the prototypes, trying experiments, to measuring relevant data, and exploring new con icts. All phases used a feedback loop to ensure the requirements of end-users. It further allows developers to improve product/service features based on a continuous feedback loop.

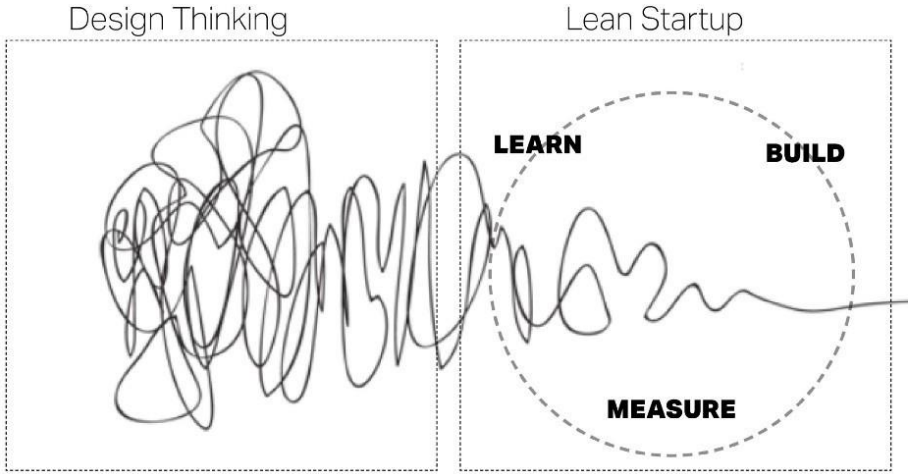


Figure7: design thinking and Lean startup approach

2. External analysis

German-British astronomer Sir William Herschel is credited with the discovery of infrared in 1800. Herschel found that red light had the highest degree of temperature change in the light spectrum, however, infrared heating was not commonly used until World War II. During World War II infrared heating became more widely used and recognized. With the widespread use of infrared, infrared heaters were invented.

After a number of years now, there has been an alternative on the market that is more compact, electric, long-wave infrared heaters. In this chapter, the market of low-watt infrared heating products, smart infrared heating product positioning, the trend, the stakeholders are explored to provide a solid context on which a design canvas can be built.

The purpose of the context study is to answer following questions:

- **What are current local infrared heating solutions'?**
- **Who are stakeholders'?**
- **What should OficeVitae target on as a Startup in the infrared heating market'?**

2.1 Current solutions

Currently, there are a bunch of electrical infrared heating solutions in the market designed for local heating. However, as of today, there are almost no organisations or companies that are offering a smart heating heater solution in low wattage for ofices or residential places. A short overview of the current solutions will be given, in order to clarify ofice demands and residential demands and position the smart product in the market.

2 1 1 ursue the electrical heaters with low wattage

The igure 8 shows various local heating solutions provided in the market. Several companies are active in Dutch market providing infrared heating solutions for home and ofice. Such as SmartHomeSupply, Infraroodverwarmingstore.nl, etc.

Different companies offer different sizes and wattage heating panels, most of them are in high energy consumption, only a few companies offer infrared heaters around 100 watts to 200 watts (4 out of 15 suppliers provide low wattage panel solution in the appendix A of the list of low watts commercial heating product), such as Aabo Greentech[5] (wellltherm), Topheat.EU[6], FENIX EcoSun infrared heating[7], and Mi-heat[8]. This inding shows that the interest in lower temperature heating is growing and several infrared heating ilm manufacturers are responding to this demand. Most of them have a simple squared appearance, and usually covered with aluminium surface or fabrics.

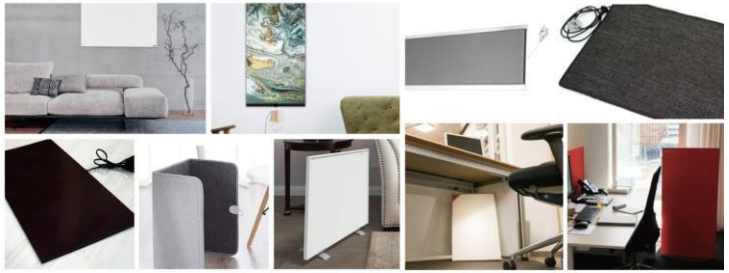


Figure 8: Low watts products in the market

2 1 2 Home ofice & Fice heating differences

Most infrared heating solution suppliers not speciically focus on households or companies, but both. There is not a big distinction between

the infrared heating products for home and ofice. However, if we look into the detailed categories, quite a few differences have existed as a home product, such as a children lock, night sleep mode, and stronger safety protection with a higher waterproof level as the igure 9 shows. The reason behind it is mainly because of the home context and the usage environment is more complex compared with an ofice environment. Apart from that, a report or a digital platform to illustrate the amount of electricity saved is popular or a selling point to the end consumers, especially in-home use heating panel markets as the igure 10 shows.

Figure 9: home heater

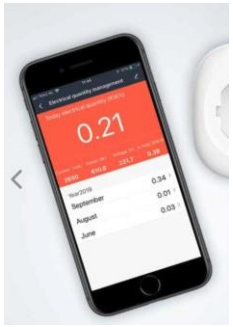


Figure 10: electricity usage report

2 1 3 Smart local heating solution in the ofice environment

PIR sensor detection

In the ofice market, the amount of smart local heating solutions is less. The most similar smart solution provided by competitors is the one from Heatfun as the igure 11 shows, they provide a local heating panel placed under the ofice desk which can connect a PIR (Passive infrared) sensor or a control unit with wires to detect the human presence and personalise the local temperature. The negative effect of this is wires and inconvenience for installation, the product itself is not well integrated.

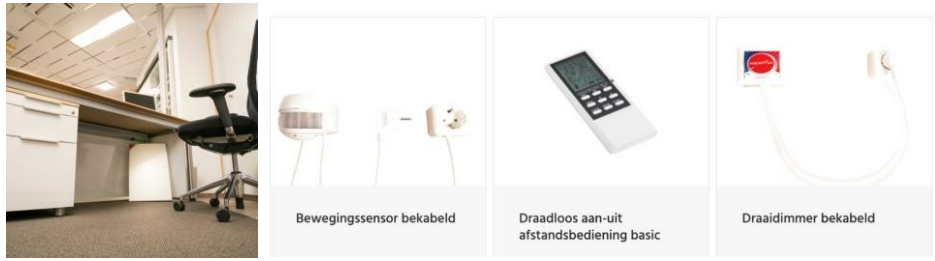


Figure 11: Heatfun local heating solution

Application support

Some smart applications supporting the HVAC system (Heating, Ventilation and Air Conditioning system) are provided in the market as well. To achieve more personal heating with access to local temperature, Smartspaces has developed a smart democratic HVAC control system that can adjust the air quality measures as igure 12 shows, whereby occupiers can vote on the ideal working environment for everyone. This system is smart and automated which can reduce and switch off climate control in less populated areas as people begin to leave, reducing energy spending, adjusting the warmth of each room in the ofice. It is not an integrated system with a local heating system, but as a service to help the general climate system of the ofice.

Figure12: heatfun smart infrared heaters

Local heating & lighting embedded within ofice furniture and the system

TNO has developed a smart local environment adjusting system with Ahrend in 2019.[9] The igure 13 shows the heating element and the system has been integrated into the desk. There is a presence sensor under the desk. It is installed to automatically shut down the heating and the lighting system in the event of a prolonged absence. The system is not switched off if the user leaves for a short period of time, e.g. for a coffee break, within an hour's time.

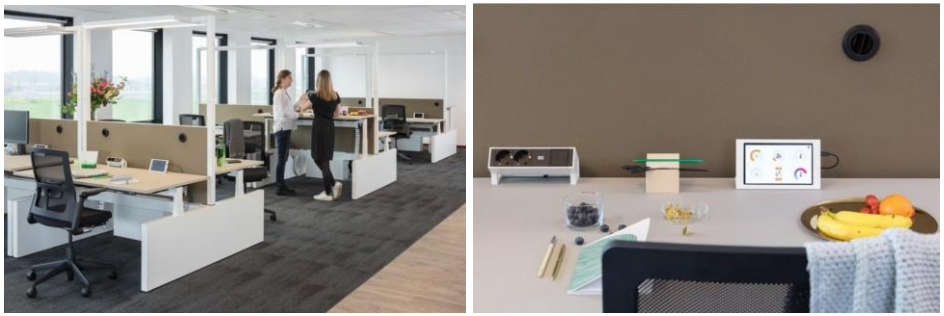


Figure 13: Ahrend integrated ofice environment control system

The result showed that up to 10% of energy can be saved form this system, mainly from the lighting, not much heating energy is saved probably because of the long interval time: the local heating system will turn off if no presence is measured within 1 hour.

Recommendations from this research are: The personal climate system is fully electric, making a plug and play application possible. This is particularly interesting in order to reduce the comfort level and energy performance in existing ofices at a relatively low cost. Secondly, information to users and adjustments in user behaviour is necessary to make the system work optimally.

Although this design is integrated and perfectly embedded into the ofice environment, it requires a lot of communication with the ofice layout, system construction, and cooperation with ofice furniture companies will cause high expenses and costs which might unaffordable fro all companies.

Individual thermal comfort system

Figure 14: Ronald Zeelen's test setup environment

In 2012, a research carried out by Ronald Zeelen[10] focused on the application of an ICS (individual comfort system) in ofice environments as the igure shows the test setup. The ICS enables each user to realise their own thermal comfort, reducing the number of comfort complaints to zero. And in cold ambient conditions (winter situations) when the ICS is used for local heating, energy saving of 3-12% is possible. The actual height of the savings depends on the characteristics of the ofice building and the existing climate system. From this research, the local thermal environment adjusting can reduce the dissatisfaction of uniform thermal conditions in the ofice and save energy. However, the complex set up and the low adaptability of the ofice environment shows its limitations of having multiple heating elements around the user in the real environment. This research also mentioned that it is crucial that user interaction needs to be

integrated into new systems to be developed in the future. Highlighting the importance of an all in one solution.

SPOT: smart personalised environment system[II]

SPOT is created by Peter Xiang Gao and S. Keshav which is a smart local environment detecting system combined with thermal comfort. SPOT relies on a new model for personal thermal comfort called the Predicted Personal Vote model.

This model quantitatively predicts human comfort based on a set of underlying measurable environmental and personal parameters collected by a set of sensors as the igure 15 shows, including a Microsoft Kinect, to measure the parameters underlying the PPV model, then controls heating and cooling elements to dynamically adjust the indoor temperature to maintain comfort. However, in reality, from the construction perspective, a startup needs to invest a lot to install this system with the agreement from the company, and the hardware installation in the real ofice environment requires a longer negotiation and building process which might not be a realistic solution for OficeVitae from the cost aspect.

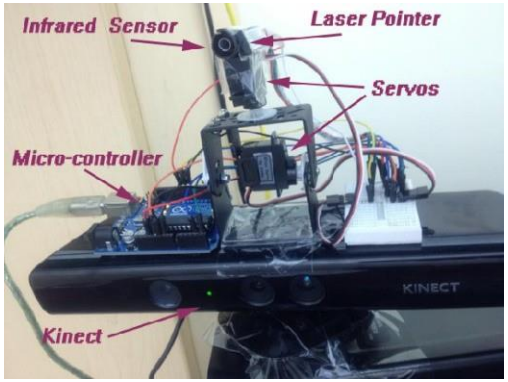


Figure 15: components of the SPOT system

2.2 Solution proposition in the market

By re ecting Segmentation-Targeting-Positioning and the Ansoff Growth Matrix as the igure 16/17 shows. As mentioned in the previous chapter, the potential of using the electrical heater to replace the conventional climate system in old buildings is large and worthwhile. The most potential and attractive market for OficeVitae is a local heating with a higher smartness integration level with an appropriate price aimed at the ofice market.

After several discussions with OficeVitae about segmentation, targeting, and positioning. The conclusion is that OficeVitae could sell new products to existing customers. In this way, as a startup company will have a lower risk of exploring the smart product. OficeVitae can have a general outline to achieve growth in the product development direction. Unlike the B2C business model, which directly sells heating products or services to employees, B2B is more feasible for OficeVitae as a startup in the earlier phase, since OficeVitae has many warm connections with organisations and companies which could be a bridge to venture into the ofice segment easily. Selling energy-saving personal infrared heating products to the company, and promoting the smart local energy-saving heating models. Especially targeting those companies who are located in the old ofice buildings, want to save energy from the conventional heating system in the long winter.

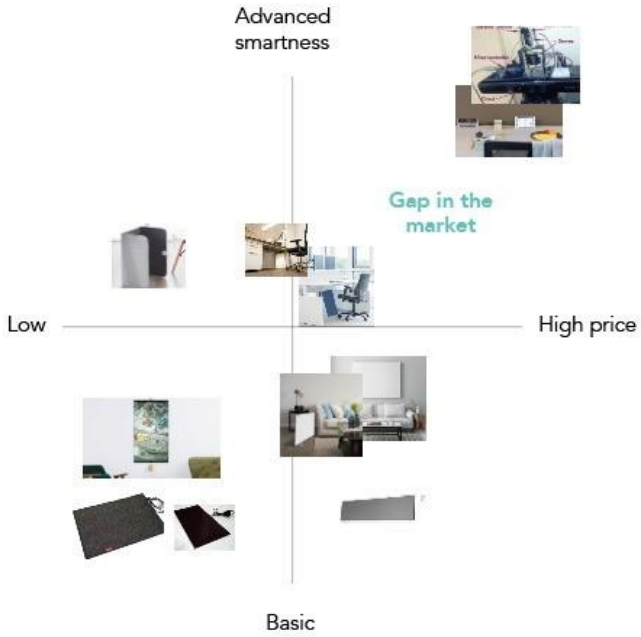


Figure 16: Positioning in the market

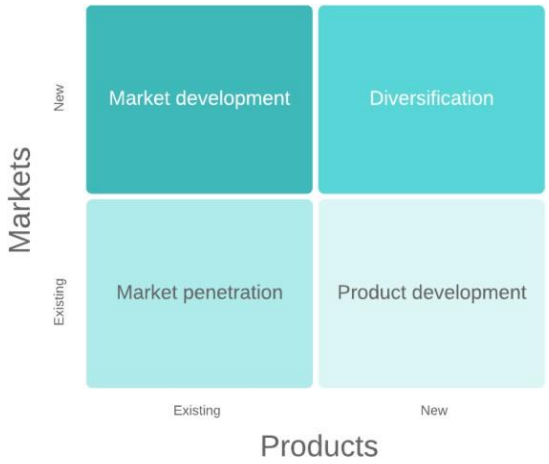


Figure 17: Ansoff growth matrix

2.3 Trend

The main context of this project is an open office environment. The time frame is not focusing on the far future, therefore recent trends of the office were analysed to minimise or rule out future obsolesce of the product. Furthermore, the standalone heater could be considered as an office furniture as well, therefore the trend of office furniture was also analysed, to find the potential requirements of the local heater production.

2 3 1 Green in office

Ecology is a popular subject today. Companies have been increasingly moving to green product designs where they are using reduced amounts of heavy metals and other toxic materials. Also by incorporating more recyclable components such as composite materials with natural resins; furniture can be ecological.[12]

Composites have become increasingly popular because of their multi-functional qualities. Carbon fibre is becoming an increasingly popular material for furniture design, due to its light weight relative to its high strength. Fibres can be used in many ways like knitting and braiding to have different forms. The rigidity of the fibers are maintained by coating or immersing them in resins of different kinds like epoxy, polyester or polyurethane. Each of the resins gives them a different property like toughness or flexibility.[13]

Office furniture supplies are focusing on using local materials, recyclable materials, updating the recycling circularity of office furniture, and even generating new products as a service rental model to serve the future market.[14] Such as the figure 18 of Humanscale ergonomic chair shown below, using fewer parts and recyclable materials, aluminum and steel in products to limit their potential impact. The Durability and Upgradeability of products are also considered - they build products to last, they won't need to be replaced often.[15] In short, companies and manufacturers are taking sustainability as a more and more essential factor when judging a product placed in the office environment.

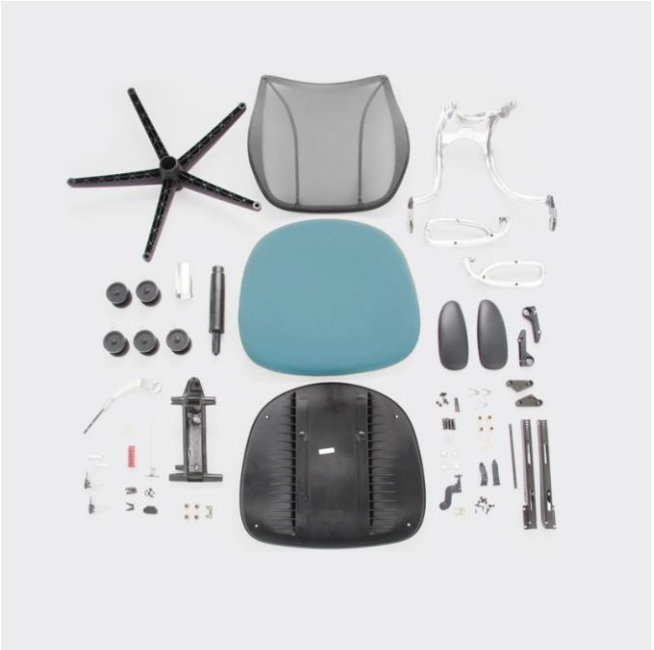


Figure 18: Humanscale chair

2 3 2 Smarter energy solution during the epidemic

In Europe, working from home is not a new thing. However, due to the epidemic over the world and government policies[16]people have to keep a 1.5m distance as the figure 19 shows. And work from home as much as

possible. It seems likely that ofices will change from 'the place to get things done' towards an 'attractor' for employees and collaborators alike in the post-pandemic world. It means the reason for coming to the ofice is transforming from a mono-purpose 'get-things-done' place towards a multifunctional, exible hub as the igure 19 shows, for meaningful interaction and collaboration.[17] This leads to space eficiency and increased collective productivity; maintained collaboration and improved cost management.

Figure 19: Employees could be monitored to make sure they observe the six-feet rule at all times.[18]

Figure 20: Kolektif House, Sanayi, Levent, istanbul

Thus, in this epidemic time, the ofice will not disappear but evolve[19]. What is more, demand for ofice space might decrease in the post-coronavirus reality due to a general upswing of people working from home. How the company eficiently allocates company resources (electricity, gas, rent, ofice furniture, etc) becomes the main task. The ofice needs to be more eficient especially about energy use since there might be fewer people in the ofice. It makes no sense to warm the whole ofice if there is only one person working in the ofice. In this project, a employees' workplace local heating solutions might help with the situation.

2 3 3 lexibility and personalization as we've never known it

We can see that multi-functional space is required for an eficient and dynamic ofice today. Ofice furniture incorporates an entirely new generation of moveable, multi-functional, lightweight, and ergonomic elements designed to it any space and purpose. [20] From movable walls and lightweight, mobile furniture, to adjustable lighting and technology, these spaces allow employees to transform rooms in an instant as the igure 20 shows a exible ofice in Istanbul.

Kanya stated that customization or personalization is an important factor in ofice spaces. The user will be motivated and ofice life is positively affected by the exible workstations designed to it his/her characteristics. Her research also showed that lightness, mobility, transformability, acoustics, and adaptation to the new technologies are seen as highlights of innovative furniture design for the new generation ofice.

2.4 Stakeholders

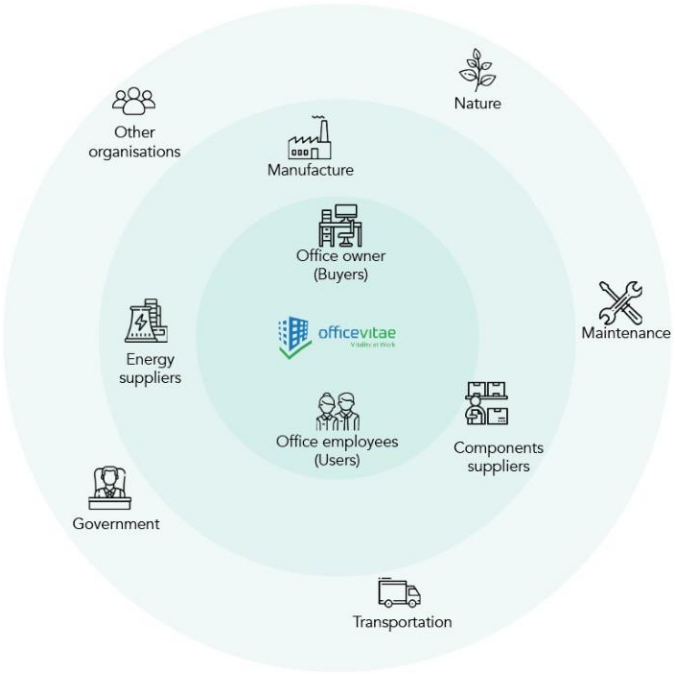


Figure 21: holders in this project

Multi Stakeholders are involved in the usage of the local heating panels in B2B business. The igure 21 presents the decision-making process and in uential parties. A company, a building, or a team decides if the heating panels should be purchased for their ofice as a sustainable heater for wintertime. The decisions can be based on the cost of the heating panel, safety regulations, building or ofice layout, employee input, and energy policy.

OficeVitae provides the heating panel to the company, needing the support of manufacturers and suppliers for the components. The heating panel can be installed by the company in an ideal situation. The technical department of OficeVitae provides further maintenance services for the company.

The installed heating panel affects a number of parties, interest parties, the user of the heating panel. For this project the major stakeholders are the end 'stakeholders' being the users, etc. and the decision stakeholders, being the company, OficeVitae, etc. The igure 22 shows the whole decision making of buying the local heater. Due to the B2B business model, the product always belongs to the company as a ixed property after they purchased it for their employees. Then the company's employees directly use heating products, which can bring warmth and comfort. And the decision making stakeholders, companies that buy the product, they pursue more energy savings, and at the same time, they hope to ensure a good thermal comfort environment without affecting the work productivity of employees. Both of them care about safety issues because electrical products often involve unpredictable damage and ires.

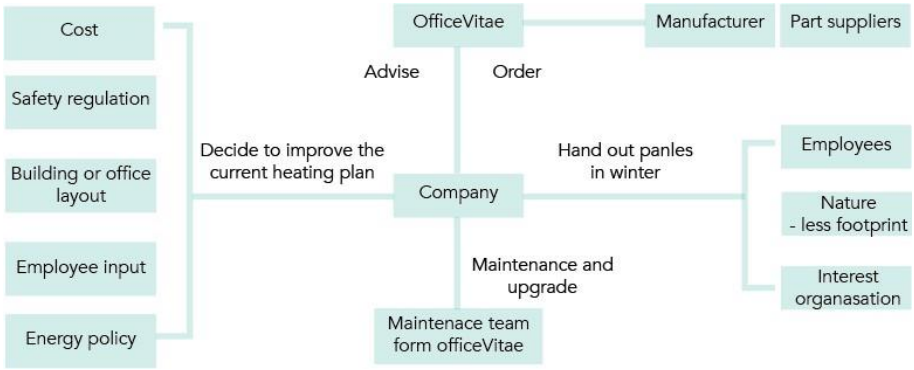


Figure 22: decision making of improve the heating system

2.5 Key insights

Following research questions were answered in this chapter:

- **What are current solutions'?**
- **Who are stakeholders'?**
- **What should OficeVitae target on as a Startup in the infrared heating market'?**

1. **Smartness of current solutions**
   Current local heater market solutions lack a higher level of smartness. It is valuable to have a well-integrated and standalone solution for the ofice environment to avoid the complex installation of the product and adapt to different ofices, which could be regarded as the main challenge of the project.

2. **Home and ofice market**
   There are some companies who already in the market and have some experience in infrared heating, there is no clear division between the ofice and home market. They are targeting both markets, but products might be different from each other, mainly because of the user context, at home, safety issues will be more considered.

3. **Strategy for OficeViate**
   From the stakeholder analysis, currently the ofice market is easier to approach for OficeVitae. It is valuable for OffceiVitae to focus on B2B since OficeVitae could use the existing warm relationship with other organizations to reduce the cost of venturing into the market as a startup.

4. **The changing of ofice**
   The trend of ofice is rapidly changing, due to the epidemic, all working rules are changed to adopt the current situation. However, the ofice will not vanish after the epidemic but evolve, becoming a more collaborative and dynamic space. Personal workplace in a shared space and individual ofice working time will be more exible and personal; it requires the product to be exible, smart, personal, light weight as well. And another trend of the products designed for ofice is becoming more and more "green", by using sustainable material and easier for disassembly.

5. **Stakeholders**
   From the stakeholder analysis, if we look into the ofice heating market, the main users are employees in the ofice, therefore, in the next chapter, more focus will be placed on the main user analysis and the ofice context mapping.

Reflection points

Collaborating with OficeVitae is a good opportunity for me to understand how to communicate with clients and ind the common interests with stakeholders. In the beginning of the project, although it is my irst time approaching the infrared heating topic, market research indeed helped me to get into the project faster and clearer. However, since I quitted the last project and headed into this new project too fast, I had limited time for restarting a new project, I need to consciously set a manageable scope for the project, and push the project by myself when it is needed.

3. Context study

After analysing the market and the trend of heater devices. This chapter describes interviews and surveys conducted among potential office users to see people's expectation of local temperature control experience in the office environment and the home office environment.

It is essential to understand employees local heating demands during the office journey and the control interaction preference. Therefore, context mapping, interview, and relevant questionnaires were conducted which provided subjective and objective understanding of the user interaction preference .

The purpose of the context study is to answer following questions:

- **What kind of infrared heating product is needed in the office'?**
- **What kind of interaction should be designed for employees while using the panel at their local working place'?**

3.1 Method

3 1 1 ontext mapping & Interviews

An online context mapping session was conducted with 6 potential users who had experience of working in an open ofice. Semi structured phone interviews were also conducted with 7 potential users to get more subjective insights. One of the interviews is conducted with an HR manager to have a more comprehensive view from both sides: potential users and buyers. The main takeaway of the context mapping is two journey maps as the igure The list presents how the context mapping and interviews were set up. The full context mapping results are in appendix B and interview questions can be found in appendix C.

Online context mapping set up:

- Part 1: Recall a working day in ofice and in home
- Part 2: Highlight your ideal local heating period and location
- Part 3: Ideate on the desired control method in ofice
- Part 4: Making collages of your aesthetics expectations of the heater at ofice environment vs at home environment

Interview set up:

- Part 1: Potential using scenarios at the ofice of using local heater
- Part 2: The ideal control solutions in those scenarios at the ofice
- Part 3: Expectations of local heater at ofice vs at home

Participants are able to join the context mapping session via Zoom (video conference software) and Miro (an online co-working platform). Before starting the session, each participant is asked to map out their work days at ofice and at home. The process of the context mapping is stored online, and the discussion is recorded via Zoom to help further analysis. All interviews were also recorded for further analysis.

3 1 2 Survey

Two questionnaires were released parallely. In the end, we had 55 valuable responses in total for the irst questionnaire and 45 valuable responses for the second questionnaire under the help of my mentor. The age of the respondents is mostly between 25 and 50. All participants have experience of working at the ofice. The full questionnaires in appendix D. The list presents how the questionnaire is composed:

Survey a:

- Part 1: Control preference of a local heater at ofice environment vs at home environment
- Part 2: The reason of selections

Survey b:

- Part 1: Validation heater aesthetics keywords
- Part 2: Energy awareness as an employee
- Part 3: User-wanted information form the heater

3.2 Procedure and Data analysis

Extensive insights and quotes were gathered from context mapping as the igure 23 shows. Most insights were mapped out and categorised into different groups by applying the Synthesis thinking method. Main indings are concluded in the next paragraph.

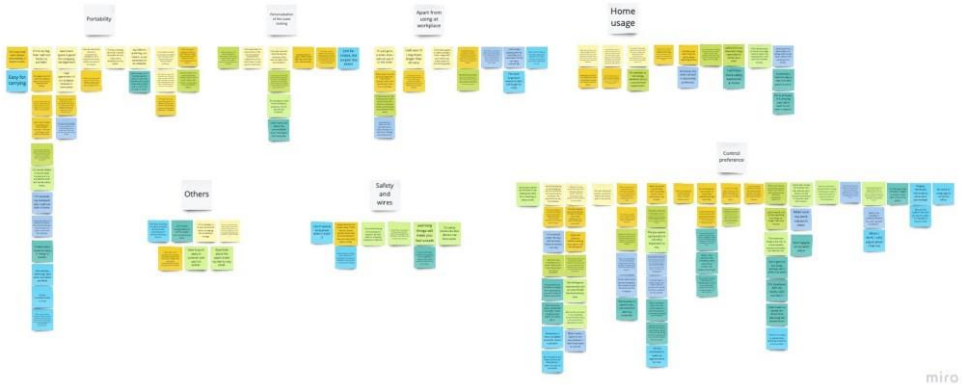


Figure 23: Insights cards from interviews categorised in different groups

3.3 Findings

3 3 1 The context of the ofice

From the interview with people who have open ofice working experience, the context of the usage environment is better pictured.

When participants were asked about the current old, conventional heating that heats the whole ofice, user behaviours look like the irst journey diagram as the igure15 shows. Not everyone will remember to turn off the heater before they leave for lunch or before they leave the ofice in real life, which means there is so much energy wasted when there is no one but the heating system that keeps working.

From the second user journey diagram as the igure 26 shows, when participants were asked about what would be the whole imagined process of using a local heater, most users will turn on the heating product after arriving at the ofice, and then directly enter the stage of concentrated work after have a cup of coffee, or they would like to have a pre-heat function to warm the workplace in advance, so as to have a warm place when they arrive. In the morning, before lunch, go back from lunch and before leaving are the most triggered moments to turn on/off the heater completely.

Both igures show they may have some short breaks during the day, such as coffee break, snack break, or go to the toilet. But all activities are close to their work desk except meeting or chatting with colleagues which might leave their workplace for a longer time. After breaks, they continue to work until lunch break. The journey in the afternoon is similar. The time for control or adjustment will be subjectively reduced especially when employees are focusing and working, because they would like to keep their focus on their major tasks: working. Actively adjusting the

temperature by employees will only happen when the temperature suddenly becomes very uncomfortable, or they will just kick it aside, as long as it is not too uncomfortable for them.

Therefore, taking too much effort to understand the control, ind the control, adjust the temperature during working are not recommended. Because this might make the product be considered as not easy to use.

3 3 2 ess phone interaction at ofice, freer methods at home ofice

In the survey a, ive different control methods were listed: the controller is installed on the control board, wireless control switch, mobile phone control, the combination of the three control methods, and others. At the same time, the interviewees who chose "other" and "a combination with the above control modes" were asked to brie y explain the reasons for their choices. The inal results of several methods are shown in the igure 24 below.

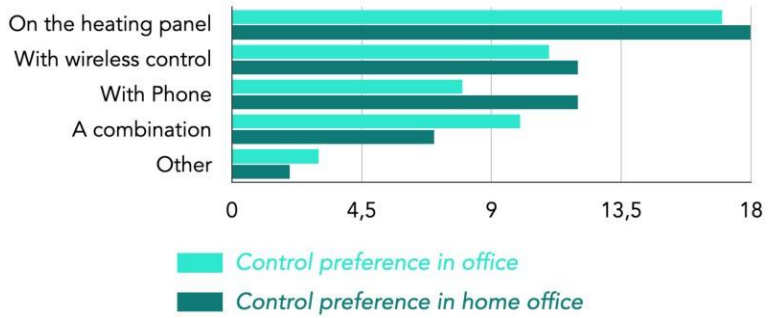


Figure 24: control method preference in ofice and home

In general, people prefer tangible control methods, such as a control unit placed on the heater. Unstable connection and possible delayed heating feedback of wireless control might be partial reasons that people do not prefer a digital method. From the comparison, it is not dificult to ind that the proportion of using mobile phones to control the temperature in the ofice is the least (8 out of 55 responses). Because using mobile phones frequently might draw their attention and reduce their productivity.

People prefer to use more personal control methods at home compared with ofice environments, such as voice control and the integrated smart house heating system mentioned in this research. Reasons are that the homework area will be more personalized and private compared to the ofice working environment, and there is no need to worry about disturbing others at home ofice. So people will choose a more personal and freer control interaction at home environment.

Partial participants chose the combination of various modes. The irst reason for this result is that the questionnaire does not specify the use scenarios, only "workplace environment" was mentioned in the questionnaire, which leads people to choose a mixture of various modes in various use scenarios to achieve the highest convenience.

Quotes: "It really depends on the scenario. If I'm resting at the bar, drinking coffee, I wouldn't carry the remote control but my phone. If I'm focusing on sth, I wouldn't want to use my phone frequently which can be a distraction."

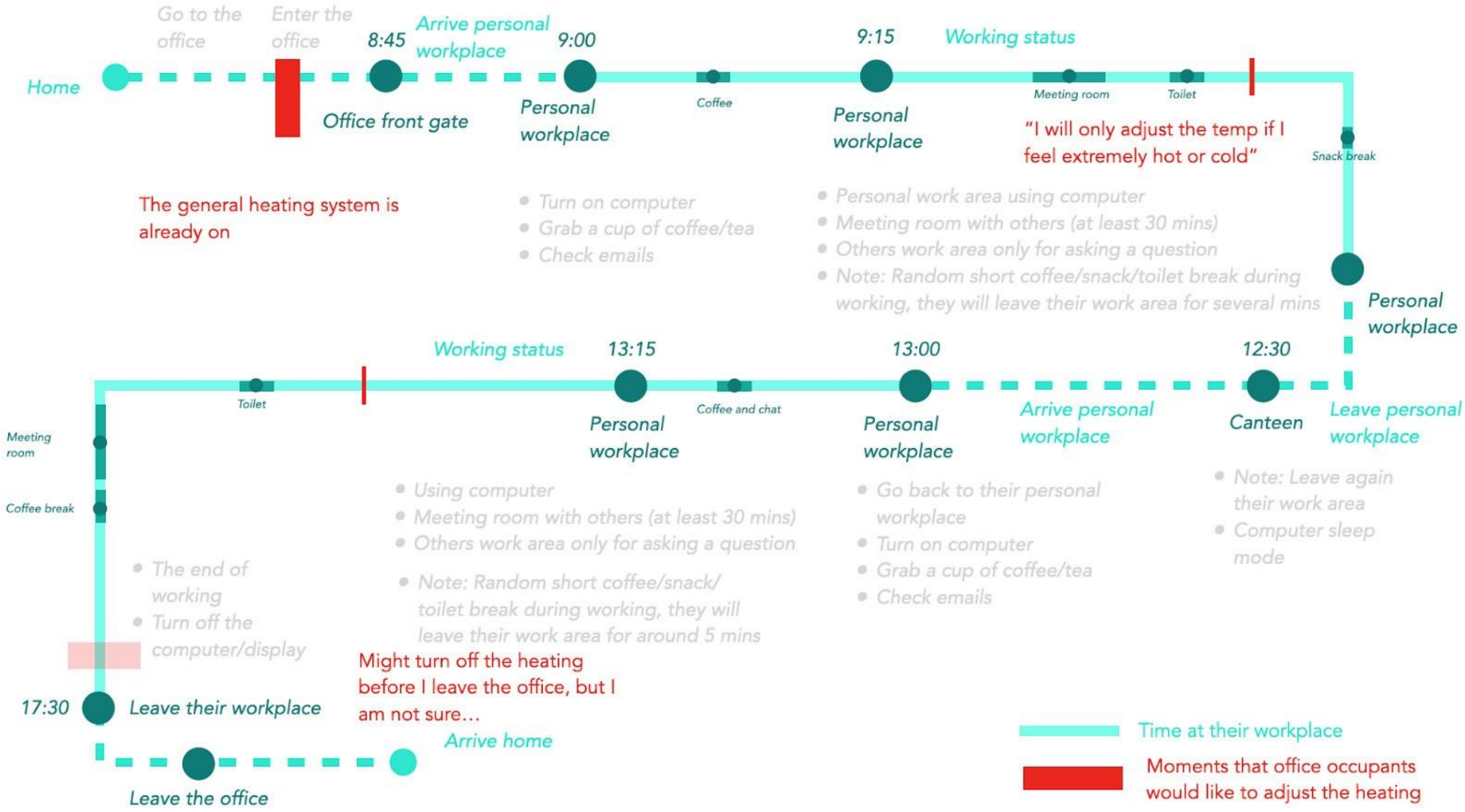


Figure 25: User journey of using a normal conventional heater in the ofice

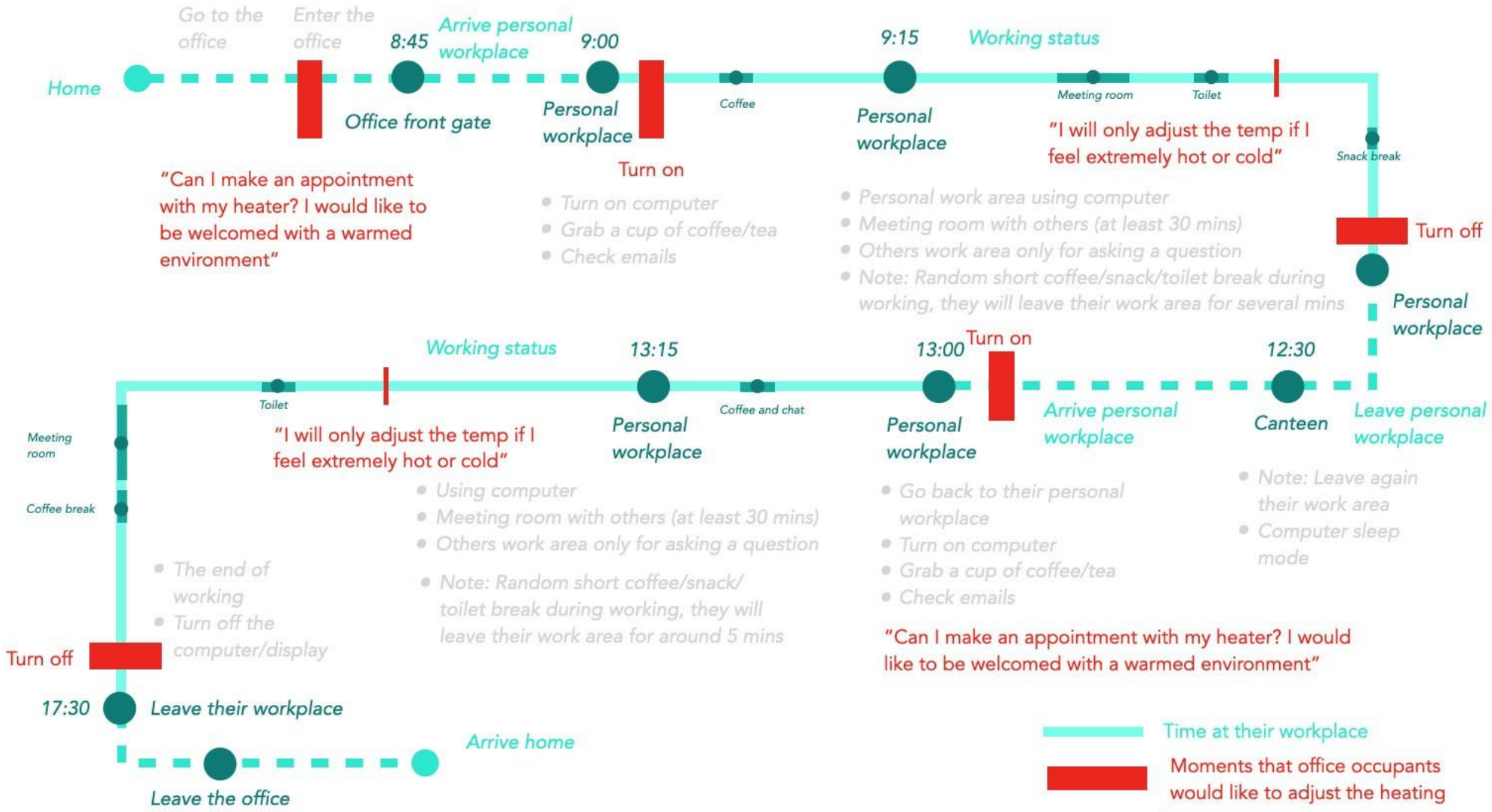


Figure 26: An ideal user journey of using a local heater in the office

3 3 3 Aesthetic preference at ofice and home ofice

During the context mapping session, igure 27 shows images provided to participants that allows them to create a mood board for ofice heater and home heater. From the inal mood boards, most commonly liked shapes are curved with adequate ilet as the igure 28 shows. A more rounded shape is preferred at home environment. Thin and looks light. Hidden in the environment is important, elegant but not stand out are the same requirements both in ofice and home ofice.

Lightweight, simple, unobtrusive are keywords for ofice heater looking which were validated with questionnaire as the igure 29 shows. Warm, kind, peaceful are keywords for a home looking. Safety looking is a common requirement in both contexts. Most people would like to have the possibility of personalisation of colours when they own this product.

Two different preferences of material among potential users, metal, resin plastic, simple fabric with cool colours which looks clean and reminds people of an ofice looking. Fabric with warmer colours, leather which represents a warm and home feeling.

Figure 27: Inspirations images

Figure 28: ofice (left) vs home (right)

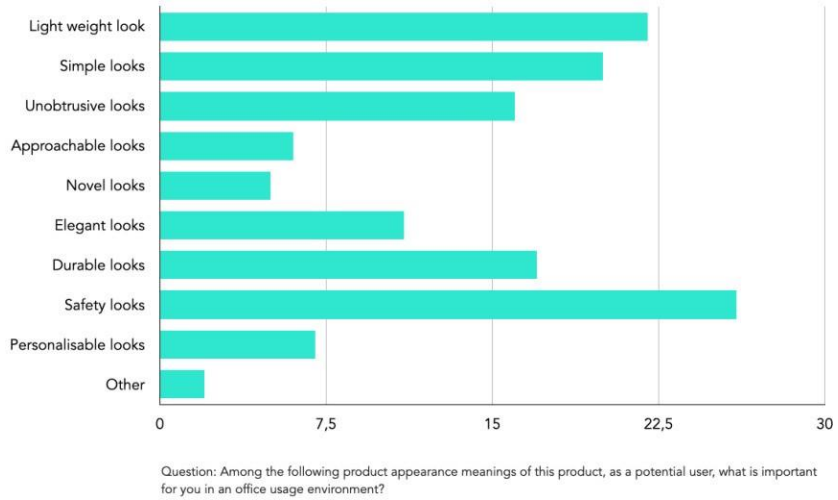


Figure 29: keywords validation

3 3 4 Thermal comfort and energy saving conflict in the office

In survey b, the question about the employee's motivations of saving energy for the office was asked. The figure 30 shows the result, most of them think they would balance their energy related decision and their own thermal comfort, but they will mainly based on their own thermal comfort once they think the energy saving behaviour will sacrifice their thermal comfort.

This result is also found in literature, Nisiforou found that everyone is familiar with the concept of "saving energy", same as employees in the office, employees say that they want to save energy and that "collectively" they are willing to take action, at an "individual" level, they are not willing to affect negatively their own comfort.[21] However, Masososand thinks changes in employee energy-use behaviour and attitudes should be considered as coherent options for cost effective energy saving. A difficult approach, yet with the potential for long-term impact. [22]

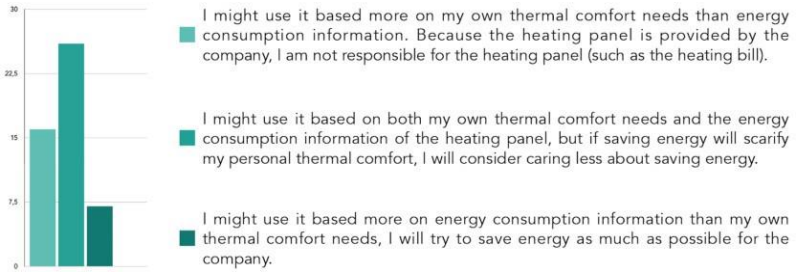


Figure 30: con ict between personal thermal comfort and energy saving

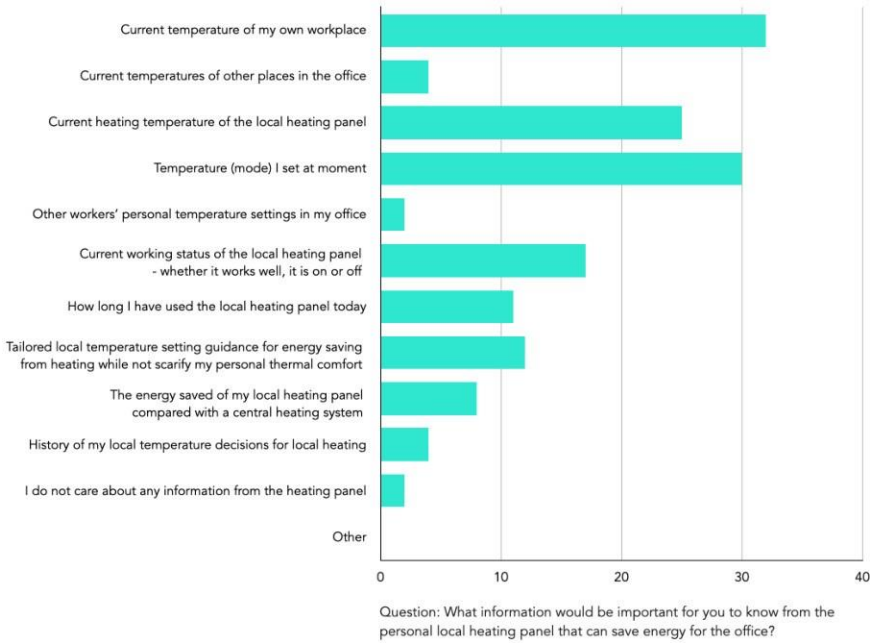


Figure 31: information related to a local heater

Besides, according to most participants, energy related information seems less important for employees when operating the heater. Figure 31 shows that most interested in information are "the current temperature I set", "the heater temperature", "current temperature of the local workplace", which is more linked to the local human thermal perception of the ambient. This information will mostly be used as references for users for a further heating temperature setting.

Thus, saving more energy by changing the energy behaviour of employees without scarifying their own comfort is a dificult task. For this project, it is more important to show users that the heater works the same as the conventional heater, providing suficient heating which meets users thermal comfort expectation. Let users understand the product is even better and smarter with an energy saving feature. So as to give the user the conidence, build the trust of using the smart heater, and probably even raise employees' energy awareness in the future, as a longer energy saving strategy.

3.4 Target end users and buyers

The heater targets ofices and buildings where the heating is still powered by natural gas or heating pump. Through mapping the context and establishing the understanding of the context, it is obvious that employees wish to establish a comfortable thermal working environment with minimum effort, without losing their productivity during working. Then a target user model of employees is built: Employees with ages from 20 up to 65 based on the dutch retirement age. The education level is high, the preferred working environment is the ofice environment. The current end user group is quite generous and wide, because the product is still in a developing and exploring market phase.

However, a general end user model can not be neglected as the target buyer of the product since the project is aiming to B2B. Most buyers are mainly executives of companies, thus an interview is conducted with an 20 years experience Human Resource manager. The end result are two buyer personas as igure 32 shows: Sophie and Jan who would like to save energy costs for the company during winter time while providing the same comfort to their employees, maintain the same productivity as before and not interfere with other ofice activities and the general ofice space. Meanwhile, some smart features were thought about for future smart design.

Figure 32: personas

3.5 Key insights

Following research questions were answered in this chapter:

- **What kind of local infrared heater product is needed in the office?**
- **What kind of interaction should be designed for employees while using the panel at their local working place?**

1. **Physical interaction is preferred**

   From the context mapping, interviews and questionnaires, the result shows that employees prefer tangible which is quick to ind, not easy to lose. Especially in the ofice environment because they would like to concentrate on working instead of being distracted by phone or other digital devices which requires time to operate. However, a freer control method could be applied in the home ofice, because people feel more casual and informal at home. After the discussion and feedback from the client, the project will mainly focus on the shared ofice environment considering the market position of the OficeVItae as a startup.

2. **Easy for use simple and direct**

   The most important thing I have learned from employees' interviews is their priority when they are working in the ofice, which is their productivity. Therefore, the product should be easy for use, quick for learning then employees can easily focus on working after they interact with the product.

3. **Aesthetic qualities**

   Lightweight, simple, unobtrusive are key aesthetic qualities in the ofice environment. More personalisable looking and warm material (wood, leather) is preferred in home environments.

4. **Buyer and user**

   Meanwhile, if we look from another perspective, from the buyer side, the product should not interfere with ofice activities and the ofice environment. Especially employees' productivity and safety are the most important issues.

5. **Energy saving awareness**

   Most employees do not care about energy saving in the office environment, mainly because they are not responsible for the electricity bill. Once there is a con ict between their thermal comfort and energy saving, most of them will irst meet their thermal comfort expectation and then consider energy saving. Thus, providing suficient heating is the base and the prioritisation of the project, however, it is valuable to consider raising their energy awareness to save more energy in the long term.

Reflection points

In this tough time for everyone, online interviews and collaborations are a new experience for me, thanks to all participants' kind help. However, due to the limited partial sample size, buyer's insights are concluded based on one interview with a human resource manager and discussions with Oficevitae. Thus, more buyer insights need to be concluded for further product development in the future.

4. Basics of human thermal comfort in office

"This is a cold winter. you come to the company early in the morning and see that no one is in the company, so you leave your backpack at your workplace and come to the overall thermostat. You are very happy to be the irst to adjust the thermostat. After you adjust the temperature that you think is appropriate, you start your working day. Colleagues come one after another, and for a while, the working colleague next to you starts to complain about "how is the indoor temperature so cold" while putting on his coat. In the afternoon, when the weather turns warmer when you return to my work area from lunch, you actually feel a bit hot. So you repeatedly adjust your clothes and maybe even open the window to make you able to concentrate on your work in a cooler environment "

The arguments of the central thermostat and the one temperature in the office for all have never stopped, therefore it is important to understand the local heating beneits and how to implement the local heating correctly and eficiently in the office environment.

The purpose of the human thermal comfort study is to answer following question:

- **What kind of local infrared heating is needed in the office?**

4.1 Temperature argument in the shared ofice

The HVAC systems have been widely applied in commercial buildings which utilise natural gas or oil to heat the air, which typically creates a uniform environment for a large group of persons. It consumes 50% of building energy use in developed countries.[23] However, high levels of occupants' satisfaction are often not achieved despite substantial energy use. It has been shown that narrowing the range of conditions of the indoor thermal environment does not bring higher than 80% satisfaction with thermal comfort[24].

According to a well-known study by Fanger, there are individual differences in experiencing thermal environments and no thermal environment can satisfy everybody[25]. The higher the number of employees sharing an ofice, the higher their dissatisfaction, and the more likely they would argue about the temperature regulation in the shared ofice[26]. Therefore, it is impossible that there is a temperature that can it all.

4 1 1 ersonal thermal comfort deinition

The reason behind the argument is individuals' thermal comfort expectations that are different from each other. By the deinition from ASHRAE standard, thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

In another word, it is a combination of a subjective sensation (how we feel) and several objective interactions with the environment (heat and mass transfer rates) regulated by the brain. (Isidoro Martinez, human thermal comfort)[27] To be more speciic, there are six primary factors that directly affect thermal comfort that can be grouped into two categories as igure shows: personal factors - because they are characteristics of the occupants - and measurable factors - which are conditions of the thermal environment. The former are metabolic rate and clothing level, the latter are air temperature, mean radiant temperature, air velocity, and relative humidity.[28]

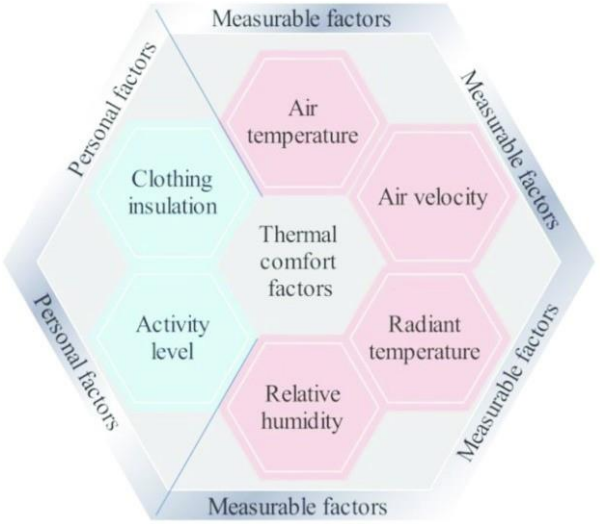


Figure 33[29]: Six factors that affect human thermal comfort perception

Apart factors mentioned previously, age, previous accommodation (e.g. changing from indoors to outdoors), habits (e.g. clothing difference among seasons and sex), personal preferences (some people feel comfortable cold or hot), and actual mood may have an in uence.[30] From the study, it is clear that an individual's thermal comfort is complex and there is no standard for everyone. This is also mentioned in Ashrae standards: Since there are large variations from person to person in terms of physiological and psychological satisfaction, it is hard to ind an optimal temperature for everyone in a given space.[31]

4 1 2 Beneits of the personal comfort system

The need for individual control of thermal environments is currently widely recognized.[32] Fanger also recommends individual thermal control can be applied to handle personal variations in thermal preference.(P.O. Fanger, 2001).[33]

A local heating device can be understood as a personalised conditioning system (PCS) that focuses on every single person's thermal demand. PCS can improve energy performance and user comfort. because the energy is deployed where it is actually needed.[34] This focus makes it also possible to improve people's subjective thermal comfort and even provide a more pleasant thermal environment. [35]

Apart from the beneit of a higher satisfaction level of the interior thermal environment, according to D.P. Wyon, individual control of room temperature is one of the central issues in improving working conditions and productivity.[36] Besides, research by de Dear and others has shown that the perceived ability to control one's thermal environment tends to widen one's range of tolerable temperatures.[37] In short, a good individual thermal control can contribute to a better working environment with a stronger feeling of the control and positively in uence employees' productivity.

4.2 Thermal comfort in a non-uniform environment

In the ideal usage context of this project, the ambient temperature remains at a low level and employees use a local heater to support individuals thermal demands, so as to save energy from the general heating system. Thus the area close to the local heater is slightly higher than the rest of the ofice. In such a non-uniform environment, how to make the user feel comfortable is an important question.

Actually, a test of using local heating products done by Deng (2016) in a non-uniform environment (16 celsius degrees) also observed that in a non-uniform cooler atmosphere, customized heating greatly enhanced human thermal sensation and comfort, possibly due to the fact that local heating can increase the mean skin temperature of the human body and the high mean temperature of the skin increases the overall thermal feeling and comfort. [38]

E. Arens and Zhang (2009)[39] found that unlike the conventional thermal comfort studies on whole-body exposure in a uniform environment where the human body is considered as a whole, people's reaction to asymmetrical environments depends on the thermal sensations of their local body parts.

They also investigated different body parts thermal sensation in a uniform cool environment and found that hands, feet, legs, arms are consistently cooler than other body parts. These body parts are the major indicators of discomfort in cool conditions. And subjects' overall comfort closely followed the most uncomfortable local body parts in a cool environment.[40]

On the contrary, in that study, E. Arens and Zhang found that people do not mind a cool sensation in the head region in cool environments but are sensitive to a warm head-region sensation in warm environments with less comfort.

Although warming the feet is very effective at enhancing comfort, there are some ergonomic issues found with the particular foot warmers used during Tabu's research test.[41] Another interesting insight from Yingdong He (2016) is that the larger heated area of body parts contributed to extending acceptable temperature range in cold environments. [42]

Given these insights into this graduation project, these results suggest that heating on extremities where it gets cold easily may eficiently improve personal thermal comfort sensation in cool environments. To avoid uncomfortable feelings generated by using a local heater, areas close to the head should remain cool and fresh with less upwards heating towards. In this way, employees could maintain a good thermal comfort perception in a non-uniform heating area. Apart from that, due to the ergonomic perspective, heat feet might not be the ideal solution.

4.3 Thermal injury by touching

During the interview, many people mentioned they will touch the heater to confirm that the heater is working correctly. Therefore, when people touch the heater intentionally or accidentally, in order to avoid burns, the overall working temperature of the panel should be restricted.

Usually an actual skin temperature of 44 degrees Celsius is regarded as the lowest temperature needed to cause damage to the skin; at this temperature, a second to third-degree scald would be reached after an exposure time of 6 hours. [43] Contacting a hot object and getting burned is a type of thermal injury that is a time-temperature phenomenon whereby the rate of tissue cell protein destruction exceeds its rate of self-repair for an amount of time suficient to terminate cell metabolism. The rate of protein destruction increases with temperature, thus decreasing the time required for thermal injury as illustrated in igure 34. [44]

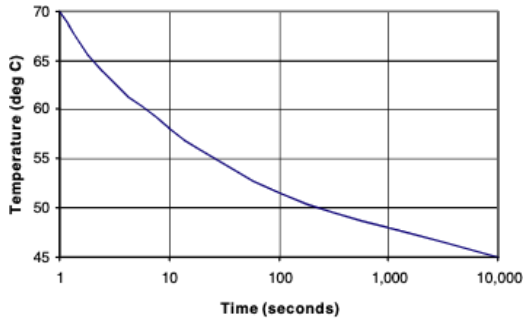


Figure 34: Threshold temperature vs. time at temperature for skin burns.

From the chart, when the temperature is around 70 degrees celsius, people can get skin burns immediately, when it reaches 65 degrees Celsius, people might get injured by the heat within 3 seconds, when the temperature becomes 60 degrees Celsius, the time for skin burns extends to 6/7 seconds.

However, the threshold time of getting burns varies with different materials on surfaces. The IEC 60950-1 (2005) standard does take into account material types and their effect on maximum permissible touch temperatures as the following table 1 shows.

Parts in OPERATOR ACCESS AREAS	Maximum temperature (T_{max}) °C		
	Metal	Glass, porcelain and vitreous material	Plastic and rubber [b]
Handles, knobs, grips, etc., held or touched for short periods only	60	70	85
Handles, knobs, grips, etc., continuously held in normal use	55	65	75
External surfaces of equipment that may be touched [a]	70	80	95
Parts inside the equipment that may be touched [c]	70	80	95

Table 1: Touch Temperature Standards[45]

From the table, it is obvious that the maximum surface temperature is the lowest for metallic surfaces and maximum for plastics and rubber due to their different thermal conductivity. However, it does not mention the factor of the thickness of the material. As an electrical heater, the surface is a thin layer of polyester fabric based on the research on the material, see the appendix E, people will touch the heater longer than a few seconds, for short periods. To avoid the unexpected injury, a proper maximum of the heating temperature and its surface temperature should not be higher than 65 degrees Celsius.

4.4 Key insights

Following research questions were answered in this chapter:

- **What kind of local infrared heating is needed'?**

1. **Beneits of local individual heating**
   Local individual heating control can not only beneit the overall thermal satisfaction level of the ofice environment but also generates a stronger feeling of control of the environment, which can eventually contribute to employee productivity.

2. **Warm lower body to rise the overall comfort level**
   The heater should cover people's extremities as much as possible, because people sense the temperature around them mainly with the skin, and a subjective thermal comfort perception is usually determined by the most uncomfortable body parts. Thus in a cool environment, extremities should be warmed since they tend to get cold and uncomfortable quickly in a cool environment.

3. **Enlarged heating area**
   By enlarging the heated area, more body skin surfaces are warmed, the thermal comfort sensation can be positively increased. Nevertheless, the head should be fresh and cool because it can feel uncomfortable easily in a warm condition. Based on these insights, a well-distributed local individual heating could maintain a good thermal comfort perception in a cool environment. A lower body heater combined with the heater under the armrest might be a potential direction for further investigation.

4. **Temperature limitation**
   People will touch the surface on purpose (check the heater working status) or by accident, to avoid the chance of getting low-temperature burns, the overall working temperature of the panel should not be higher than 65 degrees celsius.

Reflection points

In this chapter, the maximum temperature has not been decided, mainly because of limited information on speciic temperature standards for infrared heating products. According to touch temperature standards, we learned that skin burns can easily happen when a surface temperature is higher than around 70 degrees celsius within a few seconds if the surface is in high thermal conductivity. Therefore, the surface of the local heating probably should not be too warm, and it is still necessary to observe users in the practical context and determine the safe temperature range based on user feedback, which can contribute to follow-up design.

5. Technical challenges

Most modern heating systems are primarily based on the heating of air. For heating buildings, radiant heat offers many advantages over air heating. It is more eficient, creates a more pleasant and healthier indoor climate, and requires no thermal insulation.

Over time, the eficiency of the heating element has developed into faster and smarter to warm people as an alternative way of conventional heating. In this chapter, the technique of infrared heating ilm and smart sensing technique are explored as solid guidance of further concepts selection and build up.

The purpose of the sensing technology study is to answer the following questions:

- **What is infrared heating'?**
- **What kind of heating element do we need'?**
- **What are the available sensing technologies currently'?**
- **What kind of automated occupancy sensing is needed in the ofice context'?**

5.1 Infrared heating analysis

In this project, the carbon heating ilm will be the main heating method, this chapter draws a study on the knowledge of infrared radiation and the heating element. Relative issues will be discussed in this chapter as well: infrared heating eficiency of the infrared heating ilms, infrared heating deinition, and its safety issues.

S 1 1 Types of infrared heating

Optical radiation is divided into ultraviolet, visible light and infrared. Ultraviolet and infrared are invisible to the human eye. The igure 35 shows there are 3 types of infrared radiation: infrared A, B and C.[46] IR-A is a short wave infrared: 780nm to 1,400nm (3400 ° C to 1800 ° C), IR-B is a medium wave infrared: 1,400nm to 3,000nm (1800 ° C to 690 ° C), IR-C is a long-wave infrared: 3,000nm to 1,000,000nm (690 ° C to -273 ° C)

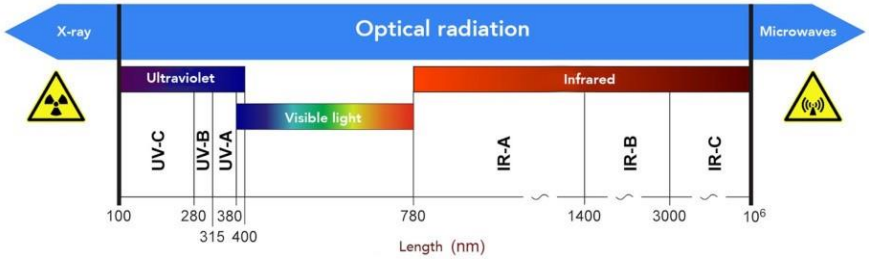


Figure 35: The electromagnetic spectrum (wiki)

The electric infrared heaters, and the only ones suitable for domestic heating, produce IR-C, long-wave infrared (far infrared) radiation. Unlike the high watts brighter radiators, they do not glow red-hot. That is why they are called "dark emitters".[47]

Long wave IR-C radiation contains all temperatures between -273 ° C and 690 ° C. This shows that all people, animals also radiate IR-C. The most common infrared heating is the sunshine, this means this type of radiation does not permeate the skin or cause any negative consequences for your health.

S 1 2 How infrared works

Infrared heating is a heating system powered by electricity. When electricity passes through the carbon printing layer, based on Joule's law,[48] the resistance rises, and the passed electrical energy is converted into heat and released, thus achieving the effect of heating the surrounding environment, a small part of the energy is converted into conduction.

With infrared heaters, the electricity is converted into infrared radiation. As the igure below showed, its transformation eficiency could achieve 57-58% when the surface temperature is around 100 degrees as igure 36 shows. A higher temperature means higher infrared heating transmission rate. Infrared heating is maximum 100 ° C to 110 ° C, while radiators are between 60 ° C and 80 ° C. Under oor heating is a maximum of 40 ° C.[49] The more powerful the radiation and the more directly it is experienced by humans.

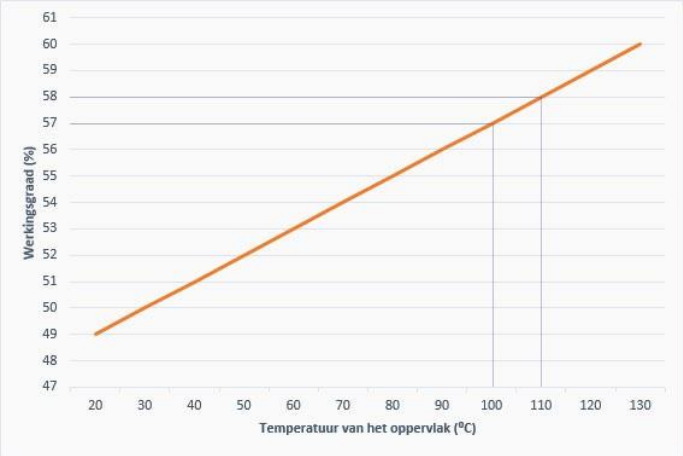


Figure 36: The maximum achievable efficiency of infrared heating (longwave IR-C infrared panels) can be seen in the graph below.[50]

S 1 3 Advantages of infrared heating

When compared with a conventional heater, as the figure 37 illustrated below, a conventional radiator causes a convection current, where air circulates around the room. The hottest air gathers on the ceiling, the cold air sinks and gradually circulates, heating the air in the room, warm the room by means of convection. Meanwhile, infrared heaters work by emitting longwave radiation. This radiation less warms up the air, but warms the objects and people that are exposed to the radiation. This allows for a much more direct way of heating where less energy is lost. Eventually, the entire room will be warm, because warmed objects give off their heat slowly.

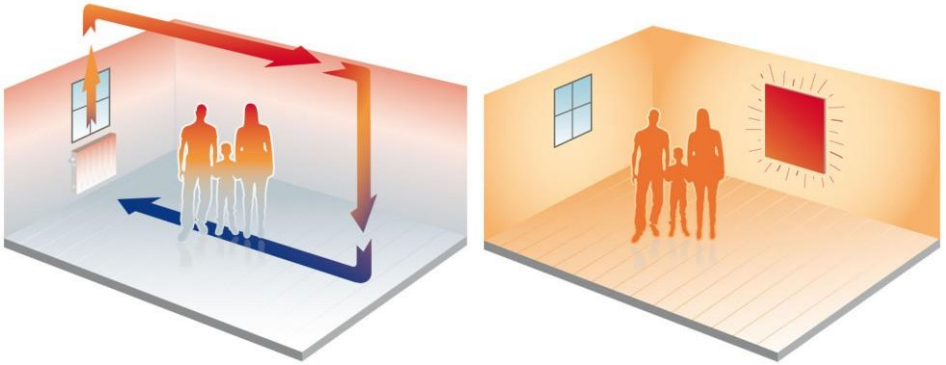


Figure 37: (Left) Convection: The heat is distributed unevenly. (Right) Radiation: An infrared panel radiates objects directly. [51]

Targeted heating is currently the most important application of electric radiant heat. The feature has been used in very large buildings or semi-open buildings to create unequal temperature zones. So one of the most important benefits of using infrared film to warm the workplace locally is creating an individual comfort level in a shared place[52] , which is impossible to achieve with air heating.

Another advantage of infrared heating is that it causes less air circulation. Because convection circulates the air, particles also move around with the air, even though they are invisible. The warming of the air also causes the air to significantly dehydrate, which might dry out our skin as well. These problems less exist with infrared heating.

5.2 What is infrared ilms

The carbon heating ilm is decided as the initial ideal of the heating element. The carbonic heating foil consists of a Polyester (PET) substrate layer with printed carbon heating stripes. The size can be varied from different suppliers. The heating ilm has been widely applied in oor infrared heating systems because it is extremely thin, light, and waterproof.

The igure 38 shows the composition of the infrared ilm:[53] Flame-Retardant PET Film which is an abbreviation for polyethylene terephthalate, part of thermoplastics. For the safety reason, PET thin ilm should meet the VTM-0/VTM-1/VTM-2 standard requirement of insulating or have a suficient ame-retardant UL 94 level. And carbon Paste which will be printed in the middle which is a ine black powder with carbon being the main heating element. Then silver/copper booth bars are used for increased conductivity and minimize electric sparks caused by direct contact between copper foil and carbon heating section.

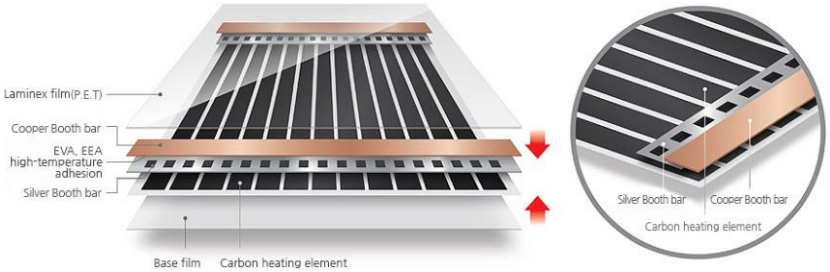


Figure 38: Structure of Far-infrared ray heating ilm[54]

S 2 1 Heating eficiency of infrared ilms

The main power consumption of the infrared heater is the heating element, in order to explore the possibility to save more energy from the heating element, a heating eficiency test of low watts heating ilms was conducted. The goal is to determine how many watts is needed for a fast heating rate. The igure 39 shows the test set up and the inal result. During the test, the ambient temperature is around 23 degrees celsius, the surface temperature of the heating element is measured by a temperature measurer and recorded every 5 minutes. The size of the ilm is all in 0.5 meter square. The below igure shows the results of heating speed of ilms in different watts, from 45W to 170W. It is obvious that the overall heating eficiency of the carbonic infrared heating ilm is non-linear. Higher watts, the speed is faster. Once the wattage is lower than 100W, the heating speed becomes extremely slow, and the maximum temperature is under 60 degrees celsius.

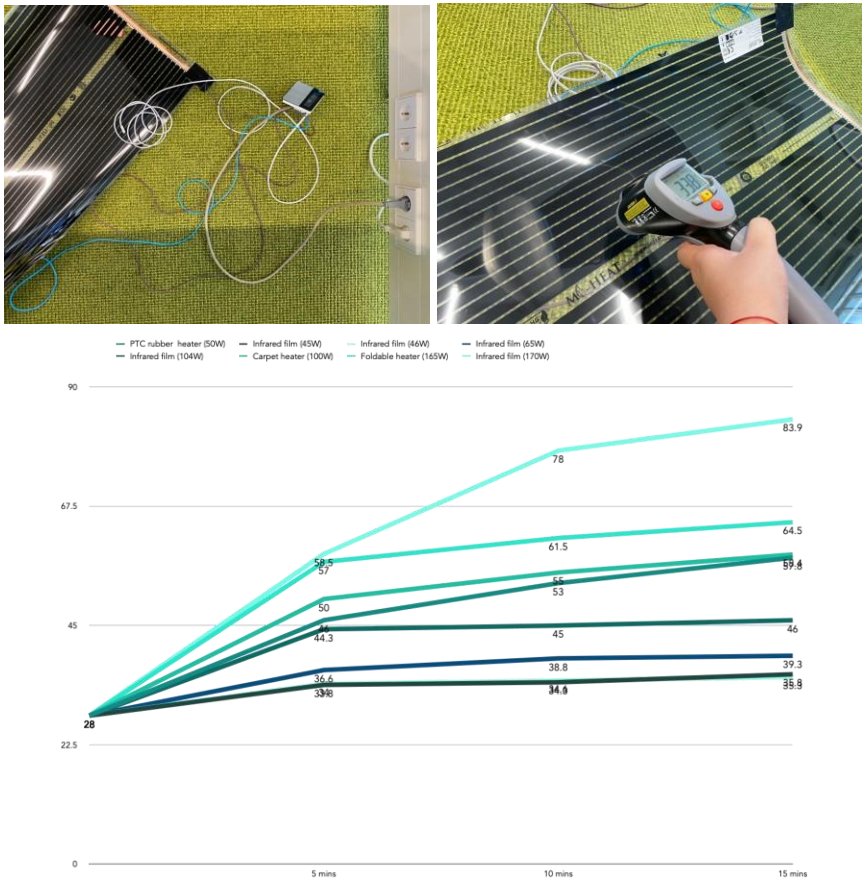


Figure 39: Test set up and heating rate of heating elements with different power

The irst test indicated a ilm in higher watts means it can reach a temperature faster. Another test about the heating and cooling rate of an infrared heating ilm is done to understand the heat loss rate. During the test, a 170 watts ilm was used, the ilm was placed under the desk, and towards the lower body parts. From the igure 40, it is obvious that the ilm needs only 5 minutes to research 65 degrees celsius, after turning the main power off, the temperature drops to 50 degrees celsius in 30 seconds. After 1 minutes, the temperature decreases to 35 degrees celsius. From the other light blue curves that are located in a lower position, we can learn that the skin temperature is usually below 33 °C without heater in the test environment. When the heater is warm enough, researched 60 degrees celsius, the skin temperature will increase and maintain at 34 degrees. celsius. The darker blue curve indicates the temperature of the fabric covering the skin. The fabric temperature increased as well due to the lower body heating.

Previous studies into how many minimum watts to reach a suficient heating rate has shown that ilms in higher watts have a faster heating rate and a higher overall temperature range. With the aid of a high-watt heat ilm, the temperature of the lower body increased within ive minutes. According to the tests that we have carried out in the selected ilm, watts around 170W is able to achieve an adequate heating speed.

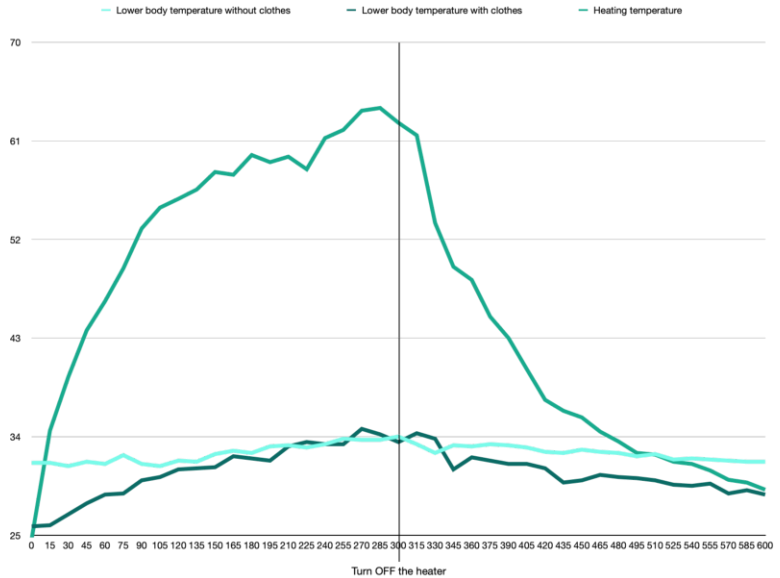


Figure 40: Heating and cooling rate of the 170W heating ilm, skin temperature with cloth.

S 2 2 Safety

Infrared ilms are safe as a heating element under s proper usage. The carbonic layer in the infrared heating foils is covered by PET layers which keep the ilm well sealed, ameless, and waterproof.

However, overheating protection is still needed for unpredictable situations. Such as connection loose, product overheated, electronics are broken. During the usage, although the heater is used at low temperatures, users need to make sure that the heater isn't covered - especially not by anything ammable - and that it's in good condition. Particularly be cautious for any damage to the heater or fraying of the power cord.

The casing needs to protect the electronics and connection of wires to avoid unsafe situations. The waterproof feature is not necessarily required in the ofice environment as an element will be placed under the work desk, but it is probably essential in the home environment, because of a higher possibility of contacting with water at home (if the product will be used in the bathroom).

Objects that can damage the heating ilms include nails, screwdrivers, scissors, and sharp objects. Especially the copper busbars part where it needs to be protected and not exposed. Theoretically, it is possible to bend the sheet up to 180 degrees without cutting them into two pieces, but if the heating sheet is bent to 180 degrees and bends back and forth, repeatedly turning over, the copper part of the heating sheet will have It may be pulled, causing cracks and short circuits.[55] But it is possible to cut them into two pieces and reconnect them by wires and insulation tapes.

5.3 Infrared thermal transformation rules

This chapter gathers some basic formulas of infrared heating calculation.

S 3 1 The fundamental laws of Infrared heating[56]

As IR heating has evolved, so has the fundamental science that underpins the workings of its heat transfer, but a main laws apply:

Stefan-Boltzmann Law: Gives the total power radiated at a speciic temperature from an IR source. The Steffan-Boltzmann Law relates primarily to infrared emissivity. Calculating the power radiation from an IR source based upon the object's surface area temperature and together with a black body factor. A perfect black body has a factor of 1 - with other materials varying in that factor. When we allow for the emissivity of normal materials the Stefan-Boltzmann Law becomes:

$$P = e\, a\, AT^4$$

P: The heating emissioned
i: The emissivity of the material
a: The Stephan-Boltzman constant
(5.670367 x 10-8 kg s-3 K-4)
A: The area of surface
T: The absolute temperature of the surface

Using this law means we can calculate the net heating transfer between Object i and Object j with the following formula.

$$P_{rad} = e_i\, a\, A_i F_{ij}(T_i^4 - T^4_j)$$

Prad: The heat ow rate from surface i to j
i: The emissivity of the material i
a: The Stephan-Boltzman constant
(5.670367 x 10-8 kg s-3 K-4)
Ai: The area of surface i
Fij: The form factor between surface i & j
Ti Tj: The absolute temperature of the surfaces

Based on this formula, to have a higher heating eficiency rate, we need:

- A higher surface temperature of i
- Bigger radiated area geometric factor of j
- A higher emissivity of the surface material of i
- A bigger heating surface of i

Apart from Stefan-Boltzmann Law, the igure 41 shows Inverse Square Law and Lambert's Cosine Law also mentioned direction and distance factors between the heating element and the object.

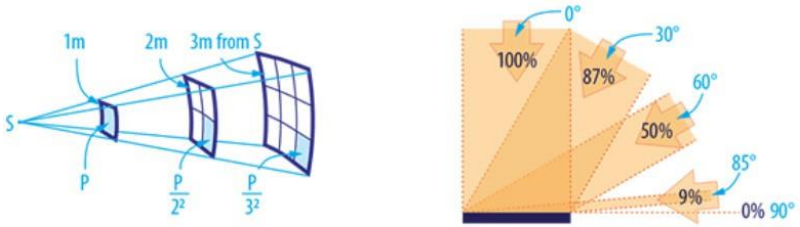


Figure 41: the Inverse Square Law (left) and Lambert's Cosine Law (right)

The main conclusion behind these two laws are: The closer the heated object is to the heating object, the more eficient the heat absorbed. And the more the angle of irradiation is toward the heated object, the higher the eficiency. On the contrary, the lower the eficiency, the greater the heat loss.

S 3 2 Situation in the ofice

Where the panel should be placed to get the highest heating eficiency?

It depends on the purpose, if the purpose is the whole room heating, then placing it on the ceiling is a good choice, with extremely high heating temperature. It can cover a larger area, many objects absorb radiation and re ect on each other. Less air will steam through the ceiling panel compared with a panel placed upwards or vertically on the oor. The heater placed vertically under the desk will lose partial heat via air absorption as well, however, the desk surface can store heat under the desk, slow heat loss. The heater placed upwards will lose most heat, because the air streams through the whole surface, and nothing could prevent it.

From the energy eficiency perspective, our goal is using low watts heating ilm. Assuming the heating area is the same because the distance on the ceiling is too far, its energy consumption must be increased to get a higher heating temperature to get the same heating speed of a low watts heating ilm placed under the desk, next to the lower body.

Therefore the vertical placed panel under the desk and placed as close as possible to humans is better than the upwards and downsides location for a local heating purpose in an open space while using less electricity.

5.4 Occupancy sensing technology

Employee's occupancy detection is the main function of the project. human sensing (also called human detection or human presence detection) encompasses a range of technologies for detecting the presence of a human body in an area of space, typically without the intentional participation of the detected person. If the heater could "know" when there is no user behind the desk by detecting the occupancy of the employees, which means there is no need to turn the heating on at that moment. So the heater could turn itself off and save more energy wisely. In this chapter, various possible technologies have been discussed.

S 4 1 riteria

The most important requirements related to sensing technology are listed below. For now, different weights (from 1 to 10) are given based on the importance, in the end, they will be incorporated in the inal list of requirements in the next chapter.

Reliability (8): The occupancy of the employee determines the heater should be on or off, the detection of a stationary person should have minimum errors and be least affected by other ofice activities.
High Integration level (10): The most important goal of this project is a standalone system, thus, keeping the system simple is essential.
Low energy consumption (7): For the company, saving energy is important, the detection should not require too much energy as extra energy waste.
Appropriate price (5): For the production, the price of the detection unit should match the value added by the function.
Acceptance (6): Detection should be acceptable for most ofice workers.

S 4 2 ossible Technologies

Modern technologies proposed or deployed for human sensing include different categories[57], as the table 2 shows. Based on the ofice environment, the possible measurable variables aligned with each technology have been illustrated in igure 42, advantages, and disadvantages with comments are listed in the table 2 as well.

Technology	Measurable variables	Pros	Cons	Comments
Acoustic sensors	Detect sound made from human	- Cheap	- Inaccurate proof of occupancy in a shared place, will be affect by other office activities - Privacy issue	Not good for local occupancy detection
Image recognition of human shapes	Recognise seated human figure	- Very accurate - Less affect by other office activities	- Privacy issue (unacceptable for employees) - Complexity of installation and integration - Need learning time - Higher cost	Not good for public space occupancy detection
Infrared detectors	Detect infrared emitted from moving human on the seat	- Accurate with moving people - Cheap - Easy for integration - Sensitive with human motions	/	- It is a good choice - Not sure about the accuracy with micro movement when people is working - Not sure about whether the sensor will be influenced by the infrared heating
Pressure detector	Detect pressure on the seat/floor and convey signals to the heater	- Accurate about the stationary posture when people is working - Sensor is cheap	/	- Not good for this project - Probably need wifi or Bluetooth for data transfer
Chemical sensors	Detect the composition of CO2 in the air	- Sensor is cheap	- Inaccurate proof of occupancy in a shared place - Unstable data	- Not good for this project - Probably need to place close to human and wifi for data transfer
Radar	Detect vital signal from human/reflected wave from moving human or objects and convey signals to heater	- Accurate with moving people - Big range - Microwave sensor is cheap	- Will be accidentally perceived as "there is a human" by other Non-human object. - Narrow detect angle	- Probably not good for this project, need further investigation of its detection range - It is a potential solution with a microwave sensor with a short detect

Table 2: comparison between different detection technology

Figure 42: measurable varies when a human seated at the workplace

First of all, there is no doubt that using the camera, image recognition is most powerful and trustworthy for detecting employee occupancy. However, due to privacy and personal information regulation, they might not be ideal solutions in the ofice environment. Considering the open ofice space, only using the sound level data or the co2 level data are not dependable enough as the proof of employee's presence locally.

Apart from that, using wireless device detection via Bluetooth, or wii sounds like a good and simple choice, but the human behavior of what devices will be carried by employees when they leave their workplace is personal and unpredictable. Those technologies requiring WiFi might not be feasible as well, such as the pressure detection with another device which transfers collected data to the heater via WiFi or Bluetooth to help the product understand the workplace occupancy. Because the private indoor Wii access request of the product might not be approved by the companies due the privacy. Secondly, if the wii connection is unstable then it might also cause the system not working.

The infrared technology (also known as Pyroelectric infrared (PIR) sensor technology) has been already widely used in smart products and human presence detection, such as automated lights in the corridor or automated doors of buildings. Basically When a warm body like a human or animal passes by, it irst intercepts one half of the PIR sensor, which causes a positive differential change between the two halves. When the warm body leaves the sensing area, the reverse happens, whereby the sensor generates a negative differential change. These change pulses are what is detected, as igure 43 shows, which means there is a human. The different faceting and sub-lenses create a great range of detection areas and distances. Overall, it is cheap, less expensive to construct, easy for product integration and sensitive with human presence detection, it is a good function and price combination.

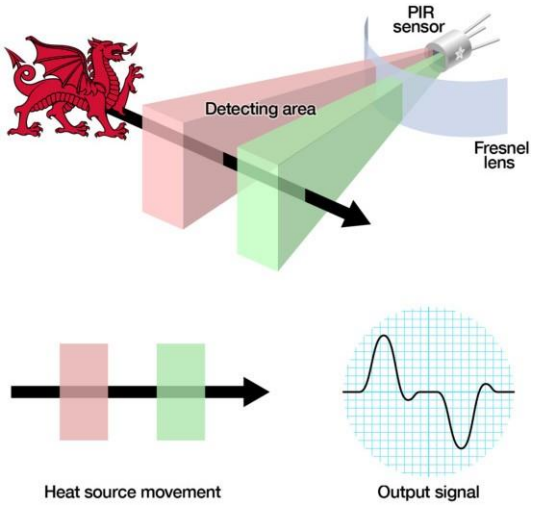


Figure 43: how PIR sensor works[58]

S 4 3 Result

Each way has their own limits, either on reliability, cost, energy consumption, or simplicity of integrating it into the product. Combining some of their features can make up for some disadvantages among them but will complicate the product, add complexity to the system and the installation. Thus, each technology will be compared individually based on the criteria.

Based on the previous criteria, by calculating the score of each technology and considering that different criteria are weighted differently. From table 3, the infrared detector turned out to have the highest score and appears to be the most approachable technology to be implemented in this project at this stage.

Technology	Reliability	High integration level	Low energy consumption	Appropriate price	Acceptance	Total
Weight	8	10	7	5	6	
Acoustic sensors	5	8	8	8	2	228
Image recognition of human shapes	9	5	4	5	1	181
Infrared detectors	8	8	8	9	9	299
Pressure detector	8	6	4	8	8	240
Chemical sensors	2	6	4	9	8	197
Radar	7	8	8	9	9	291

Table 3: Rating the different technologies based on criteria.

The full score is 10.

However, the new question of using an infrared detector is their accuracy of the detection of working people who probably do not move every second. For now, the comparison of different occupancy detection provided enough insights for the later ideation phase. Its accuracy will be tested and validated in a later validation chapter.

5.5 Key insights

Following research questions were answered in this chapter:

- **What is infrared heating'?**
- **What kind of heating element do we need'?**
- **What are the available sensing technologies currently'?**
- **What kind of automated occupancy sensing is needed in the ofice context'?**

1. **Infrared heating characteristics**
   Any object that its temperature is higher than -273 ° C radiates longwave length infrared heating. An object with a higher temperature, has stronger infrared energy, its wavelength is shorter, the amount of infrared heating is greater.

2. **Heating speed of infrared heating ilm in low wattage**
   According to the heating rate tests, a bigger watts infrared ilm has a higher initial heating eficiency and a higher temperature range. And the minimum watts to have a suficient heating speed in 5 minutes are 170W.

3. **A bigger and closer infrared heater**
   The low-temperature heating heater should be placed as close to the object that needs to be warmed to reduce the heat loss. And its heating surface should be as large as possible, to improve the heating eficiency. Placed under the desk can prevent a certain amount of heat lost.

4. **New research question**
   The infrared sensor is the cheapest and the most feasible way of detecting occupancy at the ofice. However, there is another new question that needs to be answered: Is the PIR sensor reliable enough as a standalone solution for occupancy detection in the ofice?

Reflection points

The tests of various infrared heating ilms gave suficient insights into selecting the appropriate heating element, however, I couldn't ind a heating ilm around 120 to 130 watts as the middle wattage value between ilms are higher than 100w but lower than 165w. More investigation could be done in that area.

The carbon heating ilm is light, thin, high eficient, however, there are different heating methods that could generate infrared heating in different eficiencies, such as ceramic heating, which leads to a further research of using different heating elements.

6. Design requirements

6.1 Design principles

Well integrated physically solution

Because of the ofice context requirements, a clean and tidy ofice environment requires the overall product design to avoid excessive cables and complicated appearance, the overall product should keep simple and lightweight. The product must be easy to install and remove under the desk for adaptability in different open ofices.

Well protected as a safe heating system

Safety is the base of the whole project, as a heater in the ofice. It must appear as safe, users can not be afraid to put it under the desk and next to their feet. It must work safely, with overheat protection and auto cut out for emergency situations. Once electronics elements or the heating elements are not working, the system should no longer operate by itself and show error status to the user. All safety information should be provided to the user for checking anytime.

Not interfere with ofice activities

The control unit is climate assistance in the ofice for personal heating locally, it should not obstruct employees' productivity and other activities. So as the heating unit. The product-system should occupy the least space in the personal workplace, and keep the working area organised. The temperature-related information should be provided to the user but must not disturb the user during working.

Durable

Although it has advanced integrated technology, the electronics should be well protected from ingers and dust in an ofice environment. The heater must be capable of withstanding accidental falls and other life mishaps.

Elementary but highly personalisable

The heater and the control unit enhance personal thermal comfort through the application of intuitive temperature-control technology. Not complicated. It can be no harder than turning on a light in the ofice on your desk and should not require extra steps. The control unit should require the least learning time and operate without instruction. The unit should be considered as reachable when the user would like to change the temperature.

Accurate human presence detection with minimum errors

Detection and the presence awareness is the core of the smartness of the panel, the panel should not be turned on accidentally by other employees, cleaning stuff, and other activities in the ofice during work time. And it works with minimum errors.

Fine crafted hidden in the ofice

The heater appearance should convey precisions and quality in its form and material

Not about changing sustainable behaviour but enjoy the warmth

This project aims to give employees full control of their working places, Highly personalisable warm experience in a shared place at the working place, not change your thermal comfort habits. The product-system should not force users to change energy using habits to achieve the goal of saving energy. The product -system could show the product is made for energy saving so as to raise employees' energy awareness in a more acceptable, unashamed way.

As it is it is a good heater

Even if the sensing technology could help with turning on and off automatically, the user could still manually turn on and off when the user feels uncomfortable with the set temperature. And turn it again manually when he or she thinks it is necessary to have the heater. And the adjusting range and the heating speed should be acceptable.

6.2 List of requirements and wishes

Due to the time restriction, the focus of the project is on developing a local heater for ofice context. As a conclusion of the analysis phase, a list of requirements and wishes for the data collector design is formulated, based on the checklist by Pugh[59]. Statements in grey are wishes.

1 erformance

1.1. The product should be a standalone system. (design brief)

1.2. The product should allow employees to personalise local temperatures. (design brief)

1.3. The product should let the user feel the warmth as soon as possible. (user analysis)

1.4. The panel should detect people's presence when they are at their workplace. (design brief)

1.5. The product should not interfere with other daily ofice activities. (context analysis)

1.6. The panel should be switched off by itself automatically when it is unnecessary to use the heating. (design brief)

2 rocess

3 Environment

3.1. IP21 Protected against from inger, vertically dropping water. (context analysis)

3.2. Reduce the environmental impact as much as possible. (trend analysis)

4 aintenance

4.1. The hardware parts of the product should be disassembled for maintenance. (Trend analysis)

S roduct costs

5.1. The irst product cost is around 100 euro produced by TU Delft students. (design brief)

5.2. Minimal costs without loss of product quality and aesthetics.

6 perational costs

6.1. Electricity as an operational cost should be as low as possible. (design brief)

Transport

7.1. The product should be able to be moveable by one person. (context analysis)

roduction facilities

Size and weight

9.1. The product should **it** the space under the desk. (context analysis)

1 Aesthetic appearance nish

10.1. The product should have a reliable, lightweight, simple, and unobtrusive appearance for the ofice environment. (context/user analysis)

10.2. The appearance can suit the home ofice as well with slight changes. (context analysis)

11 aterials

11.1. Durable ireproof material that can resist low-temperature heating. (technology analysis)

12 roduct life span

12.1. The electronics parts of the heater can be reused for other purposes. (trend analysis)

12.2. The materials used for the product should be as recyclable as possible. (trend analysis)

13 Ergonomics

13.1. The product and the control unit should be ergonomically comfortable to use. (user analysis)

13.2. The product can be used for standing working positions as well. (trend analysis)

14 Reliability

14.1. The product should still be possible to turn off manually during usage (user analysis)

14.2. The accuracy of the presence detection should be least affected by other activities in the ofice (context analysis)

1S Safety

15.1. The product should be safe at the ofice under proper usage (dangerous situation includes ire, overheated, short circuits).

15.2. The product should not harm the employees under proper usage. (technology analysis)

16 Related systems

16.1. Employees must describe the control unit as reachable, direct, simple to use. (user analysis

1 Installation & initiation of use

17.1. The control unit interface should be understood with minimum instruction. (User analysis)

17.2. Easy to install and uninstall at the ofice. (context analysis)

1 ommunication

18.1. Users describe the use of the control unit as not distracted during working. (User analysis)

18.2. The product should convey its environmental-energy saving purpose. (Design brief)

18.3. The product should communicate its work status actively to the user. (User analysis)

6 2 2 Requirements prioritization

The ideal goal of this project is a working prototype which is expected to be tested in a later pilot test. Within this 100-working-day project timeframe, the progress of building a fully working prototype is hard to predict. The key requirements are divided into 3 categories: physical products requirements, interaction requirements, wishes that will not have. All these prioritized requirements have to be considered in the inal design.

hysical products requirements

1.1/1.2/1.3/1.4/1.6/15.1/15.2/7.1/10.1/13.1/1.5/9.1/18.1

The product must be safe and standalone, provides personal heating instantly when it detects the employee's presence with minimum errors. Meanwhile, the product should adapt to the ofice environment, not interfere with ofice activities, and be ergonomically user-friendly.

Interaction requirements

16.1/18.2/18.3/14.2/17.1

The control unit is intuitive, simple to use, and researchable. The product could convey its "smartness" and its end purpose of energy-saving with minimum instruction.

Will ont have

Not a priority for given timeframe

All other requirements and wishes are not a priority for working prototype development in this project's timeframe.

7. Cycle 1: Concepts direction

Starting from the deined project brief, based on the list of requirements, ideas, and concepts were developed in an iterative way. With some quick act out tests with users, evaluation of these ideas was taken during the midterm and the inal design direction and concept were decided with the whole team.

7.1 Proof of initial concept

Before the concept generation, in the irst cycle, an initial validation test with an early prototype was conducted. With the help of technical support, we had the irst functional prototype with a separate control box connected with wires as igure 44 shows. There are two knobs, a LCD screen, a led lighting for the heating status, and a Panasonic PIR sensor embedded. The main power button is on the side.

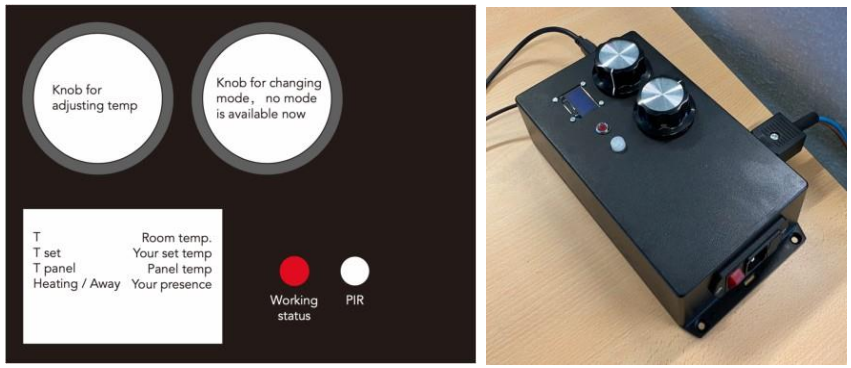


Figure 44: the initial idea of the control box

The inner components of the heating panel are the same as the earlier heating panel used for the pilot test, including the 170W carbon heating ilm, insulation foam, the wooden structure, a temperature sensor, and the fabric is replaced to a thinner and un uffy type. The assumption that an initial ideal of a heating panel combined with a PIR sensor placed on the desk was tested by the design intervention, the test was conducted in a cool environment, with a room temperature around 20-21 degrees celsius. The full test procedure could be found in the appendix F. The heating panel was placed under the desk as igure 45 shows. Participants indicated the following problems after the test:

Figure 45: prototype for cycle 1, the position of the heater and the control box

1. The heat is losing with the current at and square shape. Most of the participants were worrying that the heat is leaking from two sides during the test, not aiming at their bodies which can mean a heat waste. There is only a partial heating surface aimed at the lower body area, the rest part of the surface is towards the air.
2. The heating speed is fast enough, the compact look will not occupy too much space under the desk.
3. However, there is no space for stretching legs or put feet, because the bottom of the product is in full contact with the ground, most participants usually leave the panel a side or just leave it in the deepest location under the desk. And Some of participants also

mentioned that they probably will kick the panel due to the bulky square shape.

4. The location of PIR sensor is improper, without my explanation, most participants left the control box very far from their working place as images showed, and the PIR sensor is not aiming at themselves, which leads to the inaccurate detection. Some participants indicate that the heater will turn to not heating status although they are sitting at their workplace some time.
5. The prototype is too heavy to be considered movable. The wooden structure makes the prototype too heavy to comfortably move under the desk, although two stands improved the movability.
6. Re ecting on the image of the desk distribution, the control box is placed very far from the participant, the chunky size and unclear indications is not considered as an object that should be placed on the working desk.

The initial idea of placing the control box on the desk should have a fundamentally different design approach. This control box is both too hard to understand where it should be placed and how the presence detection works, the user is unable to understand the usage without an appropriate explanation. However, the most important insight gained from this prototype is that working is the primary focus when workers sit at their workplace. The control unit should be perceived as simple, obvious, direct as possible, to save the unnecessary learning time.

7.2 Ideas generation

Taking the design brief as a starting point ideas were generated using creative techniques as igure 46,47 shows, such as brainstorming, howtos, C-box, and acting out was used to classify all small ideas based on feasibility and basic requirements. Combining with previous research results, solutions for each function were developed, the most valuable and feasible solutions were captured in a morphological chart. Table 4 presents the inal overview. The argumentation of the main selected morphological chart solutions was presented to and discussed with the client for validation. 4 design concepts were created by combining the highest reliable solution. The next section presents four concepts detailly.

One of the techniques used to produce ideas is the use of analogies. By looking at different existing industries, analogies can be made with the design problems to ind inspiration in various existing sectors as igure 48 shows.

Sense	PIR sensor	Thermal detection sensor	Ultrasonic sensor	Sense the phone	...
Stand under the desk	With stands	With wheels	Embedded into the desk	Foldable heater	...
Heating	Carbon infrared heating film	Ceramic heating unit	Carbon fibre	PTC heating unit	...
Reachable	On the desk edge	Under the desk edge	On the heater	invisible on the office desk	Web control
Control method	Haptic control	Turning knob by hands	Pressing by feet	Voice control	...
Power of the control	Connect to the heater	Rechargeable battey	Solar energy	...	
Feedback	Animation	Lighting	Realtime energy consumption	Temperature of the heater	...

Table 4: morphological chart

Figure 46: ideation sketches, ideas on each sub functions

Figure 47: C-box method and acting out

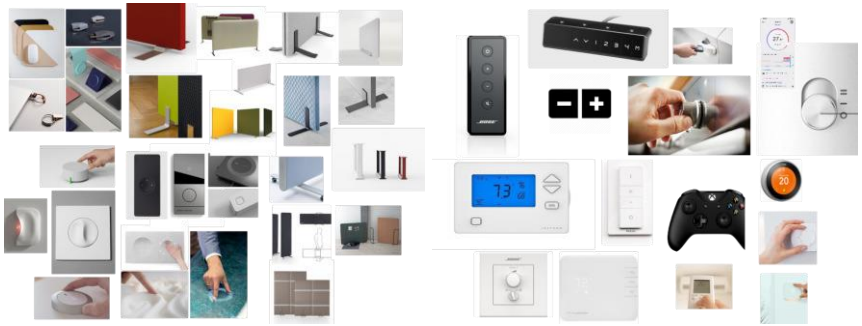


Figure 48: collage of different inspirations and analogies

8. Concept generation

Interaction by hands

During the ideation process, different interaction ideas were generated as shown in igure 49. In order to narrow down the initial direction of the interaction method, interaction of adjusting temperature by hand is considered more acceptable and intuitive than by foot control, or gesture control, which takes less learning time and effort as a user. Voice command is not recommended in a workplace where a quiet environment is desired.

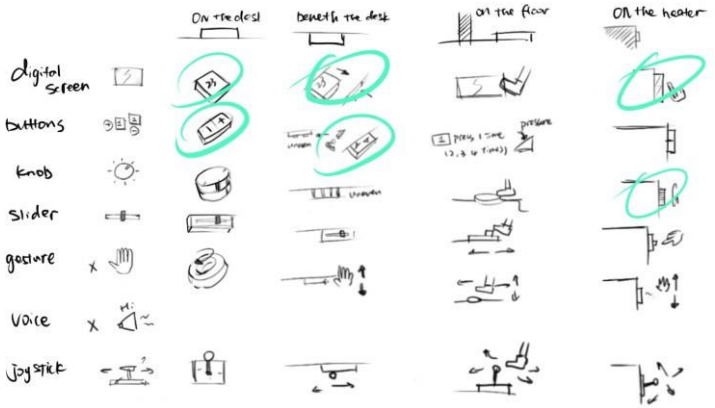


Figure 49: sketches of interaction ideas generated

Commercial heating panel

During the market investigation, we ordered some current portable heating products. One foldable heater aroused our interest as igure 50 shows. The product is 0.5m per 1m. It has following features:

- LED lighting indicator on the control unit with buttons.
- Three scales of heating temperature: High (55-60C), Medium (50-55C), Low (45-50C).
- The heater will turn off the heating after 3 hours of constant heating.
- The heater will be off when it tips over and once pulled it back to the position, it turns on again while maintaining the same settings.
- Compact and lightweight which can be moved by one person.
- The heating insulation layer is not thick enough which consists of only one 3mm layer of foam. Heat is able to leak from the back side.

Figure 50: the commercial foldable heating panel

In the main control unit, there is a PCB board which is not able to access due to the safety issue as igure 51 shows, the heater consists of several layers that stick together with adhesive layers, the inner composition can be found in igure 52.

Figure 51: insulation layer, and the control box

Figure 52: Each layer of the product

In the folded part, the heating ilm is cut into two pieces following the cutting line, then they are reconnected with short wires as a connection where it is covered with special insulation tape for the ixation as igure 53 shows below. This solution is similar to some of my ideas generated during the ideation brainstorming session of the product level.

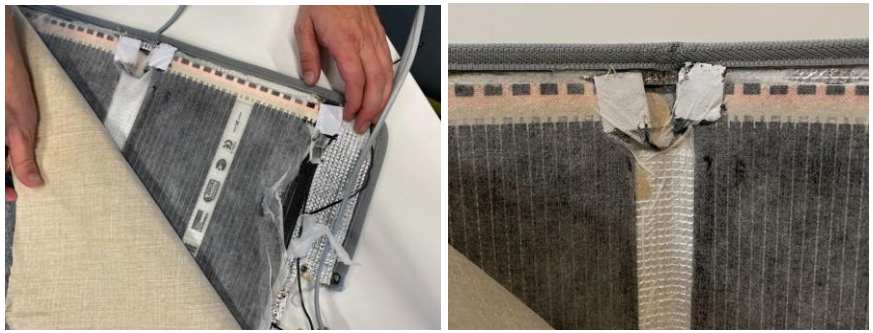


Figure 53: Close up of the bendable part

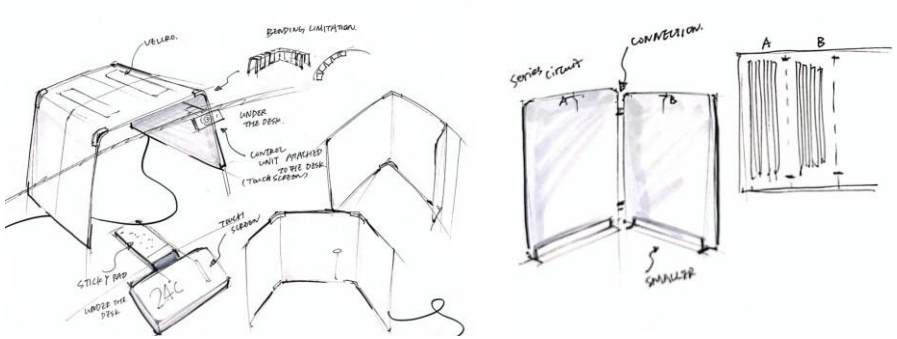


Figure 54: ideas generated in the ideation phase

This thin, compact, lightweight, a product with a large heating surface is perfect for further smartness development which meets most of the basic requirements of the physical product. As earlier mentioned, the project was executed during the covid-19 crisis. This slowed down the development of the heating element building because it was harder to access the working space and get material easily. Also because of the unexpected safety incidents, a self-made heating element and doing practical experiments without experts in the campus is not allowed. Thus, the foldable commercial heater was used as the base for further concept design and prototype.

Occupancy detection method

The most promising, feasible, cheap solution is using PIR sensors or a combination with another thermal sensor, as explained in the occupancy sensing technology challenges section.

8.1 Concept - A

Figure55:concept A's control unit and the detection principle

Concept A as igure 55 shows is based on the remote control idea, that the control unit is wireless powered by rechargeable batteries, it pairs with a heating product with bluetooth. The PIR sensor aims at the user 's upper body. Determine the presence of employees by detecting desktop activities as the igure shows. Users can adjust the temperature easily by turning the wheel. Information on energy saving and the current product heating temperature will be illustrated on an LCD screen. The control unit could be embedded into the plants holder to be less obtrusive in the ofice environment.

Figure 56: another version of the control unit

Advantages:

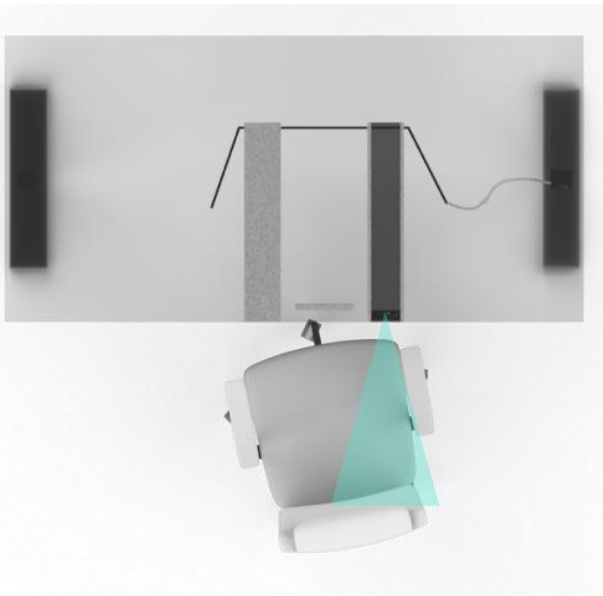
+ Wireless control system
+ Researchable for employees
+ Unobtrusive in the ofice environment

Concerns:

- Once the connection is unstable the system will not work well
- The bluetooth will consume more energy
- The control unit might be lost
- The presence detection sensor might not aim at the person due to the improper position caused by the employee, thus presence detection might not be accurate enough

Figure 57: concept B's control unit and the detection principle

8.1 Concept - B



Concept B as figure 57 shows is inspired by the table height adjuster, this concept focuses on a heating product embedded into office furniture, the heating panel is attached to the desk with sliders that allow the user to adjust the position of the heater freely, the controller is located under the table and can be slid out easily, shows the current heating temperature. The buttons are uneven and hidden on the back side of the control unit. There is the temperature information of the heater and a real time energy consumption level. The control unit connects to the heater via wires that beneath the desk, and powered by the mainpower. The presence detection is a combination with PIR sensor and the thermal detection sensor, the detected range covers the seating area.

Advantages:

+ Reachable for employee
+ More space for legs
+ Less space occupied
+ Stable wire connection between heater and control unit
+ A combination of two sensing method

Concerns:

- Complex installation that require too much time
- Inflexible for uninstallation
- Low adaptability to different office desks
- Might break desks

8.1 Concept - C

Figure 58: concept C's control unit and the detection principle

Concept C as igure 58 shows is carried out based on the idea of a fully integrated solution that the control unit is embedded on the product. Removing unnecessary devices and wires, inform users about energy information by lighting. The PIR sensor is placed on the side embedded into the control unit. The current heating temperature is shown on the control unit.The energy related information is illustrated by LED lighting bricks, the colour of the lighting changes based on the energy using status, when the current energy consumption is high, the lighting will become more warm and reddish.

Advantages:

+ Fully standalone system, without any unnecessary installation
+ Compact and integrated solution
+ Easy for moving
+ Reachable control unit
+ Less wires and hassles, low complexity

Concerns:

- Uneasy to read information under the desk
- Less space for legs and feet
- The presence detection range might be too large, some unwanted data would be recorded as well

Figure 59: concept C's control unit and the detection principle

8.1 Concept - D

Concept D as igure 59 shows is based on the control unit that can be attached on the side edge of the desk which is powered by rechargeable batteries and it can be controlled by tuning the knob to adjust the temperature and other modes. The control unit connects the heater via bluetooth. The presence sensor will be embedded into the control unit that is placed on the desk edge, to monitor the presence based on the people's upper body movement. The LED lighting indicates the current energy saving, and the heating temperature is shown on the control unit.

Advantages:

+ Wireless control unit
+ Unobtrusive in the ofice environment
+ Occupy less desk space
+ Reduce the probability of the movement of the sensor

Concerns:

- Not easy to reach
- Need battery
- Lower accuracy detection of the presence
- Lower adaptability to the ofice environment, need installation
- Once the connection is unstable the system will not work well
- The bluetooth will consume more energy

8.2 Concepts evaluation

The inal concept C is chosen using the weighted criteria method based on the relevant prioritized drivers as igures 5/6 show. The most integrated concept C has the highest score. Mainly because it is the most standalone system, and does not rely on other systems. This solution can offer an optimal choice for a local heating, as it removes wires and the need for complex systems, while still providing a practical usage, and be highly adaptive into the ofice environment. However, the accuracy of the presence detection is not validated, a further validation cycle of the concept C's presence detection is needed.

During the acting out several concepts with potential users, most participants mentioned the need for a space for their legs and feet. There is not enough space for their legs when the heater is completely in contact with the oor as igure 60 shows, which brings them a restricted feeling of their lower body. Thus, ergonomic related problems need to be taken into consideration and stands might be added in following cycles.

Figure 60: acting out concepts with employees in the ofice, they do not like the feeling of their legs are restricted

	1	2	3	4	5	6	7	Total
(Un)Install easiness (for user)	x	0	1	0	0	0	0	1
High accuracy of user occupancy sensing	1	x	1	1	0	0	1	4
Its existence do not disturb other office daily activities	0	0	x	1	0	0	1	2
Occupant minimum space at personal workplace	1	0	0	x	0	0	0	1
Standalone system	1	1	1	1	x	1	1	6
Low energy consumption	1	1	1	1	0	x	1	5
Control unit is reachable	1	0	0	1	0	0	x	2

Table 5: weighted criteria objectively

	Total	Weight	Concept A	Concept B	Concept C	Concept D
(Un)Install easiness (for user)	1	4,35	5	4	7	6
High accuracy of user occupancy	4	17,39	6	7	7	7
Its existence do not disturb other office daily activities	2	8,7	4	7	7	8
Occupant minimum space at personal	1	4,35	3	7	6	7
Highly standalone system	6	26,09	5	4	8	5
Low energy consumption	5	21,74	3	7	8	7
Control unit is reachable	2	8,7	8	8	7	6
	Total		439,13	556,52	689,61	582,61

Table 6: Evaluation of different concepts

8.3 Key insights

After ideation, the design direction, conceptualisation, evaluation, the concept C is decided with the supervisor team as a starting point for later concept development. Although there are many ideas in the beginning, in the end, the most integrated with a higher adaptability to the ofice environment concept stood out.

1. **Presence detection next cycle**
   As for now, the validated as a feasible idea is using the current commercial product as a base for the physical product design, it is safe, CE proved, which can be used for later smartness building experiments at a secured place. Next cycle will be focused on presence detection development and validation. Because once the detection is deined, the control unit design and the rest design can follow.

2. **Interaction further deinition**
   As demonstrated in the evaluation of the concept, the generated interaction ways and the current information illustrated are not ideal, as concluded from the midterm meeting. The heating temperature illustrated is not able to help users to understand the heating status. People are not able to connect 54 degrees celsius (heating temperature) with the heater, their irst impression would be the ambient temperature because most thermostats show the ambient temperature to help users to understand the current environment's thermal condition. An ambient temperature could be a reference to set the temperature when they are using a heater. However, in this project, the temperature around the user is always changing since the heater is heating locally, and the heat is streaming around the user, illustrating that showing the ambient temperature or the accurate heating temperature means nothing.

3. **Ergonomics physical product improvement**
   Standing working posture is removed from this project as stated in the MosCow prioritization section. But when people sit, having adequate space for the lower body is necessary, or a limited sensation can lead to more discomfort and complain about the products and the ofice environment.

Reflection

First of all, always keep the safety issue in mind. Taking care of all prototypes is what I have learned from the unexpected incident that happened in the ofice. Secondly, although there is a commercial product as a foundation for this project, I still need to open my horizon and conceive of a frontier in the design process. Then, communication with clients and the supervisor team is also crucial, and how to convey my ideas and concepts more effectively is an ability that I also need to learn in the future.

9. Cycle 2: Presence detection design

By researching the potential presence detection technologies, and the conceptualisation phase, the PIR sensor was selected as a cheap and feasible solution for presence detection based on motions. In this chapter, deeper research of PIR sensors and several validation tests were conducted with the target user group at the ofice to validate the accuracy of PIR sensors in the actual environment and deine the heating strategy.

9.1 PIR motion detection method validation

1 1 Tryout test

As earlier mentioned, the commercial foldable heating panel is used as the base of the physical product. In this cycle, more focus will be on the PIR sensor detection. A tryout test was done, to test the sensitivity of a normal Seeed PIR sensor as igure 62 shows. The try out test was conducted in the oice, at my workplace. I acted out some lower body movements that had been planned in advance (move feet, tap feet, change postures, leave the desk, go back the seat)while one Seeed PIR sensor is attached on the middle high edge of the product as igure 61 shows. Three tests were conducted with the different interval time of 1 second, 3 seconds, and 5 seconds, each test lasted 15 minutes.

Figure 61: one seeed sensor attached on the panel

Figure 62: Seeed PIR sensor

From the tryout test, the Seeed PIR sensor is sensitive enough to collect micro-movements data that people will usually do at their workplace when sitting. It is possible and promising to use the PIR motion sensor to detect movement when people are seated. And more motion detected when the interval time is shorter. As igure 63 shows, 113 motions detected in 15 mins with a detection interval time of 1 second although actual movements planned are around 27 movements. 32 motions detected with a 3 seconds interval time, which is close to the number of actual planned movements. When the interval is 5 seconds, the reason why the motion cannot be detected is that once the sensor detects motion, it stops working within the next 5 seconds. Based on the tryout test, a movement needs around 3 seconds to accomplish, and will not lose the main data. If using an interval of 1 second for a 45 minutes test, the sensor readings uctuate a lot, the huge amount of the motion detected will become too dificult for further analysis. So, an interval time of 3 seconds is used for a longer test which will last 45 mins.

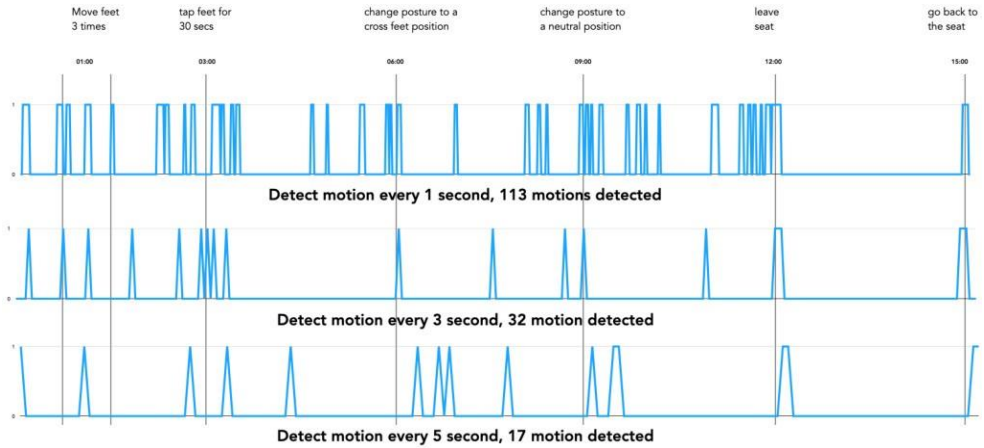


Figure 63: tryout tests results with Seeed PIR sensor

1 2 rototype building and test procedures

In this 45 minutes test, the goal is to igure out where PIR sensors should be placed where they can get enough data to determine when a person is at their workplace and when they are leaving in an actual oice environment.

Five potential locations selected for the test as igure 64 shows. Five normal Seeed PIR sensors are ixed in position with tape and clip, connected to the Arduino board and computer, motions detected will be

logged into the computer, and the data can be imported into Excel for analysis after the test. And the arduino board and wires were placed on the back to avoid unnecessary body contacts.

7 tests were performed in the ofice environment with ofice workers. The product was placed under the desk, in front of the participant, monitoring their lower body movement in 45 minutes as igure 66 shows. The research was performed following the passive prototyping approach, meaning that after the introduction, it is left for occupants to be used without providing heating. Before the test starts, the user could ind a comfortable place under her/his desk for the product. After the 45 minutes test, participants were asked to ill two questions and a semi structured question about the physical product. Tests were recorded by video for further analysis.

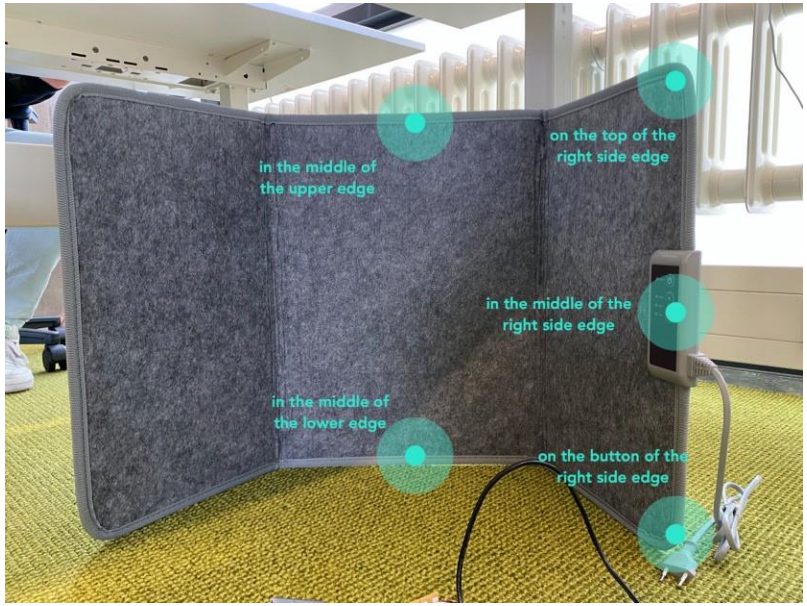


Figure 64: ive locations for PIR sensors placement

Figure 65: Prototype for tests

Figure 66: The test setup and recording view

9.2 Evaluation result

During tests, there were many activities that happened and observed in 45 minutes, such as people sitting there and working for the whole 45 minutes, or people talking with others, going to the printer or toilet, or grabbing a cup of coffee, or even leaving the workplace to get some snack from the shop nearby. Different activities caused directly different amounts of motion detected. From the previous overview of each participant result, a maximum of 243 motion were detected when one of the participants was talking with another person during the test, and a minimum of 55 motion were detected in 45 minutes when one of the participants just sat and worked for half an hour and went to the toilet for 13 minutes.

The table 7 shows an overview of the numbers of motion detected of each participant, overall occupancy time of their workplace during 45 minutes, their activities, and some calculations can be found in the table as well.

Participants	Time of occupying the personal workplace in 45 mins	Activities	Mean number of motion detected from five sensors	Motions detected in every minute
P1 184mm, male	37mins	Quick leave from the desk, coffee time, concentrating on working with computer, go to the shop nearby for some snack, toilet	73	1.9/min
P2 174mm, female	45mins	Talking with people on the seat, Concentrate on working with computer	111	2.4/min
P3 190mm, male	45mins	Change posture, call, talking with people on the seat, Concentrate on working with computer	243	~~5.4/min~~
P4 169mm, female	32mins	Go to the printer several times, Coffee, Concentrate on working with computer	123	3.8/min
P5 170mm, female	40mins	Concentrate on working with computer, Coffee	75	1.8/min
P6 184mm, female	45mins	Talking with people on the seat, concentrating on working with computer	180.6	4.1/min
P7 170mm, male	32mins	Concentrate on working with computer, call, toilet	55	~~1.7/min~~
Other calculations	87% workplace occupation rate in 45 mins			2.8 motions detected in one minute

Table 7: observation results of the detected motion in 45 minutes of each participant

Overall the seating time From the calculation, it is obvious that people move frequently when they are sitting and working although they are not noticing. By calculating the truncated mean, people move 2.8 times in one minutes. And this result is close to a inding carried out by TNO, they found the legs demonstrated approximately twice as much micro movements as the trunk, and the median number of movements is almost 1 per minute for the legs as table 8 shows.[60]

	Trunk	Legs
Median (P50)	24	57
P25	12	24
P75	48	90

Table 8: number of micro movements in trunk and legs (extrapolated to number per hour)

2 1 Relationship between the amount of motion collected and the sensor location

In table 9, it is obvious that the height of the PIR sensor location and the amount of motion detected are in a positive correlation relation. The position changes in the horizontal direction has no signiicant effect on the data collection.

The result of each sensor indicated the lower location detected fewer micro-movements while people were seated, with less data being collected; the higher position sensed more micro-movements. Moreover, the sensor placed in the middle of the upper edge position measured almost the same amount of motion as the one placed on the top of the right side edge.

The possible reason behind this may be that ergonomic chairs are commonly used in the ofice. When the sensor is placed above the middle, the sensor is aimed at the knee and thigh. When people move slightly, the

chair increases the amplitude and frequency of movement, as the igure 68 shows. So the sensor is able to sense enough data at those positions.

Participants	in the middle of the upper edge 	in the middle of the lower edge 	in the middle of the right side edge 	on the top of the right side edge 	on the button of the right side edge 
P1	96	77	~~55~~	80	59
P2	106	68	140	132	108
P3	~~320~~	~~161~~	~~226~~	~~257~~	~~251~~
P4	104	104	163	128	118
P5	113	64	70	~~60~~	66
P6	228	131	197	240	107
P7	~~68~~	~~25~~	89	83	~~12~~
Truncated mean number of motion detected	**129**	**89**	**132**	**132,6**	**92**

Table 9: the number of motion detected of each sensor

Figure 68: when lower body is moving, the ergonomics chair allow

Thus, to be able to collect enough micro motion data, the sensor should be positioned in the middle of the upper edge, or the area above the middle of the right side edge. However, taking into account the internal cable layout, the location of the edge will be more convenient and easier to access than the middle location, as igure 67 shows.

Figure 67: suggested sensor positions

2 2 Relation between motion detected and activities

The interval time of people to leave their seats depends on the type of activity. From the following igure 68, it can be seen that people have a shorter time to print documents or drink a cup of coffee, and the longest time to rest is to go to the bathroom which takes ifteen minutes. The longer breaks, including meetings or lunches, are mostly more than 15 minutes after asking the participants' experience.

From the observation of the analog output data, it can be clearly observed that when people leave and return to their seats, there is a peak of data, because people will have a lot of movements in their lower body at the moment. Thus, by using one PIR sensor, it is possible to distinguish rest time during the whole working day. But when people work in their seats, there will be irregular rhythms. Some individuals do not move a lot, but someone moves a lot. The igure shows that participant 7th moves more than participant 5th when they are both seated and working at their workplace. The full result of each participant can be found in the appendix G.

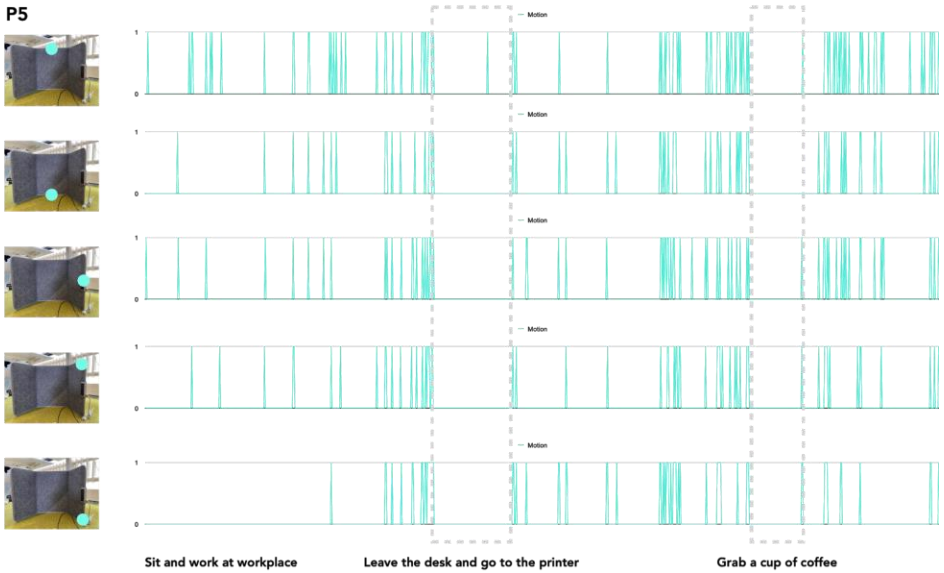


Figure 69: motion detected result of participants and their main activities

2 3 Average interval time between micro-motion

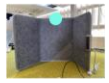
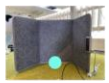
Interval time between two movement	in the middle of the upper edge 	in the middle of the lower edge 	in the middle of the right side edge 	on the top of the right side edge 	on the button of the right side edge 
Longest	3 mins 15 secs	14 mins 15 secs	4 mins 39 secs	3 mins 7 secs	11 mins
	3 mins 6 secs	8 mins 6 secs	2 mins 51 secs	2 mins 29 secs	14 mins
	3 mins 12 secs	5 mins 9 secs	1 min 27 secs	2 mins 54 secs	7 mins 54 secs
	3 mins 43 secs	4 mins 9 secs	1 min 6 secs	2 mins 3 secs	4 mins 15 secs
	2 mins 51 secs	2 mins 54 secs	4 mins 12 secs	2 mins 42 secs	2 mins 42 secs
	2 mins 35 secs	2 mins 35 secs	3 mins 30 secs	3 mins 48 secs	4 mins 12 secs
Shortest	1 min 48 secs	1 mins 48 secs	1min 3secs	1 mins 48 secs	1 min 54 secs

Table 10: the time interval for the longest time when people are still at work

How about the interval time between two movements? From table 10, by observing the data, the longest stationary time detected by the ive sensors form 7 user tests, the least sensitive is the sensor in the middle of the lower edge, and on the button of the right side edge, the longer the interval between motion detected. The short intervals collected from the rest three sensors are used as the database for the average value calculation. As a result, the average stationary time between two small movements when they are seated is at least two and a half minutes.

2 4 etection limitations

During the test, the detection range of the current PIR sensor is inappropriate. The current sensor is the most basic PIR sensor from Seeed [61]. It has a 3 meters detection distance and 120 degrees detect angle which is too large and a small amount of unwanted motion data is collected in one test based on the observation, such as the motion of

people passing, especially when the sensor is placed on the side edge, as igure 70 shows.

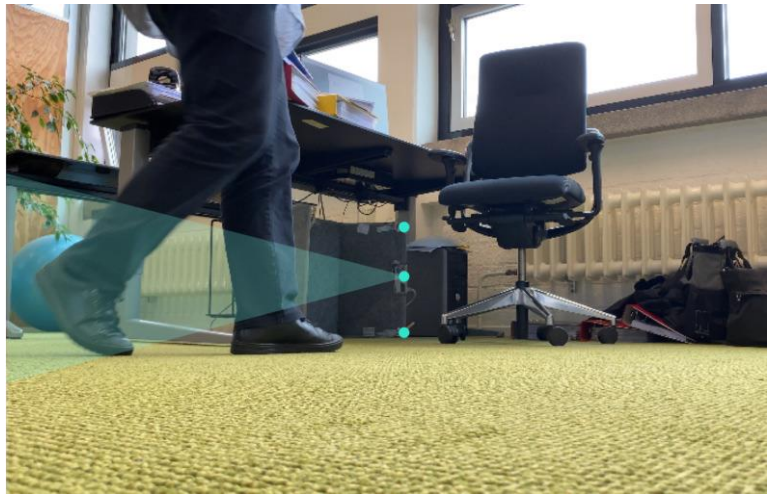


Figure 70: Recorded video clip of when other people passing

2 S Supplementary analysis

The most obvious shortcoming at present is that some undesirable data will be collected. Based on this starting point, some other researches have been conducted, hoping to reduce the amount of biased data collected.

Analog output & digital output

PIRs are basically made of a pyroelectric sensor, which can detect levels of infrared radiation. This chip takes the output of the sensor and does some minor processing on it to emit a digital output pulse from the analog sensor.

There are two types of the motion sensor output. Analog output and the digital output, the most common output is the digital output, digital pulse high when triggered (motion detected) digital low when idle (no motion detected). With an analog output, the uctuation changes are recorded in more detail instead of only high and low outputs.

Some researches found out that by using two or more than two analog sensors combining with machine learning, the system is able to predict the human action speed and direction as igure 71 shows. Figure shows an overview of a PIR sensor with dual sensing elements aligned in a motion plane and its output signal when people are walking.[62] This method could be used as a support to identify the human movement path in the future.

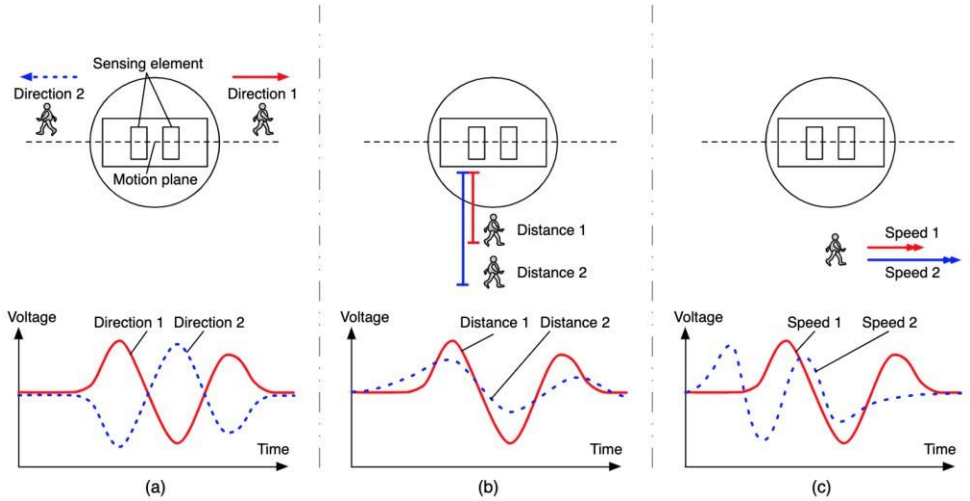


Figure 71: A schematic presentation of a pyroelectric infrared (PIR) sensor with dual sensing elements aligned in a motion plane and its output signal when walking: (a) the output signal in the case of walking in different directions; (b) the output signal in the case of walking at different distances; (c) the output signal in the case of walking at different speed levels.

However, adding more PIR sensors for the detection, collecting data relied on the wi connection, uploading data via wi, and learning the amplitude, the time for model training leads to a more complex system which might not add much value to its core function, as the igure 72 shows. Redesigning the ampliier of the sensor to ilter out the drastic amplitude generated by other activities is another approach to ilter out

the biased data which leads to future research and design opportunities, in this project redesign the ampliier is excluded in the initial scope.

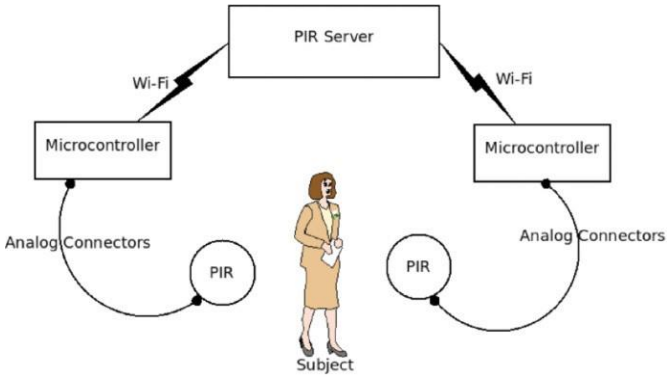


Figure 72: PIR sensors implementation in a smart system

Besides, if we look into the basic information of analog sensors, the average distance range of an analog sensor is 5 meters[63] based on the sensors information in the market, which is too far. A far detection distance is not recommended because it increases the possibility of detection of unwanted data, the most eficient and promising approach for now is using a sensor with a detect distance as short as possible. In the next chapter, discussion about the distance and sensor selection is carried out.

A narrow detect range

Figure 73 shows the side view of the different sensor detection range from 2 meters to 5 meters with different angles, usually a sensor with longer distance detection has a narrower detection angle. A narrower angle means less detection range, which can ilter out some misreading data while maintaining a good detection ability of micro-movements, which observed from a small test using a narrower sensor (AMN33112J) from Panasonic as igure 74 shows. The small test with a narrower detection angle sensor shows the sensor collecting 127 motions in 25 minutes in a seated posture with a 1-second interval detection time of the sensor when the heating is off. And movements of people passing by were collected as well which is undesired. Meanwhile, when the heating was on, the movement of the participant' legs exceeded the detection range due to the narrowed detection angle. As igure 74 shows, the participant posture changed when the heating is on, she moved closer to the product unconsciously, the amount of the micromotion detected is 87 in 25 minutes in a seated posture, less than when the heating is off.

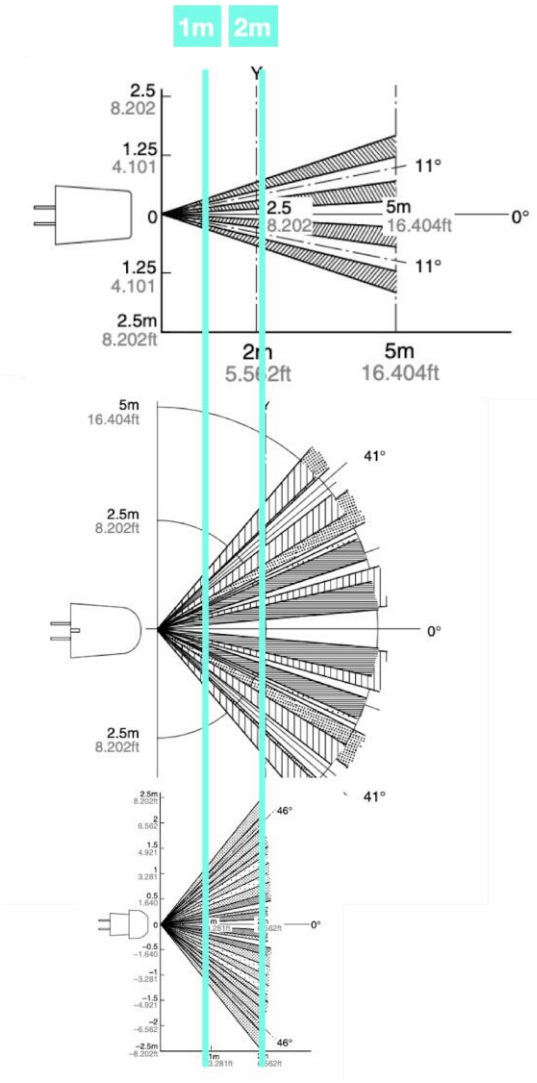


Figure 73: different sensors with various detection distances and angles

Thus, a sensor in a long-distance detection is able to collect suficient data but will be affected more easily by movements generated from a long distance. And covers less area in a short distance detection. Therefore, a sensor with a shorter detection distance and a median detect angle is recommended.

Figure 74: test with a narrow range sensor prototype

Possibility of weaken the infrared lighting

Another small test related to the material of the PIR sensor's lens cover was conducted as well, trying to avoid unwanted data with different material covered to weaken the detection distance. As igure 75 shows, a normal Seeed PIR sensor was used for the quick test. The result shows that the paper and the frosted acrylic blocked the detection. The clear acrylic layer is able to weaken the distance from 3 meters to 3-5 cm, but that detection distance is not enough for micro-movement data recording under the desk.

Figure 75: test of infrared lighting penetration rate of different material

Placement angle

A quick test about the angle placements' in uence on the data iltering was accomplished. Three simple Seeed PIR sensors were used. Three different placement was selected: towards the desk, towards the oor, and vertical placement, their detection areas changed accordingly as igure 76 shows. The prototype for the test is shown in igure 77.

Figure 76:Three locations with different angle placement

Figure 77: the prototype for the angle placement test with feet

Figure 78: the user test with the prototype

After the user tests with three participants as igure 78 shows, each test lasted 35 minutes, different ofice activities observed and participants' micro motions were recorded by sensors. One overview among three tests of the motion detected by sensors is presented in the igure 79. The full result can be found in the appendix H. During this participant test, she seated all the time, and there were no people passing by. The result shows, the vertical placement is more sensitive with micro-movements and the location towards the oor collects the least amount of motion. This inding is found in the other two test results as well.

Figure 79: an overview of one seated participant motion pattern in 35 minutes

Apart from employees working activities, there are other activities happening in the ofice as well. By asking the cleaning lady about her weekly activities, some unusual ofice events were mentioned, such as cleaning the desk, using a vacuum cleaner, as igure 80 indicates. Some other motions from some activities due to other people's movements were also considered and tested by sensors placed at different angles.

Figure 80: cleaning activities and other activities in the ofice

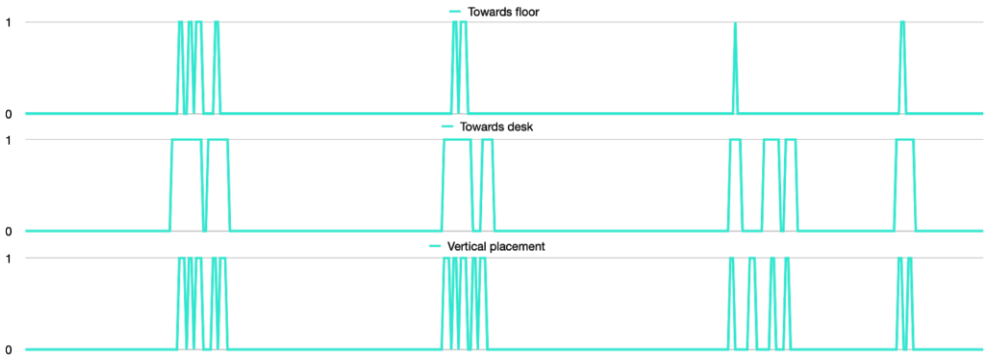


Figure 81: the output from sensors placed at different angles

Figure 81 presented the reaction of sensors placed in three different locations towards other ofice activities. The result shows that the Seeed PIR sensor will perceive unwanted motion no matter how we placed them, one reason behind it might be the larger detection angle of the Seeed PIR sensor which is 120 degrees, and secondly, the path and the range of ofice activities not related to working are unpredictable and unavoidable

since there is not a physical boundary of each one's workplace, everyone can pass by to open a window.

Since other placement positions do not signiicantly reduce the collection of useless data, and the vertical placement position can collect enough movement data, this position is determined as the inal sensor placement position.

9.3 PIR sensor selection

After the research of various potential sensors, a table 11 of comparison between different motion sensors carries out. Links for purchase and reference of each sensor can be found in the appendix I. Due to the time limitation, it is not decided to do prototyping one by one using these sensors, but comparing essential features as the main drivers to determine the appropriate sensor for the final design. In the end, the AMN32112J is selected as the final sensor for the final design as figure 82 shows. Criteria for selecting the sensor:

1. Short detection distance and median angle
2. Low cost
3. Small size for implementation
4. Low energy consumption
5. Is able to be operated under a warm temperature environment

The AMN32112J PIR sensor from Panasonic has an ideal detect distance of 2 meters with a proper detection range of 91 degrees, its size is small as well which is very easy for the implementation. It is optimized for small movements, as its typical applications are lighting controls, ventilators, air conditioners, and multi-functional printers.

Name	Image	Voltage operation (VDC)	Energy consumption	Detect distance(m)	Detect angle (°)	Operational temperature (°C)	Price (€)	Size (mm)
PIR Seeed motion sensor		3 to 5	30-50μA	3-6	Around 120	60	9.95	13x9.5
SparkFun OpenPIR		3 to 5.75	80μA	8	100	−40 to 85	13.63	30x36
Mini PIR sensor		3.3 – 5	12 – 20 μA	2-5	X=110° Y=90°	60	5.95	20x20 x12
Human Presence Sensor (AK9753)		1.71 ~ 3.63	100 μA	3-4	80	60	26	26x26
D6T-44L-06		4.5 to 5.5	5mA	5-6	X=44.2 Y=45.7	0 to 50	48.48	14x18
AMBA210207 Middle type		5.5	7mA	0.2 to 0.8	30	25	44.91	31.2x 23.1x 14
AMN33112J Spot PaPIR Panasonic		5	170μA	5	38°	-20 to 60	22.10	15.1x11
Standard 3112sensor				5	100		18.33	14.5x11
AMN32112J				2	91		15.49	15.2x11
Ultrasonic sensor		3.2 to 5.2	8mA	0.02-0.35	15	-10 to 60	13.95	

Table 11: overview of potential PIR sensor

Figure 82: the AMN32112J sensor

9.4 Key insights

In this chapter, numerous quick tests with users were conducted in the office environment to determine the movements pattern of office workers when they are at office, the accuracy of the PIR sensor and its location, placement, type.

A question from the previous chapter is answered in this chapter:

- **Is the PIR sensor reliable enough as a standalone solution for occupancy detection in the office?**

1. **People micro move a lot when seated and working**

   People move a lot when they are sitting, it is reliable to collect enormous micro motion data as a presence proof with one PIR motion sensing approach. From the data collected, after some calculations, on average in a seat posture, people micro-move around 2 times in 1 minute. And more micro motion could be collected with a shorter PIR sensor detecting interval time. Therefore, 1 second as a PIR sensor detecting interval time would be adequate.

2. **Placement and data collection**

   The higher the position of the sensor is, more data can be collected, especially when the location is higher than 25 cm from the ground. The lower sensor collects very little data. Placing the sensor in the middle or on the edge has no effect on the amount of data collected.

   The placement angle of the sensor has a certain impact on motion detection. The angle placed toward the ground senses less motion, while the angle facing upward and toward the user can harvest enough motion under the same movement. But the placement angle cannot avoid the collection of unwanted data.

3. **Workers office daily activities pattern**

   From patterns of participants' micromovements, workers' office activities are able to illustrate based on motions frequency. When people are working and seated at their workplace, random micro motions are able to be detected, and stationary time between two motions is at least two and a half minutes based on user tests. When they have breaks, there will be no motion detected, when they leave the desk or return the desk, there is suddenly a peak of the micromotion from the lower body. The breaks are divided into two types by using 15 minutes as a boundary, a break within 15 minutes is considered as a short leave including coffee/toilet breaks and a break that is longer than 15 minutes is considered as long leave, such as having lunch and meetings.

4. **Limitation of using one PIR motion sensor**

   At this stage, speciic office activities cannot be intelligently distinguished by only one PIR sensor, it is unable to avoid all unwanted data. But an appropriate angle and short detection distance are able to reduce the detection of long-distance movement effectively. Thus, the AMN3211J sensor is selected.

Reflective points

Since tests were performed without heating due to the safety reason, how people move with a heating is still unknown, more pilot tests with the heating leads to a further investigation in the future. As earlier mentioned, some unwanted data can still be detected with one PIR sensor, further research to avoid the unwanted date by using one sensor is needed.

10. Cycle 3: Interaction design development

After validating the PIR sensing is able to be a feasible and promising method to detect people's presence in the ofice. In this chapter, more focus is on the interaction between the smart heater and the office workers. Therefore, several iterations and user tests were performed to get a simple, direct, easy to use interaction design.

The purpose of the context study is to answer following questions:

- **What kind of interaction should be designed for employees while using the smart heater at their local working place'?**

10.1 Interaction method deinition

By researching the current solutions of temperature adjusting, some ideas were proposed. After a roleplay test with different approaches of adjusting temperature, the most simple, uent, direct one of capacitive touching switch was selected for further development.

1 1 1 urrent solution of temperature controlling

Blackler and Popovic (2006, p.9) [64]introduced a design methodology for applying intuitive interaction.

As igure 83 shows, intuitive interaction model indicates the impression of an intuitive, simple interaction is based on:

- Body re ectors
- Population stereotypes
- Familiar features from the same domain
- Familiar features from other domains
- Metaphors from other domains

The article notes that the important parameter for designers to use to implement intuitive interaction will be familiar features from the same and different domains. As the below collage showed, an analysis of current thermostat, conventional controller, controller s from other domains were performed.

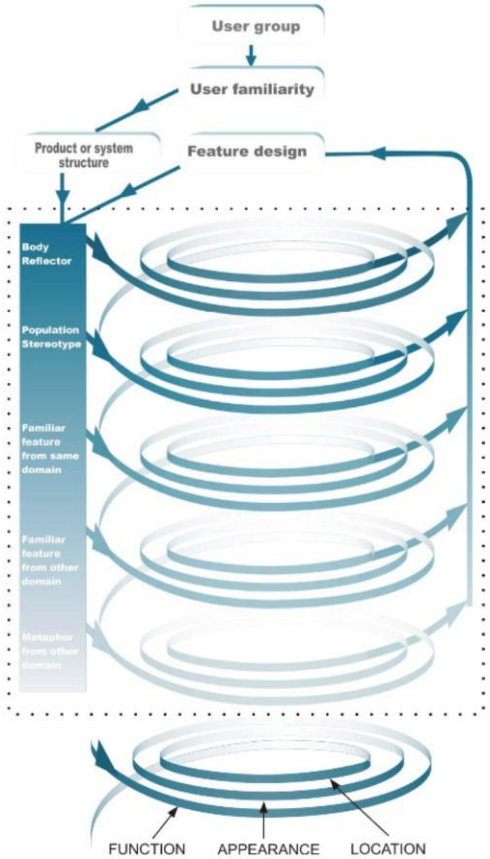


Figure 83: intuitive design model

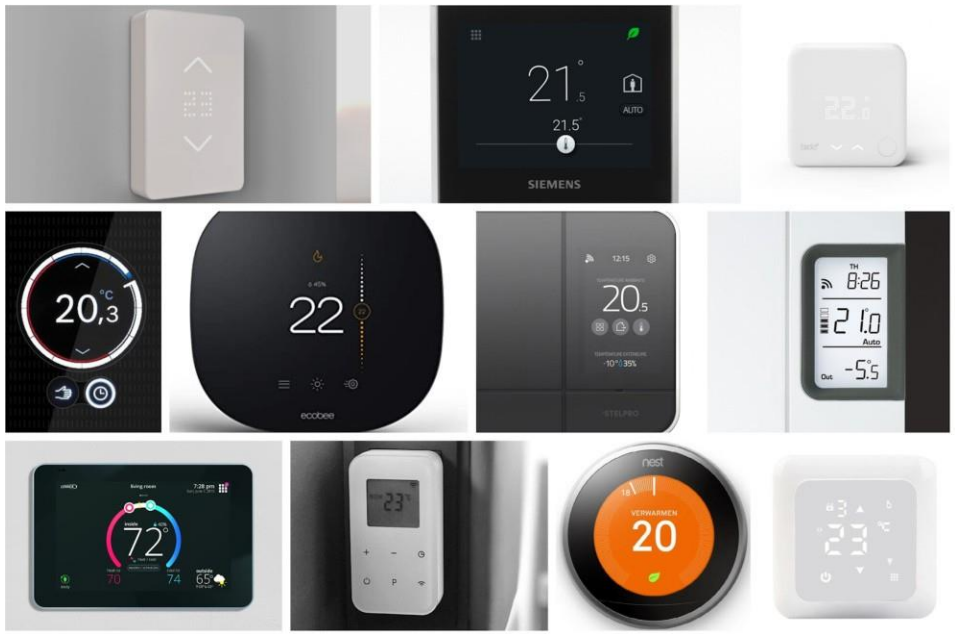


Figure 84: collage of familiar features form smart thermostats

The main characteristics of a smart thermostat are:

Informations: There is at least one number indicating the current room temperature, on and off functions, some products have two temperature numbers, one indicates the target temperature, another means the current room temperature. Modes, environment-related information such as outside temperature, weather, indoor humidity is illustrated on the control unit.

Control method: Flat touching buttons, sliding wheels, touching interaction have been used widely for adjusting the temperature.

Appearance: White colour is often used as a neutral colour for basic information illustration. Some products have an "ECO mode" presented by a green leaf which is able to reduce the temperature when there is no one while maintaining the adequate indoors temperature. Icons and text both are used.

Figure 85: collage of familiar features form local heating system control unit

The main characteristics of a controller of local heater are:

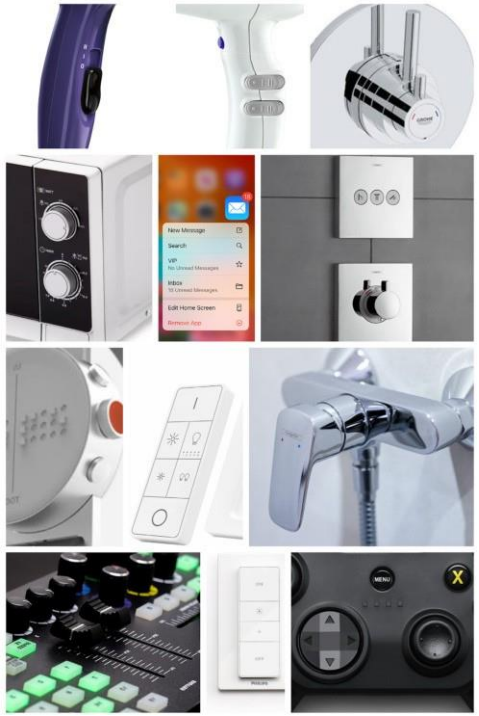
Informations: There is no number indicating the room temperature if there is no screen on the control. The main and basic function of the interface is on and off, adjusting temperature, users can adjust the electricity power, wind power or usage time as well as other inputs with some products.

Control method: As a controller on a local conventional heater, heating fan, or an oil heater, the most common control method is the knob. Apart from it, buttons also often appear on the product.

Appearance: A reddish colour, a gradually thicker line segment, numbers are used to represent the heating levels. No signiicant sign of saving energy features or any related information.

The main characteristics of other domains are:

Control method: Pressing buttons for different levels, longer pressing to operate sub function, turning wheel is commonly used in changing working status .



Appearance: The light bulb symbol that increases proportionally on the button serves as a reminder of increase or decrease in brightness. Uneven surface and different texture on hair dryer and game comptroller are also used as another sensing perspective as a control unit. Lighting is used to giving feedback as a physical music editor. As a bath tap, red is considered as warm and blue is considerate as cold.

Figure 86: collage of control methods from other domains

1 1 2 KA model

The interaction is based on the functions. The most fundamental function of the product is providing heating, and there are other features that are possible to be added to the product as well, such as different modes, adjust the temperature, auto turn off the heater during the short break, etc. The possible functions list is generated under the discussion with the client and inspired by the previous study of controllers in the same domain. To prioritise different features so as to clarify essential functions for further interaction design, the Kano model is applied.

The Kano model is a theory for product development and customer satisfaction developed in the 1980s by Professor Noriaki Kano, which classiies customer preferences into four categories, as the list showed below.[65]

1. **Threshold attributes (Must be)**
   Other product features are simply expected by customers.
2. **Performance attributes**
   Some product features behave as what we might intuitively think that Satisfaction works: the more we provide, the more satisied our customers become.
3. **Excitement attributes (Attractive)**
   There are unexpected features which, when presented, cause a positive reaction.
4. **Indifferent attributes**
   Naturally, there are also features towards which we feel indifferent.

After calculating the score of each feature a KANO model is carried out with an online calculator[66] based on 16 questionnaires answered by employees, a full questionnaire can be found in the appendix J. Figure 87 shows the distribution of 13 features. Considering their importance level (the size of the circle), the results suggested that fast heating speed is considered as a top performance feature, followed by auto switch off only for a longer leave (a leave longer than 15 minutes), manual override of the heating. Remembering my settings is considered as the most attractive feature, followed by the information on working status and the adjustable detection interval time of auto-stop heating. Adjusting by levels or degrees and showing the heater's current heating temperature are considered as indifferent features. The importance level of the rest features are weighted not as much as previous features, which will be excluded in this project temporarily.

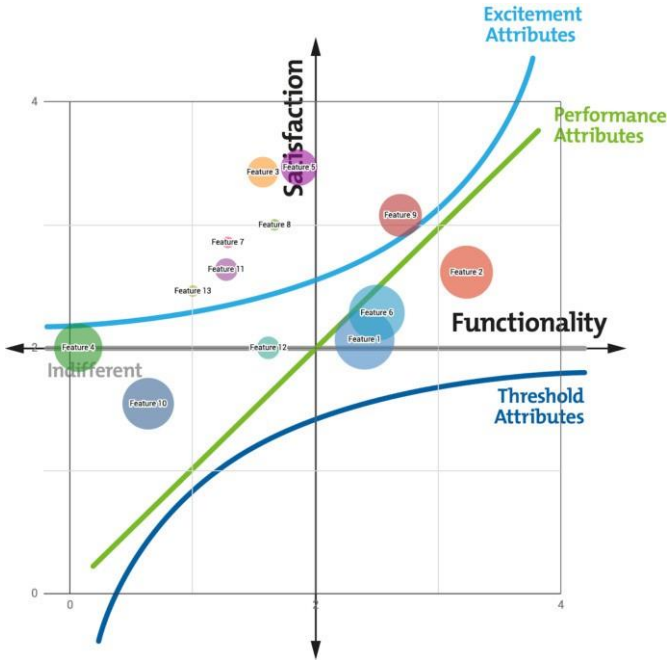


Figure 87: different functions located in the Kano model

Threshold attributes	Provide sufficient heat in a cool environment	
	It is safe to use at the office	
	Able to personalise the local temperature	
Performance Attributes	Feature 1	User can feel warmth within 5 mins
	Feature 6	Manually switch off the heating
	Feature 2	Auto switch off only for a longer leave (longer than 15 mins)
Excitement attributes	Feature 9	Information of working status
	Feature 5	Remember my setting
	Feature 3	Adjustable interval break time (5 mins/10 mins/15 mins)
	Feature 7	Preheatting
	Feature 8	Notification of the heater is working well
	Feature 11	Show local air Temperature
	Feature 13	Timer of heating time
Indifferent features	Feature 10	Adjust by levels / Adjust by degrees
	Feature 12	Show heater's current heating temperature
	Feature 4	Auto on when user arrive their desk next morning

Table 12: the priorities of different functions

There is no doubt that a quicker heating speed is mostly desired as a local heater, basic functional features are on and off of the mainpower (heating), turn off the heating after a 15 minutes leave. Thus, people prefer to have a warm environment when they come back from a short break. Information of working status and remember my settings are delightful features for users. To keep the system simple and direct, the adjustable detection time is excluded in the interaction design after the discussion with the team.

1 1 3 Initial intervention of temperature adjusting

A use process list[67] focused on the interactive activities is made to schematically check the activities that the heater will encounter during the irst usage with basic functional features. This list helps to deine what functions and information that the control unit needs to provide for the inal design. The underlined words are important elements that are necessary to be illustrated on the control unit. Following shows the use process for the irst time:

- Position the heater under the desk
- Plug the heater into the socket
- The heater is completely off
- Turn on the main power
- Select the temperature
- The heater is heating with the occupancy detection is on
- Turn on/off the smart detection (optional)
- The heater reached its heating level after 5 minutes
- The heating is off when there is no human presence detected within 15 minutes
- The heating is on again at the same heating level when detected motion
- Check the caution information when the connection is loose or any problems with electronics insides.
- User should unplug the product and contact the company for the maintenance.
- The heater is completely off after oice hours.

Based on research of the beneits of local individual heating and the Kano model, adjusting temperature personally is the core function for this project, also the key interaction activity during the usage. From the study of the existing temperature control methods, four different basic interaction prototypes of adjusting temperature were generated as igure 88 shows from left to right, to validate the interaction quality of each of them:

1. A knob allows adjust temperature by degrees
2. A knob allows adjust temperature by three levels from off to low, middle, and high.
3. Capacitive touch sensors with lighting indicator which allows adjust temperature by three levels, and an on/off function
4. Normal buttons with lighting indicator which allows adjust temperature by three levels, and an on/off function

Figure 88: four different interaction methods

1 1 4 Interaction method comparison

The goal of the test is to validate different adjusting temperature method's interaction quality, 6 employees participated in a user test, the full procedures and results can be found in the appendix K. During the test, participants operated four control methods individually, and illed a

questionnaire of its interaction quality based on an interaction quality vocabulary.[68] Figure 89 shows the setup of the user test.

Figure 89: User experienced the prototype and scored a different interaction quality.

Figures 90/91 of the interaction quality results shows that it is more stepwise and powerful when adjusting temperature by the knob in levels. However, there is no big preference between adjusting by degrees and by levels from the Kano model, it is an indifferent feature.

When the comparison between knobs, buttons, and touch buttons, although all three methods are direct, apparent, instant, there are some obvious differences in the other qualities of interaction. The knob is considered the slowest, the most stepwise, slight approximate, but also the most powerful. The normal pressing button is considered as median uent, slightly powerful. The touching buttons are the most fast, uent, precise, gentle, with the least effort.

Apart from that, two attractive qualities were scored for each controlling as well, the touching approach scored the highest one, which showed its potential to help the product convey the feeling of premium. Thus, The touching capacitive switch was selected as the main interaction method for further development.

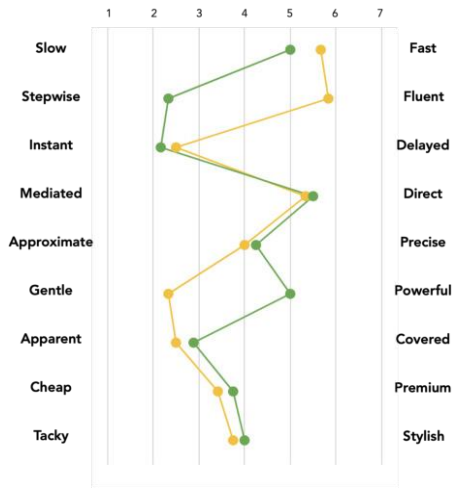


Figure 90: interaction quality results of the different interaction method (1)

- *A knob allows adjust temperature by levels*
- *A knob allows adjust temperature by degrees from off to low, middle, and high*

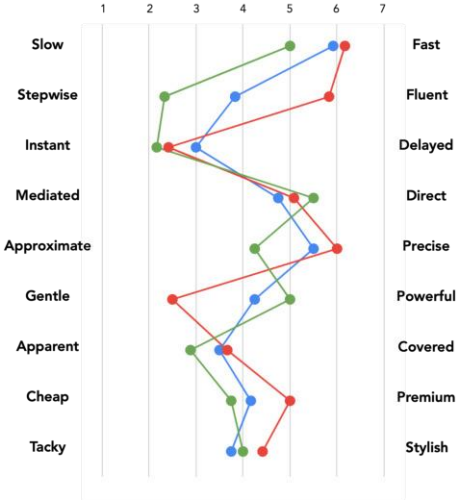


Figure 91: interaction quality results of the different interaction method (2)

- *A knob allows adjust temperature by levels*
- *Capacitive touch sensors allows adjust temperature by three levels*
- *Normal buttons allows adjust temperature by three levels*

1 1 S Icons and texts validation

A questionnaire was released to validate some ideas of the usage of icon and texts for the touching interface design by applying the datum method [69], comparing different ideas and understanding what characteristics is able to indicate the feature clearly. The full questionnaire and results can be found in the appendix L. Figures 92 shows some options of initial icon ideas aligned with different features. With 10 responses, icons and designs were scored the highest is highlighted in blue square.

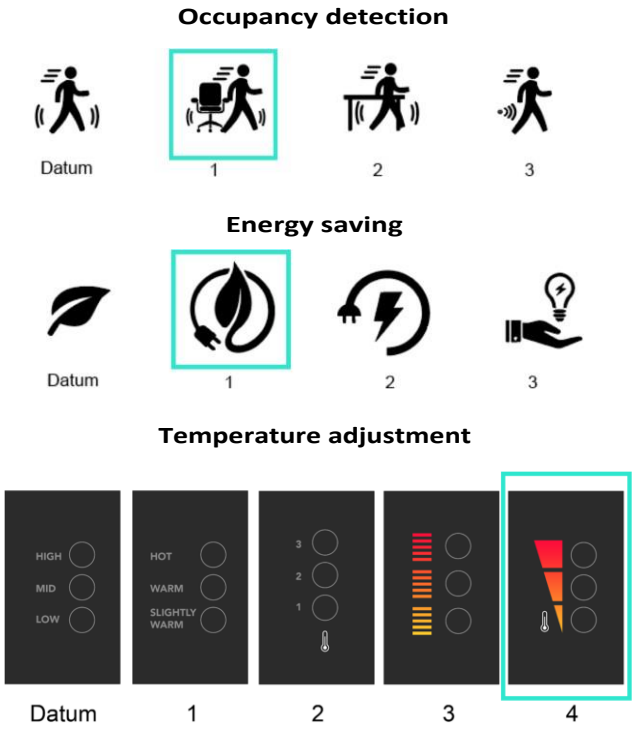


Figure 92: initial icon ideas of touching interface

There are some characteristics that are able to be applied in a further design based on users feedback. The icon of the moving person clearly conveyed the meaning of the heater detecting a person is leaving its place, but actually, when people are sitting at their workplace, the information should be "presence detected". It reminds the focus and the information that should be conveyed in later design.

The leaf is able to convey the information of using clean energy, or using a lower temperature to warm locally, which is not desired. Also, the rest design can not connect the saving energy with the smartness, people will think the product is charging when there is an element of the plug. The increasing blocks in reddish can quickly indicate the function of adjusting temperature compared with text.

In order to get more insights on the control interface during user use, to help improve the design. Tests combined with actual usage scenarios were conducted, which is introduced in the next section.

10.2 Initial interaction design validation

In this section, a roleplay user test was executed to validate the initial interface design and the whole user experience under the form of heat. At the end of the validation, some new insights were carried out and implemented in the next iteration cycles of the interaction design. To prevent covid-19, necessary procedures were taken into account such as distinct hands before the test and after the test. The heater will be removed every time when there is no test for safety reasons.

1 2 1 ethod

6 employees participated in the test voluntarily, during the test, participants were asked to accomplish some tasks in certain scenarios (ill sudoku as working, watching the video as having a conference, leave the test space as having a toilet break) as igure 93 shows, the designer pretended to be the "machine" to provide the smartness of the occupancy detection. The full procedures of the user test can be found in the appendix M. After the test, participants were asked to ill 20 questions based on Likert scales.

In order to stimulate the real usage scenario as much as possible, a small meeting room was used as a chamber room to get a cool environment as igure 94 shows, where no people were using it. When the window opened and the door of the room closed, the air temperature could be lower to 18 to 19 degrees celsius in the morning, and a fan was added on the table, in any case, that the air temperature was higher than 19 degrees celsius. An air temperature sensor on the black box was placed on the table to detect the air temperature of the room. The local heating was provided with the commercial heating panel.

Figure 93: doing sudoku as working, watching video as having conference

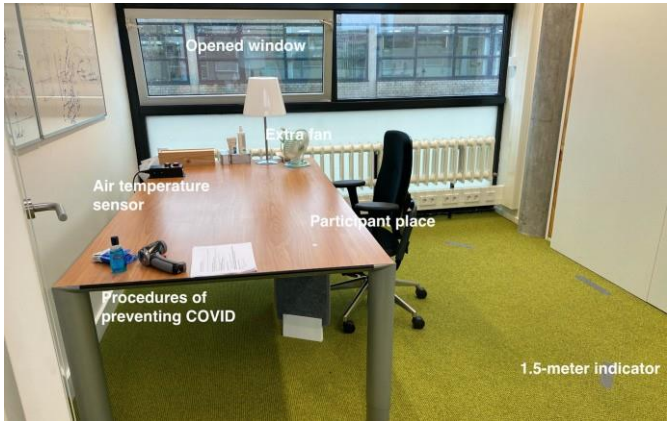


Figure 94: test set up environment

1 2 1 esign intervention

After the interaction quality test with different control methods and a validation questionnaire of icons, an initial interface of capacitive switch was created by using the phone, which is able to stimulate the same touching feeling. Figure 95 shows the capacitance switch. The working principle of the capacitive switch is using body capacitance. [70] The electrode can be placed behind a non-conductive panel such as wood, glass, or plastic. The switch keeps charging and discharging its metal

exterior to detect changes in capacitance.When a person touches it, their body increases the capacitance and triggers the switch.

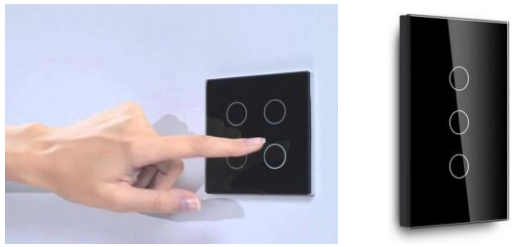


Figure 95: capacitive buttons with transparent glass layer

Figure 96/97 shows the prototype for the test, a 3D printer phone holder is attached on the edge of the heater for placing the phone. The content of the initial interface design is shown. Red, yellow, and green are used as the key colour cue for different information, some icons are used to inform the user the working status of the heater. There is animation of the temperature setting added into the interface, when the heater is heating, the red circles are ashing and when the heater reaches the targeted temperature, the ashing stops.

Figure 96: prototype for the test

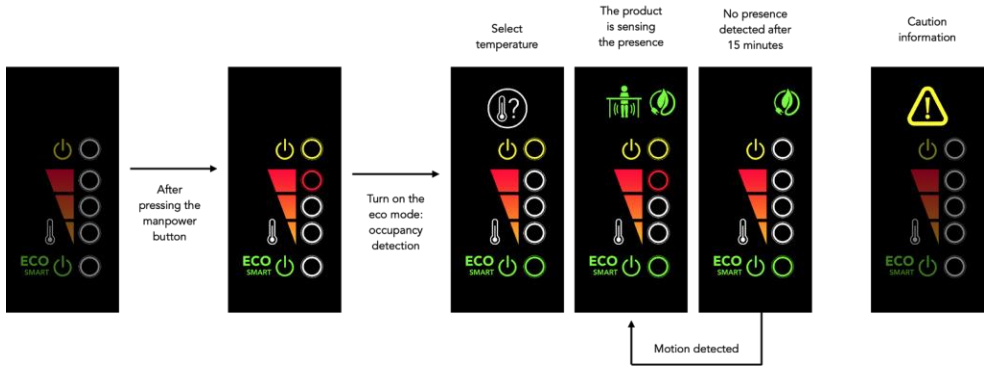


Figure 97: the work ow of the capacitive touch buttons interface

1 2 3 Results and indings

Main functions

After the test, some valuable insights were carried out. There are four scores of the thermal comfort perception and thermal sensation of with heater and without heater as table 13 shows, which was scored based on the descriptor scale shown in table 14. The overall score of using local heating is higher than the score without local heating.

In a cool environment around 18 to 19 degrees Celsius	Thermal comfort level	Thermal sensation level
Without local heater	-0.83	-1.17
With local heater during the test	0.50	0.83

Table 13: score of thermal comfort and sensation of with local heating and without local heating

It shows that with a local heating, less cool was sensed, a comfortable warmer environment was perceived by participants. The result shows that a local heating contributes to the local thermal conduction of a cool environment positively. They have a stronger feeling of control of the local environment. People are satisied with having a personalisable local heater at ofice.

Scale value	Thermal comfort descriptor	Thermal sensation descriptor
+3	Much too warm	Hot
+2	Too warm	Warm
+1	Comfortably warm	Slightly warm
0	Comfortable	Neutral
-1	Comfortably cool	Slightly cool
-2	Too cool	Cool
-3	Much too cool	Cold

Table 14[71]: Thermal comfort scale and thermal sensation scale.

During the test, participants liked the approach of "set the temperature and forget" with the person detection on. Besides, they did not often turn the "ECO SMART" off, because they felt the motion detection did not directly affect the heating provided as one participant mentioned. Indeed, the temperature of the heating was not in uenced by motion detection, it was controlled manually by the user. Thus the "ECO SMART" is suggested removed and set as a default setting which is also able to help the system be simpler and save more energy in daily use.

Quote from participant: "Nowadays I expected all new products to be eco and smart, so I didn't need to control that. I did not notice a difference in its functioning with it on or off."

Findings of sub functions

Participants did not often touch the interface once they found their personal settings, and they did not mind if they needed to turn on again the next morning.

Actually, they preferred the auto turned off heating after the ofice hours feature. Because it probably could make them confused if the heater is working accidentally on the next morning at six due to an unwanted motion detected. It ensures safe and eficient heating.

Appearance

The physical control unit location during the test was not considered as an ergonomic comfortable place, it is not reachable for users as igure 98 shows. The score of the reachability was 5 out of 7 based on the Likert scale. The physical position of the control unit should be closer to the user. And the information on the control unit needs hierarchy. Although colour codes helped participants to distinguish different functions and features positively, two power icons and the overall distribution of the interface confuse participants.

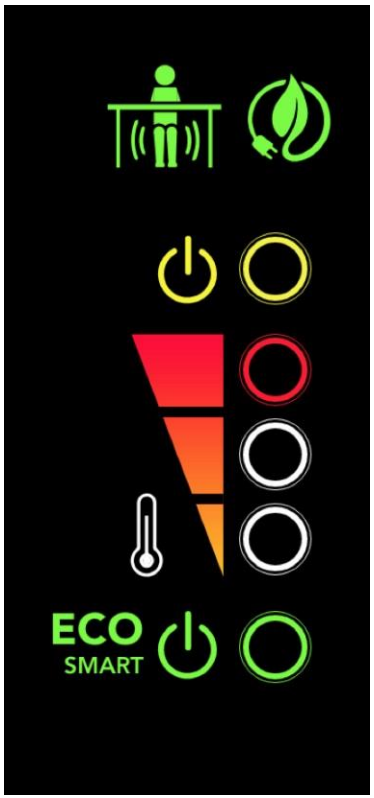


Figure 98: the location of the control unit, the overall interface

Figure 98 also shows the initial design. Three levels of the heating scale are used during the test, but when the user is asked to describe " how many levels are preferred as a local heater", half of them chose 5 levels instead of 3 levels. The reason mentioned by some participants is that a larger temperature scale psychologically gives a stronger feeling of the

personalisable temperature, and a higher ability to adjust the local temperature. Thus a 5 levels heating temperature scale is implemented for the inal design.

Quote from participant: "More options creates higher expectations on the thermal conditions being perfect"

The understanding of the smartness

The relation between the presence detection and energy saving was unclear to participants, there are two main reasons behind it: irst is that when the participants checked the control unit, the location of the information was too hard to notice some working status indicator, the top part of the interface where the information located was blocked by the desk surface. The information should be placed in a lower, more visible place.

Besides, icons and text were readable but participants were uncertain about the meaning behind the icons as one participant stated. The function was clear during the test under the proper test scenarios, but it was hard to link " ECO SMART" to the person's detection at their irst impression. People usually link the eco and the icon to a feature by using a lower temperature to warm the space to save energy or using clean energy to power the heater, not the person detection. Thus, the current design is not intuitive enough for users to understand the smart features and how it works with motion detection.

Quote form participat: "It is very readable, but I had not understood all the signs listed above without explanation."

10.3 Interaction design improvement

In this section, ive quick and loose iterations of the interac interface design were performed to improve the usability of the interaction design. Taking different insights from other IE students into account, a lighting is added into the interaction. In the end, a simpler, clearer design is carried out.

1 3 1 ighting indicator

Lighting is added to the inal design because the space under the desk needs a stronger indicator of the information. One assumption is that lighting indicators are able to make people understand the smart feature of person detection quicker because the PIR motion sensor technology is widely used in interior smart lighting design. People probably are able to connect the person detection with the lighting changes. The ideal condition is that when the light is turned on, people could understand it means the product senses a person's presence and is working, providing heating. When the light off means no person's presence is detected, while the heating stopped.

Lighting could be a simple intermedia that supports the communication between the heater and users. To be intuitive lighting information, some lighting information from other domains were explored. As the caution information, yellow and a warning sign with an exclamation mark is used based on a study from the collage of caution information from other domains as igure 99 shows.

When the heater is still on but without heating, it means that only motion detection is still on, the heating was actively turned off because the presence of a human body was not detected. It is similar to the standby mode of a computer or TV that it is on, in a sleep mode which can be woken up easily. Figure 100 shows some examples of standby lighting indicators. Blue dimmed lighting is commonly used as a standby lighting indicator, which conveys a feeling of enabled and available. Thus blue lighting is used to indicate the working status when there is no motion detected. In order to reduce information con icts, red is used as an indicator of temperature, yellow is used as an indicator of caution information.

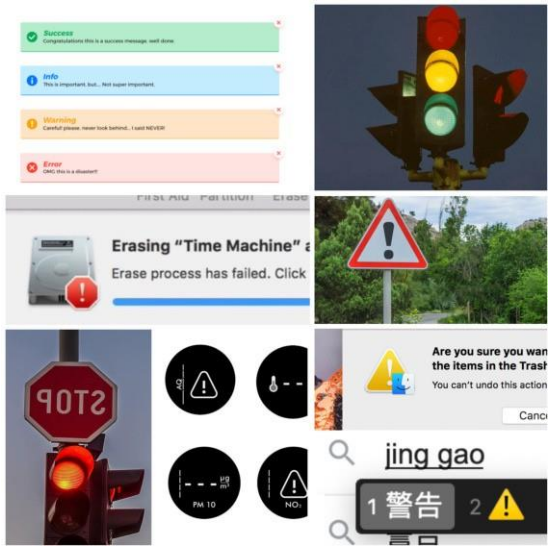


Figure 99: collage of caution information from other domains

Figure 100: collages of stand by lighting from other devices

1 3 2 Iteration results of interaction design

To validate the lighting design and the overall interaction design. Five interviews were performed with several IDE students to bring new input into the design. The interview was conducted via Zoom as igure 101 shows, during the interview, the background was brie y introduced, there were three main questions discussed after I described the using scenarios and illustrated the animation of the control unit in XD adobe. Three main semistructured interview questions are:

1. Was the prototype clear to you?
2. Can you understand its smartness?
3. Was the lighting clear?

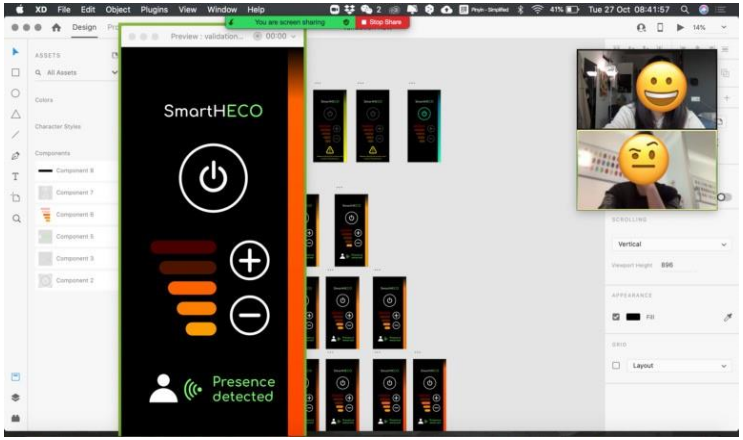


Figure 101: interview via zoom for the interface iteration

With the iteration loops, the understandability of new interface design is easier than the initial design. All insights are concluded in three categories. lighting, information, location. Valuable insights were implemented into the inal design after a careful consideration and discussion with the supervisor team.

Lighting

Most participants clearly understood the red means the heater is working, the yellow means the heater is broken, the blue means the heater is standby. The transformation from red to blue lighting conveys the sense of the heater detecting my occupation during the test, which reminds them of the auto lighting. However, some of them have the concern that "A red lighting thing next to my seat for me or others probably looks like an alert." Thus the end design using an orangish red represents temperature.

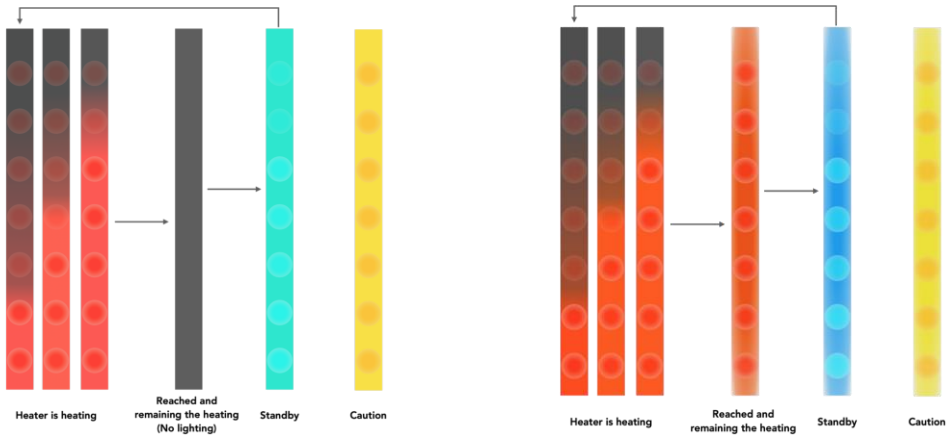


Figure 102: iteration results of lighting

At the beginning of the iteration, there is only one repeated animation of the temperature rising representing the heater is working. And then the reddish lighting will be off after 5 minutes when the targeted temperature is reached. But it made one participant feel strange because her experience shows when a lighting indicator is on means something is happening, such as the induction cooker. If it is off, it might mean it is not working. Therefore, when the heater remains temperature, the red lighting should be on which indicates the heater is still working. So the lighting information of the product remains temperature is added as igure 102 shows.

The light of the standby was too green which leads to an impression of green energy. Thus the colour was calibrated to blue after some interactions shown in igure 102 as well.

For the lighting changes, the yellow light was static at irst, but the prioritization of "caution" is higher than "the heater is heating" or the "heater reached the set temperature", which has a higher hierarchy. Thus its light changes should be different from the rest and visually stronger. Thus a ashing animation is added which is able to drag users' attention and help them distinguish the caution status from the normal status effectively.

Information

With the lighting, the information is clear for users, but the general style could be more united. Figure 103 shows the process of uniting style and simplifying components.

Figure 103: process of using less components and improving style, the right one is the end design

In one of the iterations, without any text, one participant felt dificult to understand the functions without my explanation, when the version with a short description of person detection was shown to him, he felt much more clear and easy to understand the features of the product. To achieve the goal of requiring the least learning time with minimum instruction or without manual, short test description is necessary.

The "ECO SMART" name and its sign is removed from the design to reduce the chance that the product is considered as lowering the temperature to save energy. More description and icons were added in the caution status to help users to understand what happened and what they should do later as the igure showed.

Figure 104: tips for caution status

Location

Most participants do not think they will often check the interface which probably is harder than checking the lighting. If the lighting is placed at a location where it is easy to be seen, it would be a great quick indicator. Most of them agreed that a led lighting on the side is easier to be seen by them, perhaps the lower location is easier to see, but it still needs to be evaluated. Figure 105 shows the selected location of placing the lighting strip for the later inal evaluation test.

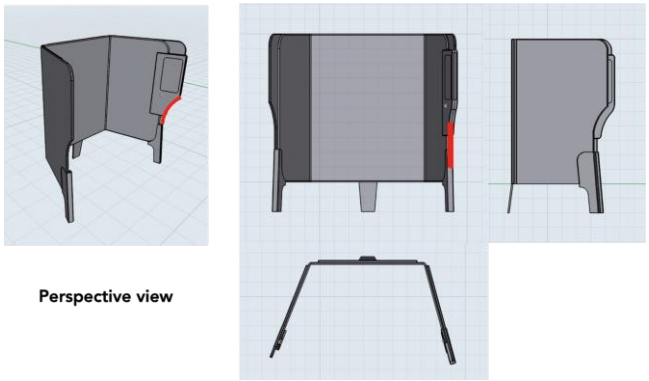


Figure 105: CAD model to illustrate the location of the LED lighting

10.4 Final interaction design

Figure 106 shows the inal design after 5 quick iterations. The QR code that can be scanned shows the control process and the animation of the led lighting. The lower igure 107 shows the simpliied work ow of the capacitive switch interface. The overall interface switch was simpliied with thick white lines that have a stronger contrast with the background. The style was also uniied, clearer with fewer elements.

The key information of the person detection remained and clariied with a human icon, an icon of infrared detection, and a short text description. The heating scale becomes ive levels to give more options to adjust the heating to fulill individual thermal expectations. After pressing the main power switch, the heater starts to heat automatically to a median level that requires less learning time and steps. There are ive status of lighting aligned with the working status:

- The heater is off.
  No lighting.
- The heater detects human presence and it is heating to the target temperature.
  Red led lighting is wiping on the strip from bottom to the top repeatedly with the reddish colour aligned with the interface temperature levels' colour.
- The heater reached the target temperature, and is maintaining the temperature.
  Red led lighting stays statically in that colour.
- The heater is on standby mode, the heating is off when people leave for a longer time. (longer than 15 minutes)
  Led lighting turns to a static light blue.
- There is something wrong with the heater, it stops working
  Led lighting is ashing in yellow.

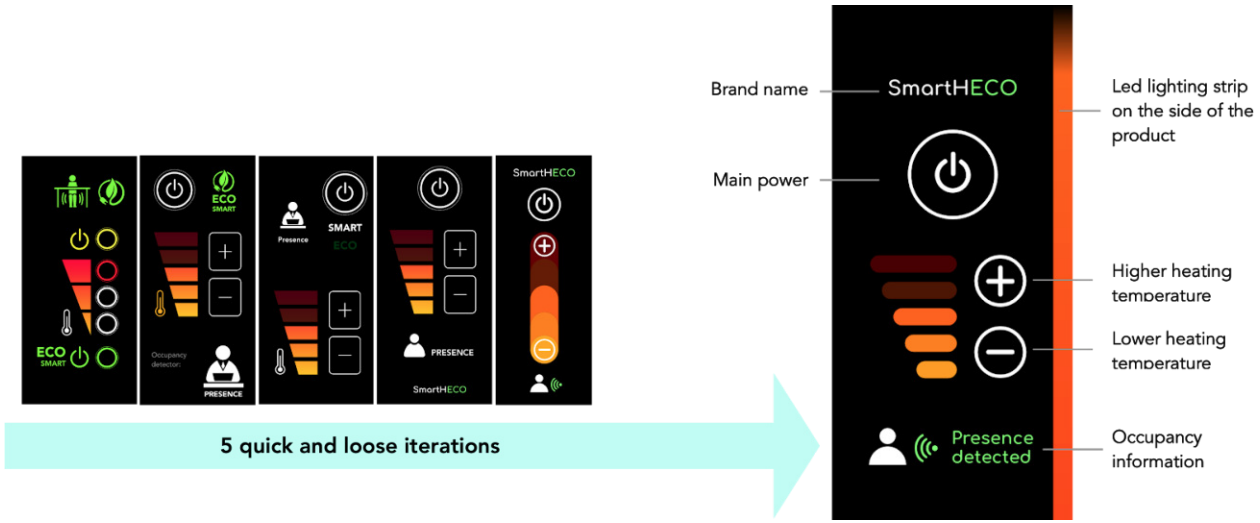


Figure 106: 5 iterations around the interface design and the final outcome

Check the animation by scanning me!

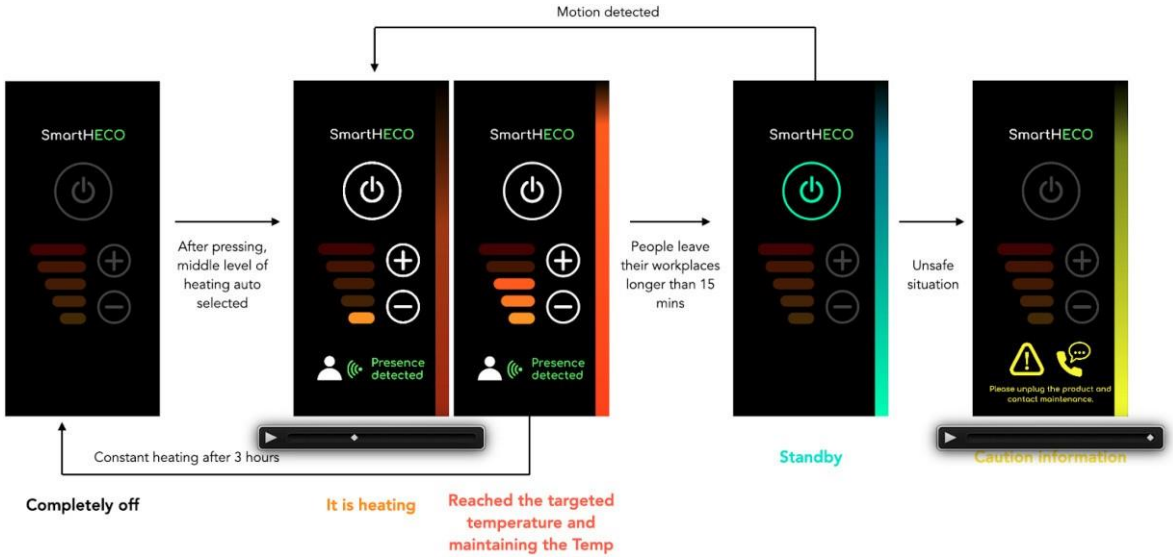


Figure 107: simplified work ow of the final design of the interface

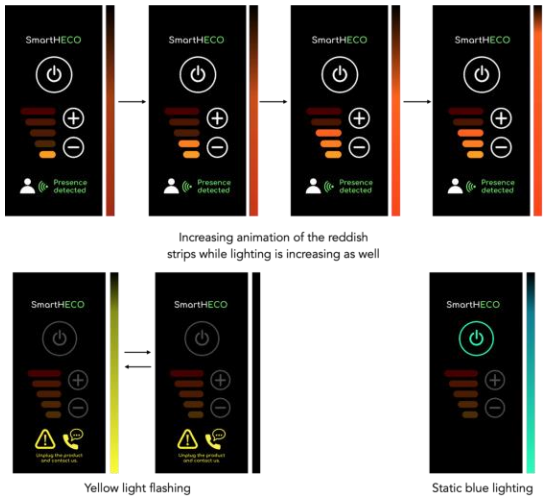


Figure 108: animation description of each lighting information

10.5 Key insight

In this chapter, by establishing a Kano model, priorities of each feature were found. After several user tests and online interviews, a inalised interaction solution was carried out which consisted of capacitive touch switches, and a led lighting strip as a quick indicator.

1. **Priorities of functions**

   The most important functional feature is to make the user feel warm in ive minutes which re ects the decision of the type of the infrared heating ilm, the power should not lower than 165W. The second important feature is personalising local temperature. Following with the rest smart features: maintaining the heating during a short break, and remembering my settings.

2. **Capacitive touching switch**

   Among four different interaction methods, the user test of the interaction qualities suggested that the capacitive touching sensor is able to be the main interaction approach, because it is fast, uent, apparent, and also has its potential to be premium and stylish.

3. **Interaction usability test in a simulated environment**

   From the Kano model and the second user test, participants prefer to have a warm place when they return from a short break, such as a coffee break, going to the toilet or just a quick chat with colleagues. It is acceptable for people that the heating is off when they back from a longer break, such as having lunch or meetings. Participants like the feeling of set and forget, they appreciated the motion detection feature which is re ected from the second user test.

   Surprisingly, they did not mind turning on the heater next morning manually, instead, they felt more safe with the product if it is able to be off completely by itself after the ofice hours. Besides, it is acceptable by participants and would not necessarily be a bad thing if products are on and in its eco-mode automatically, provided this mode is really eficient, convenient, clear to consumers, and most importantly, largely used by default coils save more energy in the future.

4. **Iteration of switch interface design**

   During the interaction usability test in a simulated environment, the interface was not well structured and designed, so as its physical location. All participants felt complex when there were too many elements to operate during the irst usage. Thus ive loose iteration loops of the interaction design were generated, the overall design is simpliied and the style is united. The result of the iteration with ive peers imply that the lighting can help the interactive activities during the usage. The understandability of the smartness is enhanced by adding a lighting quick indicator and simplifying the interface. And the inal interaction design is used for the inal evaluation test.

Reflective points

I felt the restriction due to the covid situation especially when I was conducting the user tests, however thanks all kind help from employees of De Bouwcampus and my peers. It also reminds me that it is needed to be exible and communicative during the project especially under the unusual period.

11. Cycle 4: inal concept

In the inal cycle, the concept was inalised by adding feet and other components. The inal prototype was tested out with users in a simulated oice environment. In the end, new input of the ergonomics, the interaction design, the physical product were carried out, and implemented into the inal design.

11.1 Feet design

In this section, some ideas of feet of the product were generated based on the human ergonomics and the ofice environment.

11 1 1 eet height deinition

To determine the proper space for feet, igure 109 shows that the European instep height is below 70 mm. The heater will be placed under the desk, the ofice desk height is usually above 620 mm after viewing different ofice desks in the ofice. The width of the carbon heating ilm is usually around 50 cm, thus to have enough space for employees' feet, the ideal range of the height is from 70mm to 120mm. And 100mm is decided as the height for the feet space for later prototyping after careful consideration.

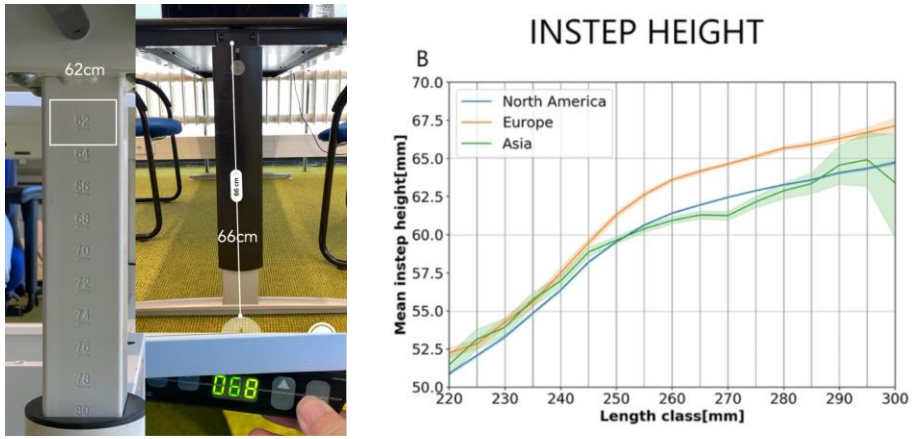


Figure 109: ofice desk height and european instep height in average[72]

11 1 2 Building and evaluation

After determining the height of the space for feet, four different wooden stands were made to have a quick test of location of the center of gravity of the heater as igure110 shows. And another usability test of three feet ideas followed up. After using the wooden feet for the tryout test, 3D printed feet were created for a quick test, in order to ind the most convenient and least affects ofice environment, the assembly time of each idea was measured.

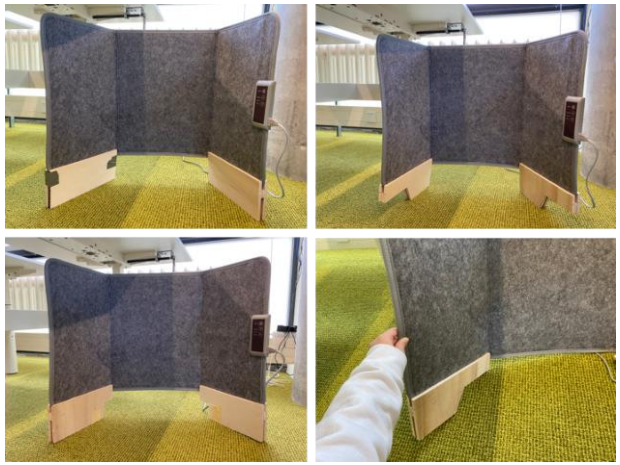


Figure 110: Quick try out with different wooden shapes stands

Clips

Figure 111 shows the overall structure of clips feet is simple, large area contacts against the ground. In order to avoid unsafe situations caused by tightly pressing to the heating surface, small protruding tubes are added inside the clip, so as to leave a gap between the clip and the heating surface. Sliding it in and assembling it costs 26 seconds. The stability is good, but when kicking the product, it tends to tip over because there is no support on the back side.

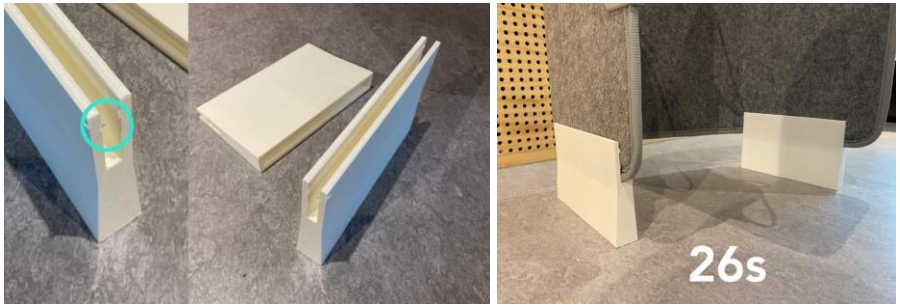


Figure 111: 3D printed stands and it cost 26 seconds for the installation

Magnetism system

Figure 112 shows the magnetism connection which is inspired by the Mac power charger, an easy and effortless design. The user can easily attach the stands on the panel by attaching it on. Less area contacts on the ground, more space left out. During the test, the installation costs 13 seconds, and the connection is good enough. No matter how you move it, the attachment to the magnet will not loosen. But the stability could be improved due to the lack of the back side.

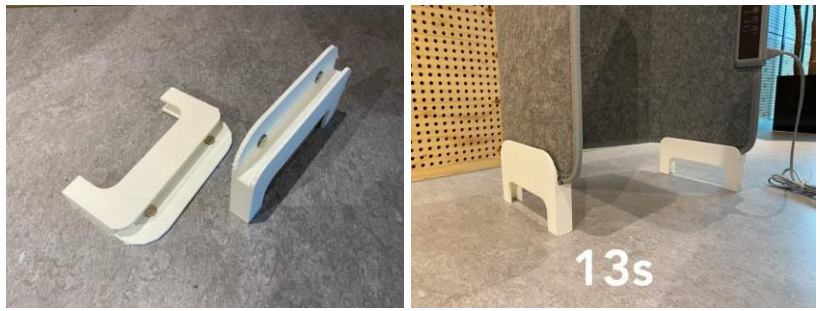


Figure 112: 3D printed stands and it cost 13 seconds for the installation

Pillar feet

The last idea is three pillars feet as igure 113 shows, three pillars are installed on the two sides and the back side. Protruding tubes are added inside the clip to leave a gap between the clips and the heating surface. It costs 18 seconds to install them, it is the most stable solution among the three, because of the back support. With pillar feet, more space can leave for human feet and legs.

Figure 113: 3D printed stands and it cost 18 seconds for the installation

All three solutions can be assembled on the product without any tools, however, the pillar feet have the strongest stability due to the triangle supports on the ground. The magnetism system is suggested as well because it is the fastest approach to install feet. The inal feet design combined the magnetism system and the three point supports as igure 114 shows. Attaching on and off requires less time while maintaining a good stability and ixation.

Figure 114: combination of the magnetism and three points support

11.2 Final concept evaluation

In this chapter, the overall product and process were validated through a product usability evaluation with 6 participants. For this, inal prototypes were created. During the inal evaluation, some ofice scenarios were acted out. In the end, combining new insights from the inal evaluation, some improvements of the inal product design were made.

11 2 1 rototype for the inal user test

After ideating, testing feet solutions, the inal feet design was created by combining some sketches of the overall aesthetics as igure 115 shows.

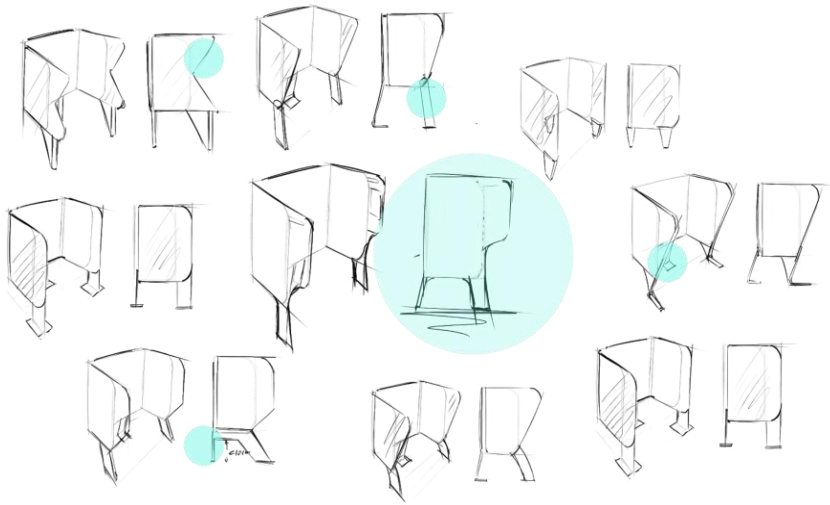


Figure 115: sketches of the feet design

The safety and production delay canceled the goal of making a nice end-user working product. Thus, the goal of the inal test is to validate the control unit interaction and the overall ergonomics. The focus of the prototyping was put on the control unit and the basic product size, as these could be new input of the project.

Figure 116 shows the prototyping phase. From making a new cover with the selected ireproof material to the calibration of the LED lighting strip with Arduino. For the magnetic stands system, three stands were made by 3d printing, the iron was cut and attached on the back side of the physical product with strong double sided tapes.

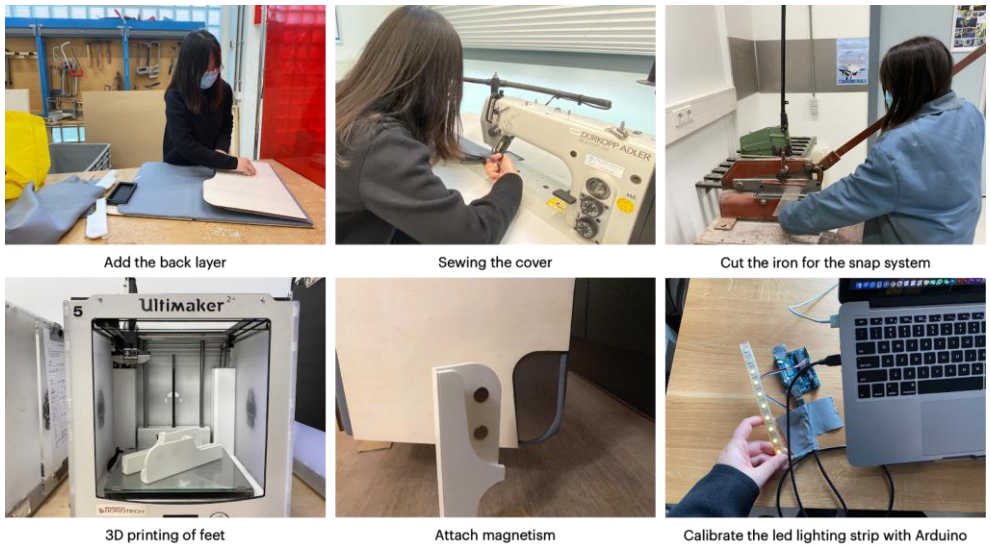


Figure 116: the prototyping phase

A 3d printed phone holder was made for placing an iphone to shorten the preparation time, instead of using real touch buttons with a well designed casing. A short LED light strip was attached to the side of the product. Figure 117 shows the inal prototype, the lighting was manually controlled during the user test.

Figure 117: the prototype for the inal user evaluation

11 2 2 inal user tests set up

The inal product usability evaluation was conducted with the following research questions. The main research question is:

To what extent does the user understand the smartness of the product by using the product at the ofice.

Sub questions are:

1. Analyse the usability and user experience of the control unit.
2. Test the usability of the physical product, in terms of movability.
3. Test the ergonomics of the physical product.
4. Test the assumption that the led lighting can be used as a useful quick indicator of working status.

In order to answer these questions, the test is set up at the computer room at the faculty under the covid-19 crisis procedures as igure 118 shows. 6 students from the faculty who have experience in a shared ofice environment participated in the test, three male and three female. Their heights vary from 157 cm to 188 cm. Videos were recorded for further analysis. Figure 119 shows the whole test procedure, the complete preparation and result can be found in the appendix N.

A pilot test was conducted before the inal test to optimise the test procedure and the prototype. The result of the pilot test was excluded in the inal result. Before the start of the test, the participants were presented with a short introduction of the background of the project without presenting the instruction of the product. Then they were asked to accomplish some tasks under my instruction within four certain scenarios listed in igure 119. After all tasks performed, two questionnaires and a semi structured interview were conducted. The whole process was recorded under the consent from the participants.

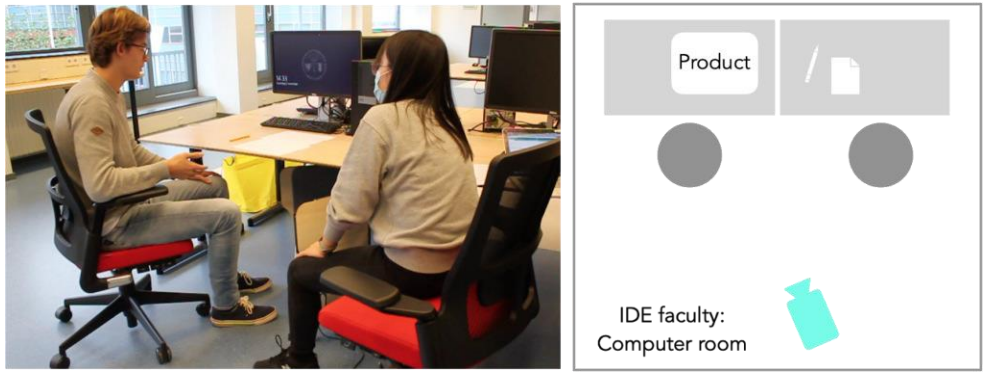


Figure 118: the test environment and the setup

Briefly introduction of the background of the project without explaining smart features and the instruction of the usage, sign the participant consent.

Have a look of the prototype and then assemble stands.

Move it under the desk, find a proper position for next scenario.

- **Scenario1: Normal working**
  - Task1: Turn on the power
  - Task 2: Adjust temperature levels
  - Task 3: Check product and the lighting

- **Scenario2: Leave the desk for a short break**
  - Task 4: Check product and the lighting
- **Scenario3: Leave the desk for a longer break**
  - Task 5: Check product and the lighting

- **Scenario4: Leave the office and the next morning**
  - Task 6: Check product and the lighting
  - Task 7: Remove it from the desk

Questionnaires (statements, AttrakDiff survey and usability survey) + interview with semi structured questions, explanation of the product and its smart features

- Was the prototype clear? Could you understand its smart features?
- Was the lighting clear? Can it helps you as a quick indicator?
- What do you think about this product in the office?

Figure 119: the inal evaluation test procedure

11 2 3 Results

There were four parts after the test. The questionnaire comprised three parts following the goal of the validation test. Part A focused on the validation of requirements of ergonomics with a Likert scale. Then Part B collected the rating of the usability and the design of the interaction prototype with a AttrakDiff survey. The part C was the SUS usability questionnaire to gain an overview of the usability of the product. The last part D was an interview to validate the communication during interactive activities and in the simulated ofice environment via a semi structured interview.

PART A: ergonomic and movability requirements validation

The irst section was about the agreement level of several statements related to ergonomics and the movability, participants were asked to rate three statements from 1 to 7 based on Likert scale, 1 means strongly disagree, 7 means strongly agree.

5.83/7

1. **"I found the product shape is ergonomically comfortable which ïts a standard sit working position."**

The score is slightly lower than 6 because the testing time is too short to give a certain answer to this question, usually a working time is a long period. During the interview, participants appreciated the lower space for their feet, only participants who are used to the posture of stretching their legs will have a concern of their comfort in a longer working time.

6.33/7

2. **"I found it is easy to reach the control unit when I want to adjust it."**

This score represented the reachability of the control unit. The score is higher than the one validated during the last user test when the control unit was placed in the middle of the right side edge, the score was 5.0. The control unit is considered reachable by rising the location and putting it closer to the user. However, when the height of the participant is higher than 175 cm, they still need to bend themselves to be able to see the interface as igure 120 shows. Surprisingly, they also gave a high score, because of the moving ergonomic chair that aids them to be able to change posture freely and effortlessly. Indeed, operating the interface with a bend posture only required a few seconds during the test, which is acceptable for participants to endure.

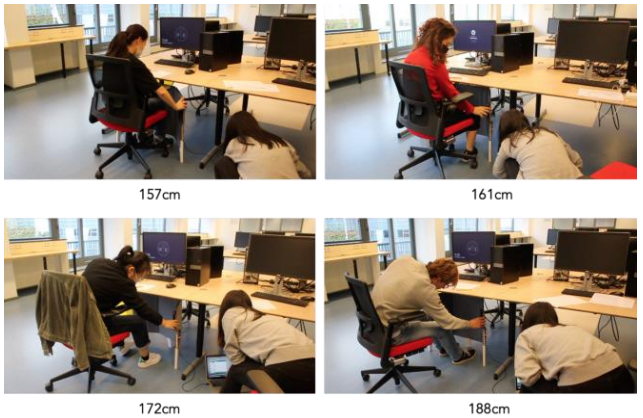


Figure: 120 participants postures when they were operating the control unit

5.17/7

3. **"I found it is easy to move in and remove it under my ofice desk."**

The physical product tipped over easily during the user test when the participants were asked to move the products in and out under the desk. Because small space contacts against the ground, too much resistance makes the process dificult. And the feet on the back side bumped against

the ground because the participant was not able to slide the product smoothly on the ground as igure 121 shows. If the ground is covered by carpet, it will be more dif**i**cult to move. Thus a follow up improvement was conducted and the improvements is introduced in the next section.

Figure 121: a participant is moving the product under the desk

PART B: AttrakDiff survey result

AttrakDiff helps to understand how participants personally rate the usability and design of the interactive product. Several key qualities related to this project were used for Part B's questionnaire. Tabe 15 shows the average mean score of each quality, the current product is simple, clearly structured, manageable, undemanding. Moreover, it is not to be considered as cheap, ugly, or repelling, although these scores related with attractiveness are lower than others. Mainly because the product is still in the prototype phase.

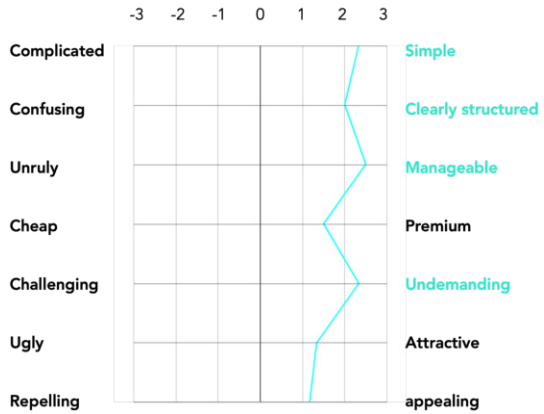


Table 15: result of the AttrakDiff survey

PART C: The System Usability Scale (SUS) result

SUS (System Usability Scale) was used for evaluating the usability of the product and inspired testers to express their feedback in the next interview section. Results from the SUS questionnaire, give the prototype a sus score of 85, scoring it between good (SUS score of 80.3) and excellent (SUS score of 85.5) (Bangor, Kortum, Miller, 2009; Brooke, 1996). Table 16 shows the irst question "I think that I would like to use the system frequently" was relatively lower than the rest statements, mainly because participants thought of their own thermal preference and the usage for other seasons when answering this question, such as summer or the time when local heating is not required at all. This statement lacks premises, thus another follow-up questionnaire was performed with an elaborated question of whether people are willing to use such a product when they do have the ability to lower the ambient heating.

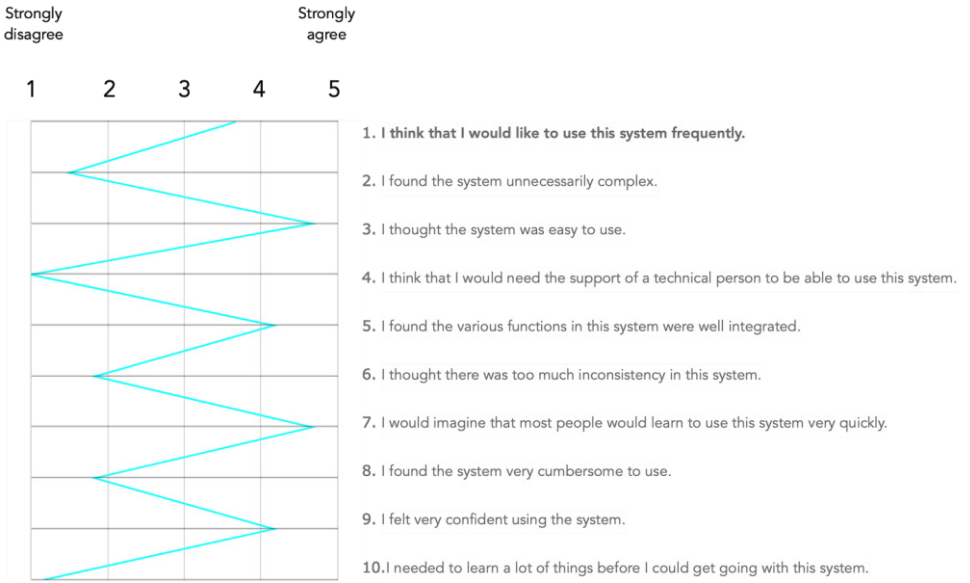


Table 16: average SUS score of each questions

PART D: Semi Structured interview

In the last part of the usability test, a semi-structured interview was performed, the following questions were asked after the test:

1. Was the prototype clear?
2. Can you understand the smartness of the product?
3. Please describe the smartness of the product in your mind.
4. Was the lighting clear? What do you think about its location?
5. Can you distinguish the different working statuses of the product based on lightings?
6. Do you think it helps you to distinguish the working status of the product quickly?

From the answers of participants the main research question is answered:

- **To what extent does the user understand the smartness of the product by using the product at the ofice.**

During the interview, without my explanation, all participants understood the smart feature that the heater provides heat based on the person's presence, and it maintains the temperature during a short break.

P6:It will turn on or off based on my presence, and if I go to the meeting and I forgot to turn it off, it will sense my presence for a period of time, andt turn off, instead of when I go to the bathroom, the range of time is not enough to turn off
P4:No, it is not really hard to understand.
P2: I like the fact that it is based on your presence

Sub research questions is answered as well:

- **Test the assumption that the led lighting can be used as a useful quick indicator of working status.**

Most of the people understood the message behind the lighting and especially the standby mode, the cool blue had a strong contrast with the red colour which represents the heater is in standby mode. The animation was clear as well, only one participant considered the yellow ashing lighting as a charging sign, but he understood it was a caution sign after he checked the interface. The possible reason behind it is the speed of ashing is too slow to get attention. In the inal design, the ashing animation is updated to be faster to be different form the charging sign.

P2: Yeah, It helps, once the red lighting is increasing or lighted, it means it is working.
P5: It is pretty clear, with ashing, more reddish means it is getting warmer, and less reddish is less warmer. Yellow lighting could mean it is charging, but I understood that it needs maintenance after I checked the interface. And the blue one means the standby.
P4: The colour and the animation are different so it can help me to distinguish different working status. Red means it is maintaining the temperature, and the blue means it is in a sort of standby. The yellow means it needs maintenance with the explanation of the maintenance.

However the position of the lighting was blocked by the 3d printed phone holder pointed out by participants, the location was too low to get notice as igure 122 shows. Because when they were operating the heater, their focus was mainly on the interface. So the visibility of the lighting needs to be improved, the solution is to make the interface embedded in the product to keep the whole surface at and raise the position of the lighting.

Figure 122: participants pointed out the visibility of the lighting

P3:I didn't notice the light at the beginning, if the lighting is aligned with the interface, it would be easier to grab my attention.
P1: If you are working, you will not really notice what the colours are, the interface is more visible than the lighting, the lighting does not really grab your attention at that location. It is too low. More sharper colours. Or just put the lighting on the top, on my desk where it would be more noticeable.
P3: my concentration was all on the interface, and the light can not grab my attention immediately. But the lighting could be a good indicator to remind me to turn the heater off or when I am far from my place, it can help me to check the status quickly.

Opinions of energy saving eficiency of local heating solution

However, when participants were asked about "Could you save energy from it? Lower the ambient temperature and use a local heating.", they answered it by comparing the general heating system and a local heating system based on the imagined energy consumption. They were unsure about the energy saving eficiency, or they have less experience and knowledge of energy consumption. A stronger proof of that is needed. Some of them thought it might be a valuable solution for a small ofice with less people, but for a bigger ofice, it was unknown for them.

P2: I like the fact that it is based on your presence, but I do not know about the energy consumption thing, if everyone is going to use this or use the global heating system, those are numbers that need more investigation into it. In general the heating system is more eficient than that everyone has an individual one.but...it might be different in a small area, emm.. because I do not know what the consumption of this thing is, so I am not sure about whether it can save energy.
P4: It is hard to tell, it might depend on the area and the number of people in the room. Maybe it will help for a small room. If a room is full of people, then a general heating might be a better solution.

But for sure, most of participants admitted the system probably can save energy when lowering the overall ambient temperature and using a local heating. And is already better than a full manual system which people might be careless with forgetting to turn the heating off. Some of them also mentioned they really like the solution of "own temperature zone" because of different individual thermal sensation preferences in a shared place.

P6: I would say yes, because I know people, myselft, I have cold feet and cold hands during the winter, and I do not want to pump up the radiator to affect everyone, so I like the fact that I can have a personal heating, which does not affect the general heat as much as your fellow colleagues. Everyone has their own eco zone.

Installation

With the magnetic system and symmetrical adsorption shapes of each foot, participants were all able to instal without any instruction as igure 123 shows. And some of them like the system very much, because it is easy and strong enough.

Figure 123: quick installation within 3 steps.

11 2 4 ollow up improvements

Movability

The movability needs improvement. A follow-up test was conducted with the previous prototype. By enlarging the surface by cardboard, it is able to slide on the carpet smoothly as igure 124 shows. Thus in the inal design, the individual feet area is increased.

Figure 124: follow up test of the feet for a better movability

Lighting

The lighting was not noticeable during the evaluation test. Thus, the location of the lighting strip is raised and aligned with the interface as igure 125 shows.

Figure 125: rendering of led lighting strip location

Besides, from the discussion with the supervisor team, the communication during the standby mode could be more inalised, conveying the information of "I am detecting". Thus a quick research from other domains was performed as igure 126 shows, in the end, an idea of blue light was created and embedded into the inal design, as igure 127 shows. When it is on a stand by mode, the blue lighting uctuates slowly up and down repeatedly.

Figure 126: Icons of loading[73], wi searching[74], waiting[75]

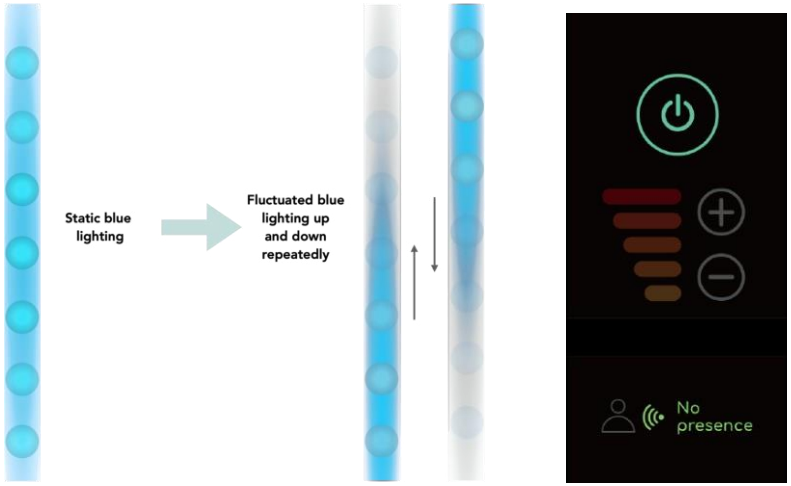


Figure 127: the update of standby lighting design and the information on LCD screen

Willingness of using a local heating

Another follow up questionnaire was released to validate the willingness of people to use the product. The full questionnaire can be found in the appendix O. The questionnaire was sent to 12 persons, 8 of them responded. The result of the main question was positive (4.125/5), people are willing to use the local heater in the ofice that can reduce the CO2 footprint for ofices and buildings.

A hint of the range for a comfortable room temperature setting in winter was provided when participants were asked about their ideal temperature of ambient temperature and local temperature using the personal heater. A suggested typical range for winter being 20-23.5 °C (68-74 °F).[76]

From the result, on average, around 19.3 celsius degrees are acceptable as ambient temperature, people will set 21.8 celsius degrees as the local temperature. This results indicates that the ambient temperature should not be too low, some of them would worry that they might feel the temperature gap when they leave their desks which might make them uncomfortable. And from the acceptance of the ambient temperature, it is acceptable to reduce the ambient temperature to a comfortable cool condition around 19 celsius degrees while using a local heating to warm individual employees.

Unobtrusiveness in the ofice

In the previous questionnaire, a question about the unobtrusiveness of a rendering was validated as well. Participants were asked to score the looking unobtrusiveness based on the rendering as igure 128 shows, 1 means unobtrusive, 7 means obtrusive, and the end average score is 3/7. The design was considered as unobtrusive at the ofice, but the obtrusiveness of the design could be reduced by uniting the style by using one darker tone so as to reduce the contrast of the grey fabric and the white backboard. And the inal appearance is shown in the next section.

Figure 128: initial design of the appearance

11.3 Final concept elaboration

In this chapter, the inal design is introduced. Including the appearance, the using scenarios, inal requirement evaluation, and the cost estimation.

11 3 1 Appearance

Physical product

The overall design is united in one style by using a darker tone to convey the feeling of unobtrusive as igure 129 shows. The curved shape is applied in the inal design, because sharp transitions in contour may be indicators of possible life threats, resulting in a negative bias.[77] In igure 129, the position of the handle is reserved on the two sides of the back casing. The lighting is located at the top of the right edge with a shaper colour to grab users' attention immediately as igure 132 shows. The full dimensions can be found in the appendix P.

Low saturated colours are used to reduce the complexity of the design, grey and black are the main colour of the product as igure 131 shows. This design could be a basic version for the ofice, the overall colour combination and the fabric could be customised by buyers or some basic options could be provided as igure 130 shows. The name of the product is SmartHECO which is printed above the control unit as igure 130 shows.

Interaction interface and lighting

Figure 133 shows the overview of the inal interaction design. It is also possible to scan the QR code of a video to check the inal interaction design.

Check the inal interface design of the capacitive switch and the LCD screen with lighting feedback

Figure: 129 rendering in the ofice environment

FIgure 130: Colour variation, the brand name location

Figure 131: renderings of the product

Figure 132: rendering of when the product is providing heat

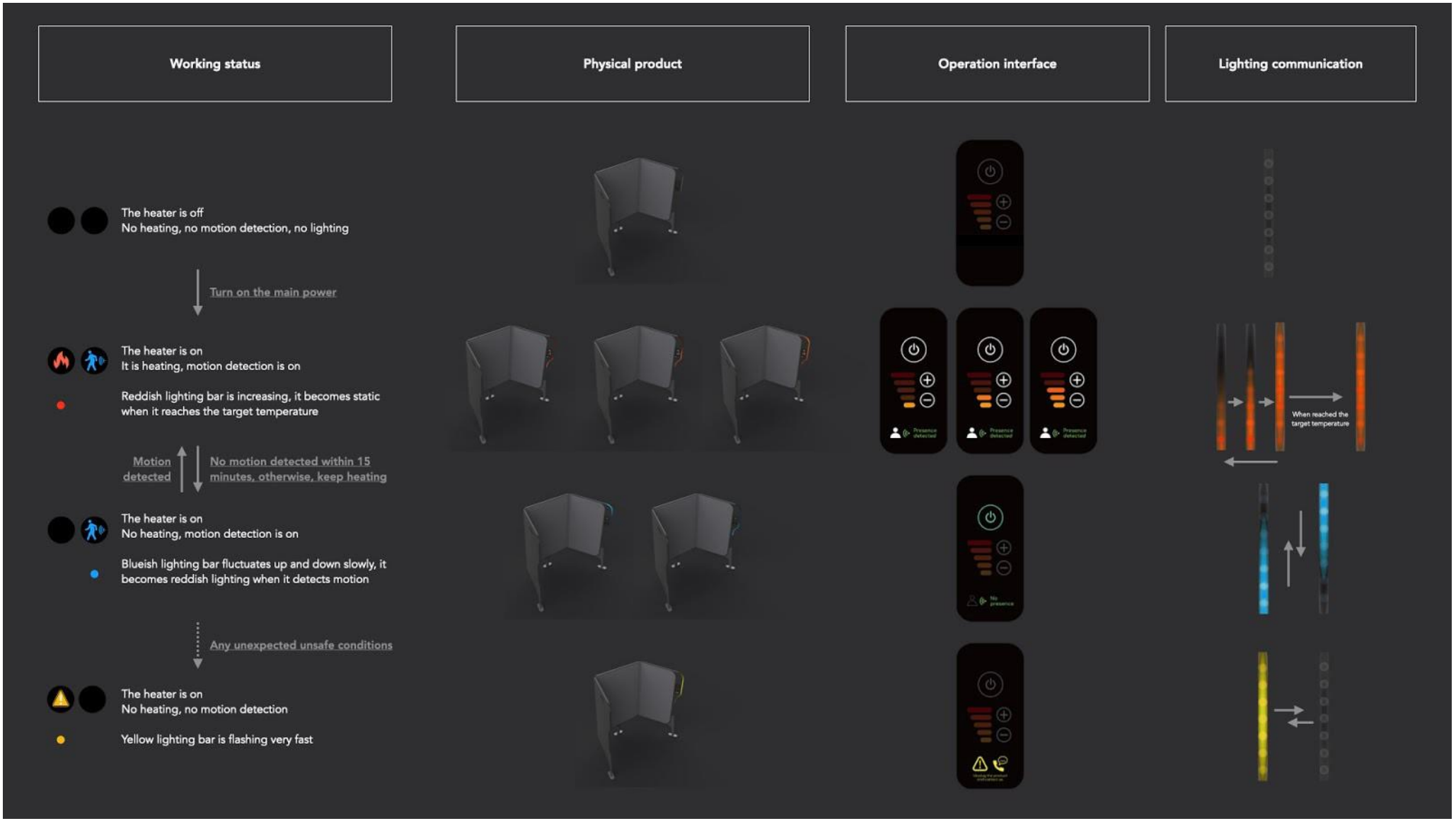


Figure 133: overview of the interaction design

11 3 2 Heating strategy

In the end, the heating strategy is also de ined as follows:
Figure 135 shows the work ow of the system. The main heating strategy is that after turning on the main power of the heater, the motion detection is always on. Once a motion is detected, the heater will provide 15 minutes of heating. Once there is no motion detected after 15 minutes, the heating is off, when there is a micro-motion sensed, the heater will restart to heat. The maximum temperature is 65 degrees celsius based on the limits of thermal injury of touching mentioned in the thermal comfort chapter. The temperature range is divided into 5 levels, from 45 to 65 degrees Celsius. The heating temperature increased by 3 degrees Celsius when adding one level.

Safety check is always processing, to avoid incidents of a loose connection, broken sensors, and overheating. Once the heater is broken or after the ofice hours, the heater will be off completely by itself.

11 3 3 ain components

Figure 134 shows the main components of the inal design. The ireproof fabric was selected based on material research in the appendix E based on speciic criteria (Low cost, low thermal conductivity, lightweight, easy for cleaning, the infrared emissivity of the surface). The fabric has lower thermal conductivity and 65-75% transmission rate[78] of infrared which ensures a great total amount of infrared heating.

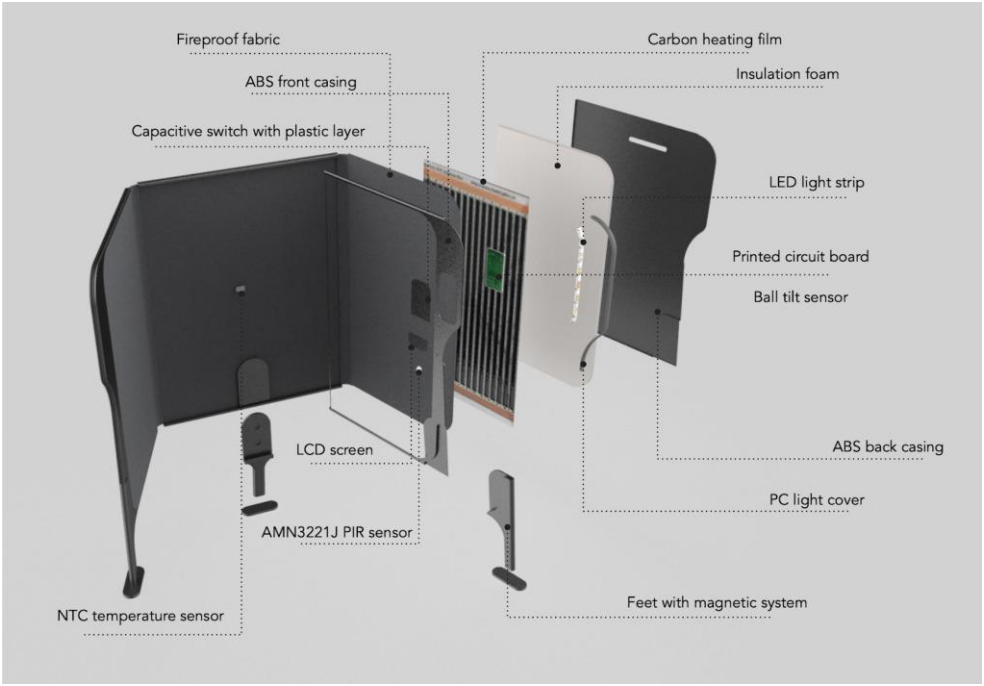


Figure 134: exploded view

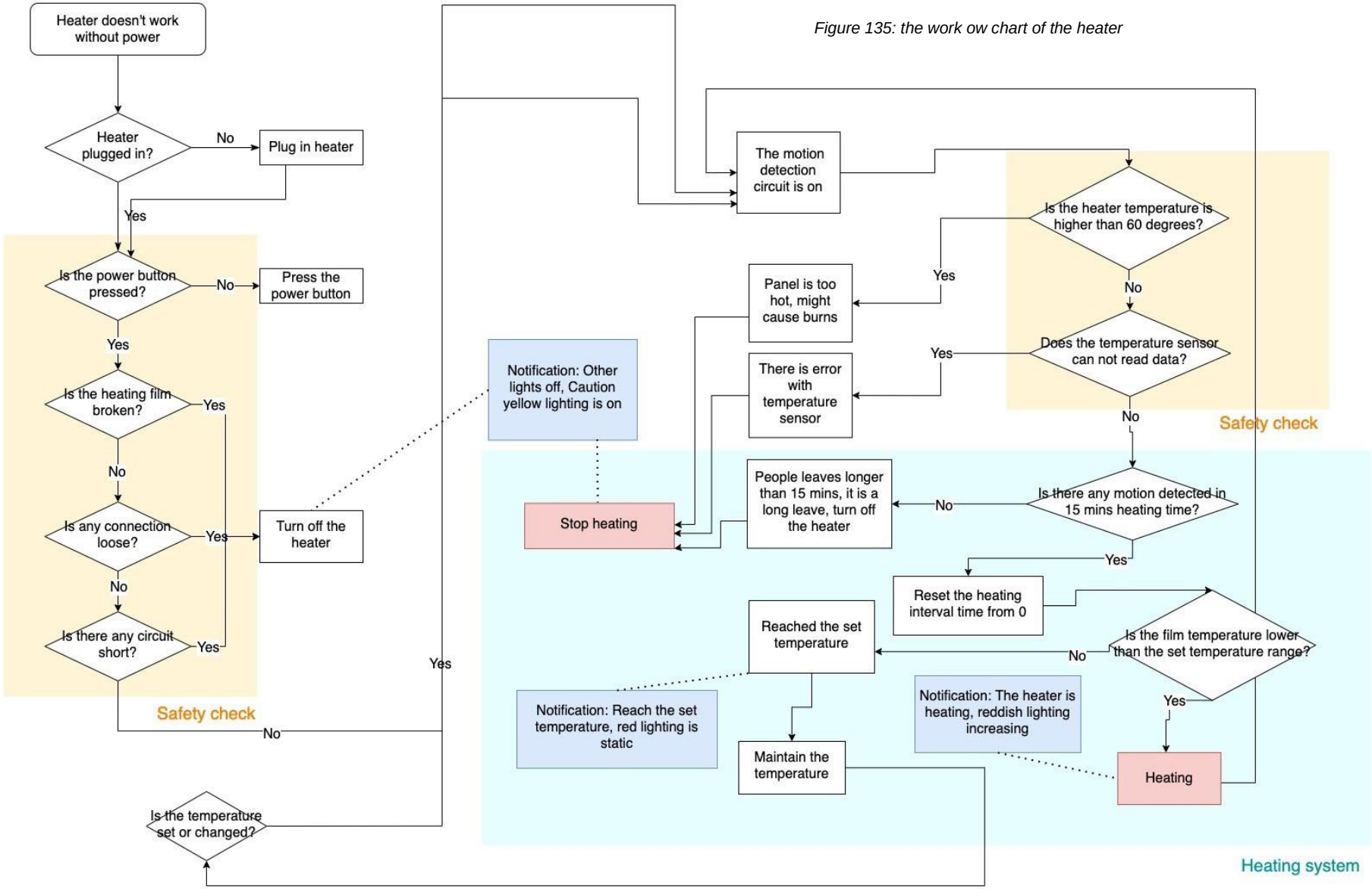


Figure 135: the work ow chart of the heater

11 3 4 inal requirements evaluation

To evaluate the inal concept, the prioritized requirements list is used as the standard. As the list shows, the highlighted text are features that have been included in the inal concept but need further investigation and validations.

hysical products requirements

1.1/1.2/1.3/1.4/1.6/15.1/15.2/7.1/10.1/13.1/1.5/9.1/18.1

The product must be safe and standalone, provides personal heating instantly when it detects the employee's presence with minimum errors. Meanwhile, the product should adapt to the ofice environment, not interfere with ofice activities, and be ergonomically user-friendly.

Interaction requirements

16.1/18.2/18.3/14.2/17.1

The control unit is intuitive, simple to use, and researchable. The product could convey its "smartness" and its end purpose of energy-saving with minimum instruction.

Standalone and intuitive

The inal concept is completely standalone, do not rely on other systems. The overall usability score is 85, which means the product could be considered with a good usability, which is easy to use and intuitive based on the AttrakDiff survey result. The general size of the product is considered ergonomic and unobtrusive during the inal evaluation and the follow up questionnaire. The 165W ilm is selected which provides the suficient and instant heating within 5 minutes after the test of the heating eficiency of low wattage carbon heating ilm.

Safety

For safety, the maximum heating temperature is suggested under 65 degrees celsius based on the limits on the temperature that people can touch as the previous section of thermal injury of touching mentioned. For the interaction, the caution information, yellow fast ashing lighting and the tips on the LCD screen ensures that the user is able to notice the safety problem and deal with it under a proper instruction. A temperature sensor, a ball tilt sensor, and an expected protection of the circuit are added to ensure the unexpected incidents, such as overheated, tip over accidentally, or any loose connection or broken sensor. But the reliability of the safety system needs to be validated with a fully working prototype in the future.

PIR motion sensor accuracy

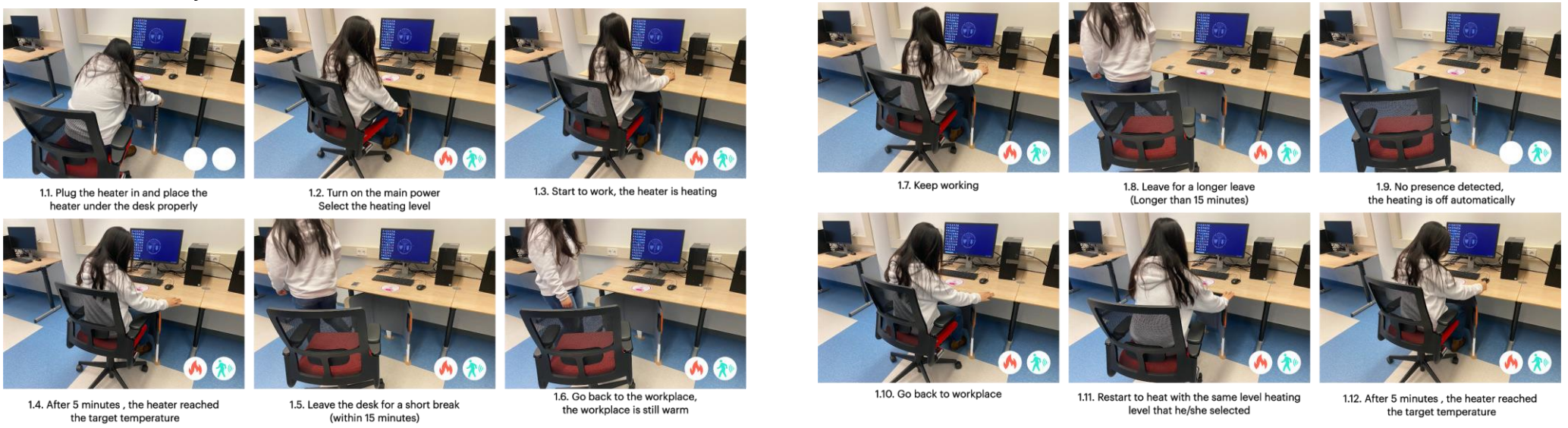
Using one PIR sensor is able to detect human presence based on results in the PIR sensor validation section, the AMN32112J motion sensor with a median detection angle of 91 degrees ensures that the adequate amount of motion data is able to be collected, and its detection distance of 2 meters avoids certain amount of unwanted motion data that could be sensed in a distance. However, unexpected movement will still be detected. When the movement enters the detection range, such as cleaning, such movement cannot currently be iltered, as mentioned in the PIR sensor validation chapter. More suggestions are described in the recommendation chapter.

Energy saving information

During the inal evaluation, all participants understood the working principles of the smartness with the interaction design. And most of them agree that using a local heater could reduce energy use compared with a global heating system. But users are uncertain about the energy-saving eficiency. Indeed, there is no energy-related information illustrated on the interaction interface or the physical product which probably could help users to understand its energy eficiency clearer. This could be included and developed in the next design cycle which is mentioned in the recommendation chapter.

11 3 S ser scenarios

Following igure 136 shows the user journey with the smart heater.
1.1 to 1.15 are a day in the ofice, 2.1 to 2.3 are related to maintenance.



Figures 136: user journey

11 3 6 anufacture and cost estimation

Table 17 shows the estimated material cost of the heater. The main components are shown in the exploded view. The material to build one local heater is 74,83 euros. The manual assembly fee and the rest uncovered manufacture fee have not been covered yet, thus they need further investigation. The purchase link list can be found in the appendix Q.

Item NO.	Name	QTY per device	Batch size	Total price (€)	Bulk price (€)
1	ABS Product casing	3	50	100	6,00
2	ABS feet	3	50	80	4,80
3	10mm x 2mm Magnetic	6	52	7,99	0,92
4	Grey fireproof fabric (unit in mm)	2000	30000	241,65	16,11
5	PC light cover (unit in mm)	250	1000	3,27	0,82
6	Capacitive switch	3	10	2,56	0,77
7	3.5 inch LCD screen	1	1	17,75	17,75
8	Capacitive screen customised	1	/	customise price	
9	Insulation/reflective layer (unit in mm)	1000	2500	4,75	1,90
10	165 W Carbon infrared heating film (unit in mm)	1000	6000	100	16,67
11	NTC temperature sensor	1	5	14,59	2,92
12	PCB	1	/	/	
13	Ball tilt sensor	1	1	0,19	0,19
14	WS 2811 LED light strip (unit in mm)	300 (15 leds)	1000 (60 leds)	19,95	5,99
Total material price					74,83

Table 17: Material and components selection

ART I SI

12. Limitation and recommendation

In this section, limitations of this research and recommendations on improving the current design of the local heart are listed and clariied. The feasibility of suggestions needs to be veriied by prototyping and more user tests.

12 1 imitations

User research and test group

In this project, a shared ofice is considered as the main environment where commonly exists disagreements of personal preferred ambient temperature. For user tests, most participants are from the building De Bouwcampus and some of my fellow students who have experience of a shared ofice. Thus, the opinions and the ofice activities patterns of the employees from De Bouwcampus have majorly in uenced the results of the design research. Their ofice patterns and opinions might be overrepresented which means my test group may only represent a small part of the opinions of the group ofemployees.

As mentioned earlier, this project was executed in the covid-19 crisis, thus it is harder than usual to reach the target user group. A limited variety of participants were able to be recruited for user tests. And the user tests were all performed qualitatively. Another limitation is the test environment, due to the epidemic situation and the project was carried out mostly in the summer, it was hard to ind an ideal cool ofice environment for testing. TNO was also too busy to reject the application of a ield test of local heating in a stimulated cool environment. Eventually, the test was performed in a small meeting room with windows open in the morning. Although the temperature was close to a cool condition, the space was too small to be considered as an shared ofice environment and the thermal condition uctuated according to the time. No heating involved tests were executed in the ofice of the OficeVitae and the computer room of IDE faculty only. Thus, it is recommended to perform larger scale pilot tests in an actual cool shared ofice environment, using a high-idelity product to evaluate the indings from this report.

Prototype

A working prototype was not built eventually due to the limited time of the project. All tests were conducted by using a commercial foldable heating product as a starting point. The active prototype test method that I stayed next to the prototype to ensure the functionality of the prototype due to electronics were not fully embedded into the prototype. Thus the inal design of this thesis has not been tested and serves the purpose of the showcase. It demonstrates the acceptance of workers' local heating and how a standalone local heater would look like. Although the estimated material cost is shown in the last chapter, the actual manufacturing cost is unknown.

Context study in an actual environment

What if the smartness is not working due to a non-technical problem? Such as the PIR sensor is covered by a trash bin or your rain pants, or people are not satisied with the default time interval set, they just cover the PIR sensor with tapes and use it manually. These problems are inevitable and exist in the actual ofice environment which need to be deined from a test performed in a real context. Since it was not possible to do ield research in a normal ofice because the government ruled that all workers should work from home as much as possible, fewer ofice activities were observed in this study. Thus further ield research to deine the potential interactive activities between the smartness system and employees is needed.

12 2 Recommendations

General

- As mentioned in the limitation section, more tests with a working product need to be conducted in an actual ofice environment. And the pilot test with the heatfun heating panel could be a starting point to validate the PIR motion detection solution.
- Besides, research more on the ofice and home ofice context, such as the trend of the ofice environment and how the personal workplace will develop under current situations.
- Keep further investigating possible scenarios to evaluate the integration of the proposed system. Such as home, school, hospital which are excluded in this project.
- Using the data collected and develop additional systems that might add extra value to the product, such as an energy consumption dashboard, ofice occupancy monitor, which companies might be interested in as well.

Physical product building

- Keep further exploring and research on the potential high eficient infrared heating technology, insulation material to ensure a good heating eficiency in the actual environment.
- Embedding a longer power wire is suggested considering the movability and the adaptability of the product. In the future, remove the power wire, a rechargeable wireless heater would be more convenient and exible.
- Continue developing the embodiment of the casing and electronics inside, keep in mind requirements for the context, such as safety circuit protection, and an adequate IP grade, preventing water and dust from the environment.
- Requires more experiments with a longer test time to ind out whether it is acceptable for employees to place the inal design under the desk, and how it might affect people's comfort in the long term.
- Although the product itself can save energy due to the smart presence detection system, the product itself could be more sustainable as the trend chapter explored. Thus, probably improve the product from material and the manufacturing perspective, using more sustainable material and considering the use of recycled material, or apply remanufacture theory to simplify the assembly process and allow disassembly which extends the life span of each component and reduces the manufacturing costs.
- Further investigation on the person detection with PIR sensors in a standalone system. There are some methods to enhance the ability to distinguish human activities with PIR motion sensors: such as using more than one PIR sensor to determine the human action's speed and direction, applying the algorithm which might need the internet connection and the support from artiicial intelligence which might complex the system. Or redesign the ampliier of the PIR sensor with analog output to ilter out the unwanted motions as mentioned in the section of supplementary analysis in the PIR sensor validation chapter, which requires more motions data to distinguish different action patterns.
- Currently, the temperature range is divided into 5 levels, from 45 to 65 degrees Celsius. The heating temperature increased by three degrees Celsius when adding one level. And this heating range needs to be tested with users to verify whether it needs to be enlarged or not.
- The time frame for the stop heating is 15 minutes, once people leave longer than 15 minutes, then the heater will shut off the heating automatically. This result requires a larger group of users' ofice activity patterns and motion data validation. Or providing a personalisable interval time adjustor could be an option in future development.

- Try more different materials, colours, inishing combinations to adapt to different aesthetics requirements in different ofice environments.

Interaction design

- As mentioned in the inal requirements evaluation, participants were unsure about the energy-saving eficiency of using a local heater while lowering the ambient temperature. The actual energy consumption should be recorded and calculated in further pilot tests in the winter. Then the actual energy-saving eficiency could be carried out based on that. So as a strong proof of the saving energy eficiency as a local heater, and this information could be added to the product label or the interface to inform users about the energy-saving results.
- Spread more thinking about switch designs, such as using uneven texture to distinguish the add temperature switch, the lower temperature switch, and the switch of the main power. Then test ideas in different reachable locations to develop the current design into a design that allows the user to operate the heater without literally looking at the control unit.
- It is hard to change an employee's thermal behavior while balancing the electricity use, also found in user research that people will prioritise their thermal comfort when making an energy-related decision. More interaction design related to rising energy awareness could be proposed and combined with the current product design to save energy in the longer term. How to trigger their curiosity and reconsider their temperature setting when making a temperature decision could be a further research topic. Information delivery, social comparison, and moral appeal could be some potential options.
- As mentioned in the limitation section, limited ofice activities were explored in this project, how the product interacts with employees and the rest of the ofice in a shared ofice is unknown. More information and communication might need to be added into the LCD screen. Such as ensuring the functionality of the PIR sensor, a distance sensor might be required to detect the area close to the sensor is not blocked or covered.
- Require further investigation of removing the LCD screen to reduce the overall energy consumption, simplifying the interface and providing information only through lighting which consumes less energy.

13. Reflection

Knowledge (Collect and analysis generate and evaluate)

In the beginning, the raw data from the last pilot test has not been analysed due to the less communication with the technical support from the last pilot place. But as soon as the project started, the knowledge of office context, infrared heating, infrared heating film, thermal comfort and presence detection technology were collected and reflected as design criteria. Before the midterm, some brainstorming sections were conducted to generate enough ideas and concepts. However, during the midterm the accuracy of the detection method is pointed out, so more validation tests on the PIR sensor were carried out. Then the ideation and concepts generation of the interaction design could be more systematically since the designer is an IPD student, who has less experience of interaction design. By asking the chair who is expert in the human centred design, later user tests were conducted under good preparations. Overall, main topics and relative analysis were concluded in this project.

Methods (Use of methods and tools dealing with project complexity)

Various design methods are applied in this project, 4 cycles are carried out. In each cycle, various design methods were applied. The project included the physical product building and the interaction system design, which was broader than expected and involved many aspects. Within each cycle, different aspects of the project were considered and validated with a great amount of user tests, the complexity of the whole project was lowered by dividing it into four smaller cycles.

Project result (Feasibility desirability viability)

The feasibility of the project is high, as the extensive prototypes were built and evaluated with users, although a further validation test of a fully working prototype with the enlarged size of the test group is required as mentioned in the recommendation. The final result meets the user's value and core needs, it is a pity that the PIR sensor and the interface can not be embedded into the final prototype due to the time limitation, but the current prototype is able to be a study prototype for later development. The foldable commercial heating panel was used as the base of the later tests and design after the midterm, which makes this project and the final result feel like an improvement instead of creating an extremely innovative solution. However, this decision was made because of the project time and safety rules, that is not allowed to test or experiment with self-made electrical heaters at the campus. Thus a CE-proofed product was used to ensure the project viability and it could be continued. And it's foldable compact and lightweight features reflects the feasibility of the final design. The outcomes of the project could potentially be directly implemented and benefit the further developments of the local heating system. I am looking forward to being able to use my knowledge to support such a valuable case.

Communication (Academic level connecting to stakeholders)

The project focused on the combination between person detection and the local heating within a fully stand alone system. It shows the possibilities of using only one PIR sensor as a promising, cheap and feasible solution at a specific placement that covered employees lower body movement to sense the occupancy. The PIR sensor could collect the motion data which provides crucial input for the heating system to save energy from unnecessary heating. The supervisor team is open for meetings and calls, two weeks' zoom meeting with the team was performed as planned, more short and individual meetings were carried out actively after the midterm in the office when Marcel or David came to the office to make sure the project was on track. Calling and messaging provided me with more instant feedback after the online meeting. A lot of valuable and well considered decisions were made with the whole team.

Project management and planning (Planning autonomy & initiative response to feedback time spent)

The project started in the middle of June, the planned graduation date should be around the irst of November, including one free week. It is three weeks delayed. There are certain delays compared to the original plan, but overall the plan is good and solid considering the unusual circumstance. The main reason behind the delay is that the initial scope of both ofice and home was too large in the beginning which cost me too much time on context analysis and ideation to ind out what are the vital problems for each context and decide the project direction. Also because I stopped my previous project and jumped into the new project within one week which I had not left much time for a pre research of infrared heating and the general context. The analysis of the trend and the ofice which might be a not necessary study for this project, which resulted in my time for researching the technology was compressed, more focus could be placed on the presence detection technology. Besides, due to the covid situation, it is harder than usual to recruit desired participants, ind an ideal test place. Longer time for the shipment during summer time, and harder to get access for the prototyping are factors that I had not expected. However, my motivation and initiative was never lowered, the designer communicated with client and the supervisor team more frequently via calling, messages, face to face discussion while keeping a safe distance to gain more feedback after the meeting. Feedbacks are evaluated and adopted to the meeting and design cycle instantly.

Personal ambition

One of the most appealing aspects of the project is the hands on prototyping experience, although a inal prototype was not achieved within the given time frame, I still learned a lot from Martin and the technical support from Karbonic. Looking back to the project, I am glad that I made the decision and embrace the new project back to that time. Although more dificulties and toughness followed, I am truly satisied that I became more brave and confident with my decisions. Meanwhile, I deepened my knowledge of smart products and sustainability, my prototyping and communication skills are developed as well. I believe that this result has a lot of potential and provides a validated future proof foundation to build upon. I am looking forward to seeing if and how the product will grow.

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ist of appendices

Appendix A

A	B	C	D	E	F	G	H	I	J	K
Product	Website	Minimun watt (w)	Minimum size (m	Minimum weight	Surface design	Heating element	Back material	Wifi connection	IP grade	
Karbonik	https://www.karbonik.nl/nl/	260	600x600(900)x2	7	Glass/(Aluminum)	Cabornic heating element		Not applicable	Not clear	
Technea.nl	https://www.technea.nl/							Not applicable		
Smart IR	https://www.smartir.nl/									
SmartHomeSupply	https://www.smarthomesupply.nl/infrarood-verwarming/classic-modellen	200	600x300		High quality heat resistant powder coating. Slightly textured matt surface	Not clear	Sturdy construction made of 1.5 mm	thick steel	IP54	
Infraroodverwarmingstore.nl	https://infraroodverwarmingstore.nl/verplaatsbare-bureauverwarming.html	350	590x590	2.2	Aluminum	Carbonic heaing foil	Aluminum		IP54	
Heatfun.eu	https://www.heatfun.eu/product-categorie/mobiele-verwarming/	145	400x600x15	3.5	Aluminum frame, Anodized metal white surfa can be colour fabric cover for printing in anotl	Infrared foil	Aluminum (Acrylic base)		IP20	
Redwell Studio (Nederland)	https://www.redwellinfraroodverwarming.nl/	250	706x306x18	5	Stainless steel, powder coated,	High efficiency infrared elements inlaid in cerami	Stainless steel		IP40/IP60	
Greenhill Solutions	https://www.greenhill-solutions.nl/infrarood-panelen-2/	Max 1400	600x600x25		Not clear	Not clear	Not clear		Not clear	
aabo Greentech (welltherm)	https://www.aabogreentech.nl/infraroodverwarming-bureau/	100	300x600x30	4	Steel	Not clear	Steel		IP20	
Topheat.EU	https://www.topheat.eu/nl/267-infraroodpanelen-kantoor	50	300x600x7		Not clear	PTC	EPDM cellular rubber.		Not clear	
InvroHeat WallHeater	https://invroheat.com/?lang=nl	430 - 450	1010x562x1		Not clear	Infrared foil	Not clear		Not clear	
FENIX EcoSun infrared heating	https://verwarmwinkel.nl/product/wand-infrarood-panelen/	100	500x320x30	2.8	Sheet steel cassette with thermalcrystal coas	Flat resistance foil	Steel	Wifi plug in switch/ build-in wifi switch	IP20 (smooth panel) IP44 (thermalcrystal coasting)	
TROTEC TIH 500 S Infrared heating	https://nl.trotec.com/shop/tih-500-s-infrarood-verwarmingsplaat.html#t15f0	300	606x505x22	5	Not clear	Infrared foil	Not clear	Wifi plug in switch	Not clear	
VH white infrared panel	https://www.verwarminghandel.nl/	350	600x600x(...)	5	Aluminum coated with smooth lacquer	Infrared foil	Aluminum	Wifi plug or other op	IP54	
Wonderwall Smart Infrarood Verwarn	https://wondrwall.co.uk/	450	1005x605x25		Frameless Infrared Powder Coating Aluminiu	Carbon Crystal	Aluminium sheet	Attached wifi unit	IP54	
Heating green	https://heatinggreen.com/	200	572x572x18	5.4	Not clear	Far infrared heat element	Not clear		Not clear	
RS pro	https://nl.rs-online.com/web/p/space-heaters-radiators/8750277?cm_mmc	300	300x900x25		white powder coated metallic surface	carbon-nickel with nano s	aluminium sheet with profiles for mounting		Not clear	
Mi-heat	https://infrarot-fussboden.de/17-5-Fireproof-Heating-Carpet-50x75cm-100	100	500x750		Fire retardant fabric				IP24	
				4.433333333						

Insights:

1. If the usage scenario expands to the home, then the IP requirements will be higher and reach the waterproof level. If it is only used in the office, the required level is not very high.
IP20 officially stands for "touch by fingers (>12.5mm) | No protection". IP54 The product is fully protected against solid objects and splashing of water from any angle.
2. 3/14 products are less than 100w, other products are high temperature and high wattage heating.
3. Most of the front and back materials used are aluminum and steel. The possible reasons are light weight, simple manufacturing, high durability and recyclability.
Apply additional coating on the outside.
4. The product can have a variety of colors by using different coating on metal or printing on textile, but need to charge more fee.
5. There are also glass or mirrors used as front surface, mainly used in home environments. But the weight will increase accordingly, and transportation will be difficult.
6. The overall design transition and development from border to borderless. All with a hard square shape.
7. No two sides heater, No modular heater.

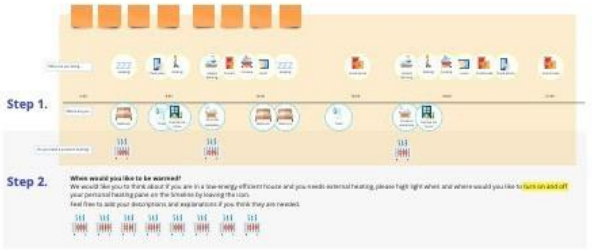
Conclusion:
1. The material for the front surface usually is aluminum or metal because metal heats up faster so that a metal panel delivers heat faster than a glass panel.
Although glass is a good heat buffer (better than metal) it is heavy and fragile. This makes the transport of the panels especially expensive. The fire retardant fabric is another option
for the heating panel as a but the durability of metal is higher than the fabric.
2. Controls/electronics are all outside of the heating panel in these products, Infrared panels with a built-in control have a lifespan of only a few years. The disadvantage is that the built-in electronics
suffer due to the large temperature fluctuations and that the life of the panels is therefore limited to two or three years. This is of course requires more attention and protection when embedded
electronics into the panel.
3. Feet/stands are usually sold separately with the panel, there are different ways of mounting the panel provided by the seller. The panel can be hung on the wall, or standalone with mounted feet
(user can assemble manually with few screws). The assembly ways depend on the user's preference and the office context. (Space underfoot)
4. Light and thin are typical characteristics that the IR heating panel have.

Appendix B

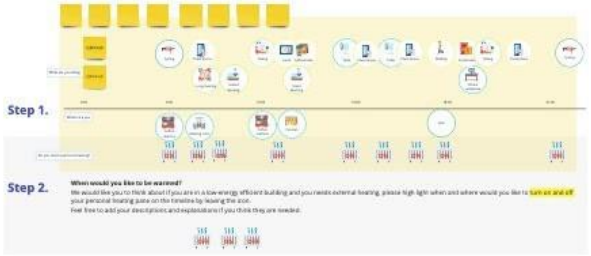

Map one day at the company


Step 1.
Step 2.

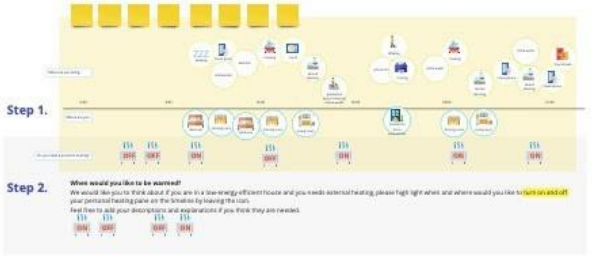

Map one day at the home office


Step 1.
Step 2.


Map one day at the company


Step 1.
Step 2.


Map one day at the home office

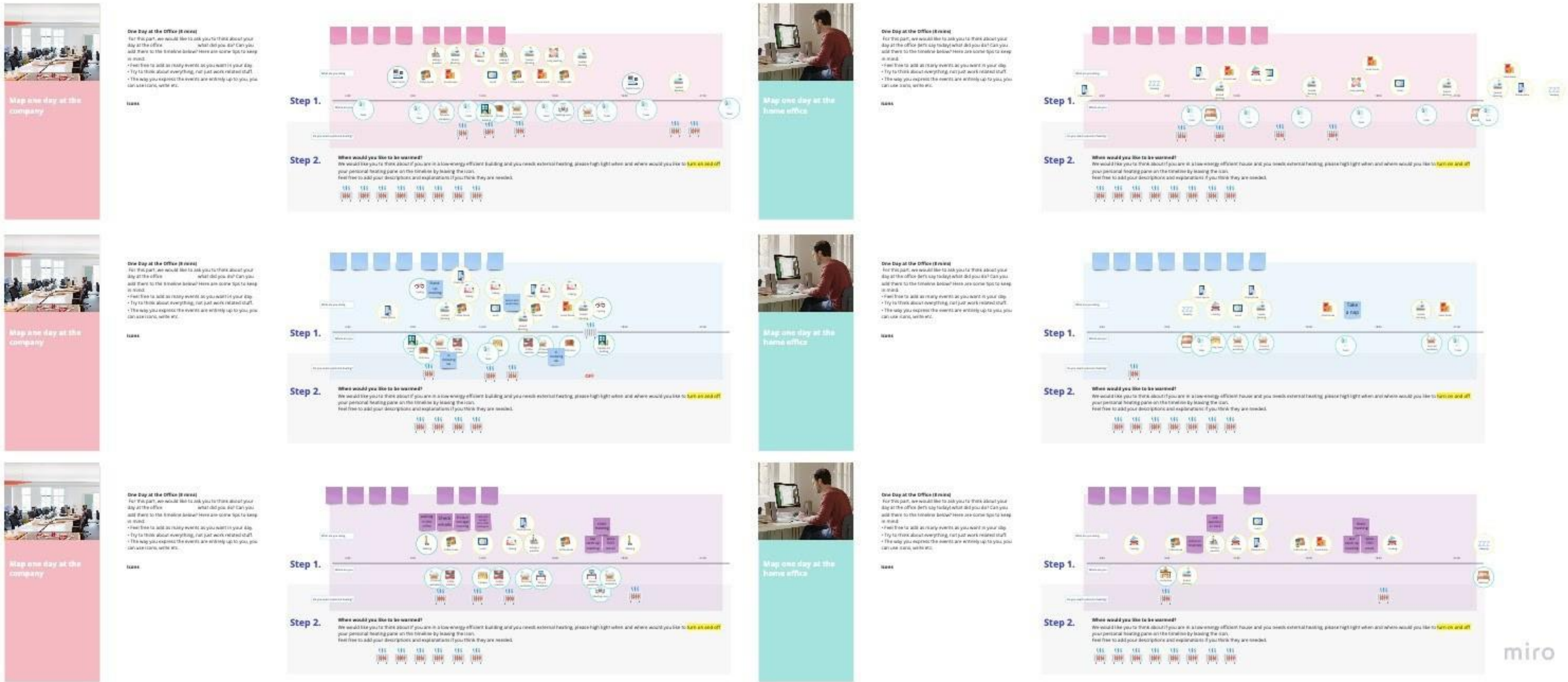

Step 1.
Step 2.


Map one day at the company

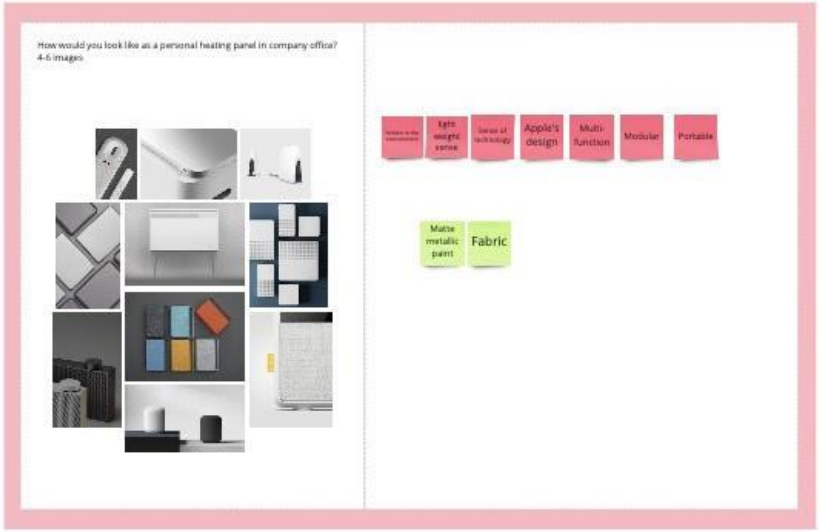

Step 1.
Step 2.


Map one day at the home office

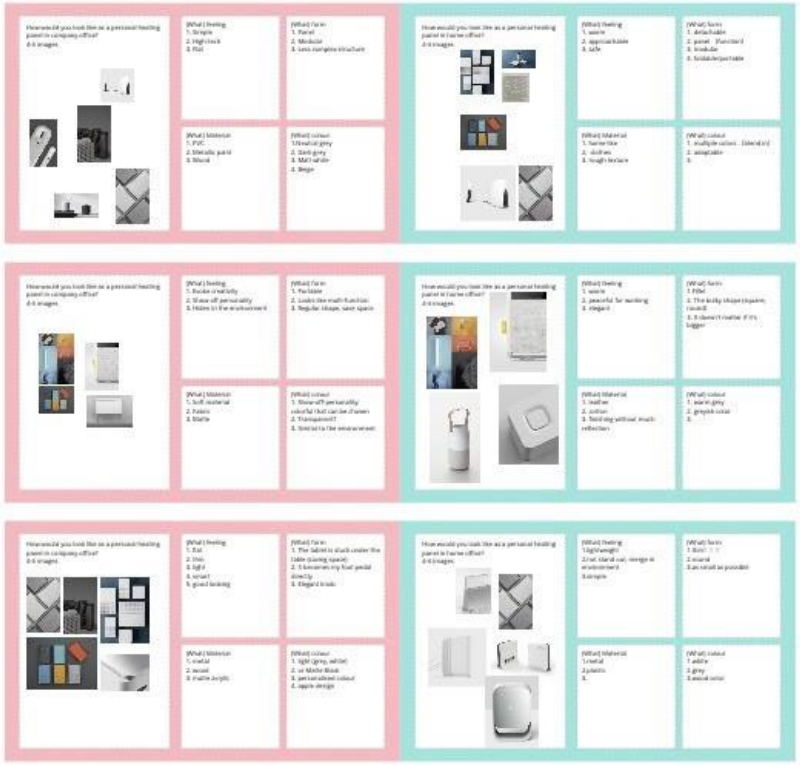

Step 1.
Step 2.
miro


Step 1.
Step 2.
miro


How would you look like next to the desk in company office?
5mins
How would you look like next to the desk in home office?
5mins
• Pick 4-5 images as your style, feel free to crop and use a part of the image
• Then describe your design language
(What) feeling
(What) form
(What) material
(What) colour


How would you look like as a personal heating panel in company office?
4-6 images
Apple's design
Multi-function
Modular
Portable
Matte metallic paint
Fabric


How would you look like as a personal heating panel in home office?
4-6 images
(What) feeling
1. warm
2. peaceful
3. elegant but not stand out
4. simple
(What) form
1. detachable
2. panel (function)
3. modular
4. foldable/portable
5. round filet
6. thin
warm
peaceful
elegant but not stand out
Simple
(What) Material
safety reasons
1.metal
2.plastic
home-like
1. clothes/leather/布
2. rough texture / finishing without much reflection
(What) colour
1. multiple colors (blend in)
2. adaptable
3. greyish
4. white
5. wood color
miro



Appendix C

Questions for the semi structured interview after the context mapping session.

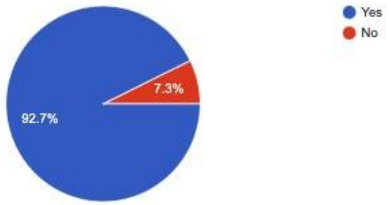
1. What kind of ofice did you work in before?
2. There are these main scenes, in which scene do you think they will be used?
3. (According to the timeline) With these scenes, which scene would you use this hotplate? (When and where)
4. Why choose these scenes?
5. (According to the timeline) In your home environment, what scenarios would you use this heating plate? (When and where)
6. Why choose these scenes?
7. (Ofice) What kind of control methods would you use in these different environmental scenarios?
8. Why choose this control method in this scenario?
9. (Home) Will you use primary control methods in these different environmental scenarios?
10. Why choose this control method in this scenario?
11. For portability, what scenarios would you use? why?
12. What do you think is the meaning of the personal heating plate to you?
13. Novel electric heater, lower than electricity price, lower than plumbing price, foldable can be an option
14. What are your expectations for the use of personal heating panels in ofice spaces?
15. What are your expectations for the use of personal heating panels at home?

Appendix D - survey a

Work experience in a home office environment

Did you have work experience in a home office environment?

55 responses



Controlling preference in a home office environment

If you are in a home office, which way would you prefer to control your personal heating panel in your work place?

51 responses

Please shortly describe the reason if you select the answer "other" "A combination of the above methods"

13 responses

- first one seems outdated and I don't want to have a heating control app on my phone
- I would like to be able to do it all these ways, since depending on the context, one might want to use different controls.
- I already have a phone so if I could just add an app it saves material.
- the most convenient way
- if i am at the table, i would like to use the wireless remote controller. If i am not at the table and want to control the heating panel in advance, i will use app on my phone.
- It really depends on the scenario. If I'm rest at the bar, drinking coffee, I wouldn't carry the remote control but mu phone. If I'm focus on sth, I wouldn't want to use my phone frequently which can be a distraction
- to have the control in every situation, having more option is the best
- If i control with a remoter i thibk it is too annoying to have many things to take care. if i control with my

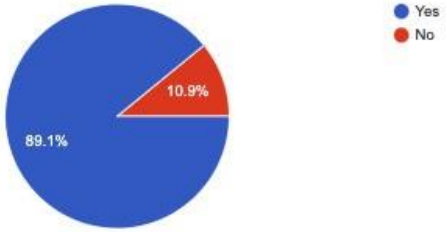
- to have the control in every situation, having more option is the best

- If i control with a remoter i thibk it is too annoying to have many things to take care. if i control with my phone, then what if my phone is broken?
- convenience
- The wireless function is ideal, but if it doesn't work it is good to be able to control the heating panel directly
- When I'm at the seat, i would prefer to control the panel directly. But in case I'm not there, i hope i can control it via my phone (e.g. pre-heat my seat before arriving office)
- imagine if I am just using my phone and I feel it's too hot or cold, it's handy to do it on my phone. BUT, I don't want to have an additional app to do so.. maybe like it could be in my Apple home kit, or the new released APPLE clip. that would be ideal
- sometimes if I can not find the controller. I can still use the phone or control the panel

Work experience in a company office environment

Did you have work experience in a company office environment?

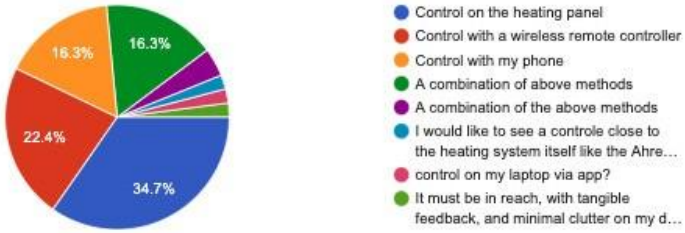
55 responses



Controlling preference

If you are in a company office, which way would you prefer to control your personal heating panel in your workplace?

49 responses



Please shortly describe the reason if you select the answer "other" "A combination of the above methods"

9 responses

- The same reason as mentioned before.
- A combination of the second and third method
- Same as before.
- Up to the Cost
- The same as last one
- if i control with a remoter then it is annoying to keep all the devices. if i control it with phone then what if it is broken?
- convenience
- because phone is always around me
- same as the previous one. but I would regard this as a personal item...and smart. so connections to

Appendix D - survey b

Design a movable and personal heating panel for office usage

Hi, I am a graduate master student from IDE. I am working on designing a movable and personal heating panel that can warm your workplace in the office locally.

I would like to ask you 3 questions about your product appearance preference for this product in a company office environment and desired information that you would like to know form the personal heating panel.

Thank you for your kind help!

Your age *

- 15-19
- 20-29
- 30-39
- 40-49
- 50-59
- 60-69
- Prefer not to say

Did you have work experience in an office environment? *

- Yes
- No

General description of the product:

A moveable standalone infrared heating panel is provided by the company in wintertime. The panel is located under your desk for your office personal workplace. This heating panel can warm up your personal office workplace locally with a low general temperature from the central heating to save energy compared with using a central heating system to warm up the whole office. In addition, when you are not in the workplace, it can sense your occupation and change the working mode to save more energy.

Among the following product appearance meanings of this product, as a potential user, what is important for you in an office usage environment? Please select 1 to 5 important meanings of them. *

Note: Below image showed the environment where the panel will be used, please ignore the shape and the colour they have

- Light weight looks
- Simple looks
- Unobtrusive looks
- Approachable looks
- Novel looks
- Elegant looks
- Durable looks
- Safety looks
- Personalisable looks

Attitude and desirable information from the local heating panel

Description (optional)

General description of the product:

A moveable standalone infrared heating panel is provided by the company in wintertime. The panel is located under your desk for your office personal workplace. This heating panel can warm up your personal office workplace locally with a low general temperature from the central heating to save energy compared with using a central heating system to warm up the whole office. In addition, when you are not in the workplace, it can sense your occupation and change the working mode to save more energy.

If the panel is provided by the company, among the following statements, which represent your attitudes when using this energy-saving panel? *

- [ ] I might use it based more on my own thermal comfort needs than energy consumption information. Becau...
- [ ] I might use it based on both my own thermal comfort needs and the energy consumption information of th...
- [ ] I might use it based more on energy consumption information than my own thermal comfort needs, I will tr...
- [ ] Other...

Among the following information, as a potential user, what information would be important for you to know from the personal local heating panel that can save energy for the office? (choose 1 to 5 options) *

- [ ] Current temperature of my own workplace
- [ ] Current temperatures of other places in the office
- [ ] Current heating temperature of the local heating panel
- [ ] Temperature (mode) I set at moment
- [ ] Other workers' personal temperature settings in my office
- [ ] Current working status of the local heating panel - whether it works well, it is on or off
- [ ] How long I have used the local heating panel today
- [ ] Tailored local temperature setting guidance for energy saving from heating while not scarify my personal t...
- [ ] The energy saved of my local heating panel compared with a central heating system
- [ ] History of my local temperature decisions for local heating
- [ ] I do not care about any information from the heating panel
- [ ] Other...

Appendix E

Material	Polyester fabric	Aluminum	Glass	Steel, stainless	PC	Plywood
Low cost (5)	Around 10 per meter	10.2 per meter				
Lightweight (5)	5	2	0	2	2	1
Easy for cleaning (5)	3	5	4	4	4	1
Thermal conductivity ($Wm^{-1}K^{-1}$) 3	0.03 (Cotton or Plastic Insulation -foamed)	205 (Pure aluminum has a higher value) 4	0.8	50.2	0.19-0.22	0.16
The thermal degradation and ignition point	Fire retardant fabric	Over 120° C	Over 1200°C	Over 120° C	Over 120° C	110° C to 150° C
Emissivity of surface 2	0.94-0.97 1	0.09 (Aluminium polished)	0.75 (glass fused quartz)	0.16 (Stainless steel polished)	0.95 (Plastic opaque)	0.924
Other	As expected, IR radiation transmitted fabric easily, but it was limited to some extent. Such as the thickness. Within the deinition of Kirchhoff's law of thermal radiation, for any arbitrary body emitting and absorbing thermal radiation, the emissivity is equal to its absorptivity.					

Links for numbers

1.Far Infrared Emissivity Characteristics and Evaluation of Different Light, https://www.scientiic.net/AMR.332-334.246

2.https://www.ceramicx.com/information/support/why-infrared/

3.https://en.wikipedia.org/wiki/List of thermal conductivities cite note-TPRC1G-6

4. http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html

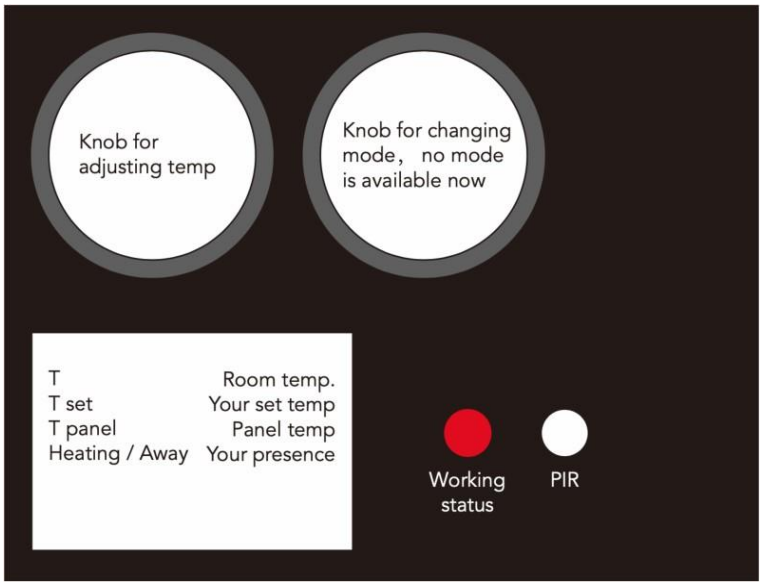
5. Thermal Properties of different materials, https://www.performancepanels.com/thermal-properties

Appendix F

This is a smart heating panel, it detects your presence.
So you do not need to worry about wether you turn it off when you leave.

Here are some instruction of the usage:

1. Please do not leave anything above the panel.
2. Please do not touch the wire connection.
3. Please feel free to adjust the temperature up to 30 degree.
4. Three is no cooling function

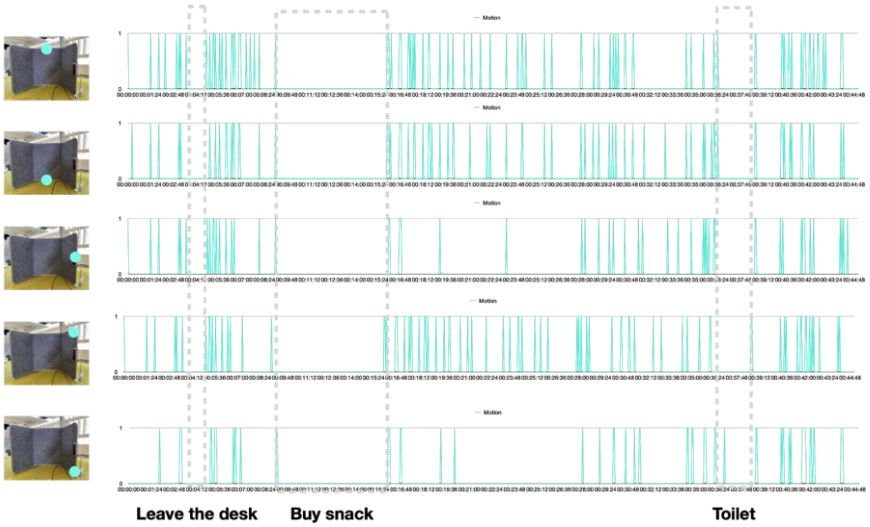


No.
Questions:

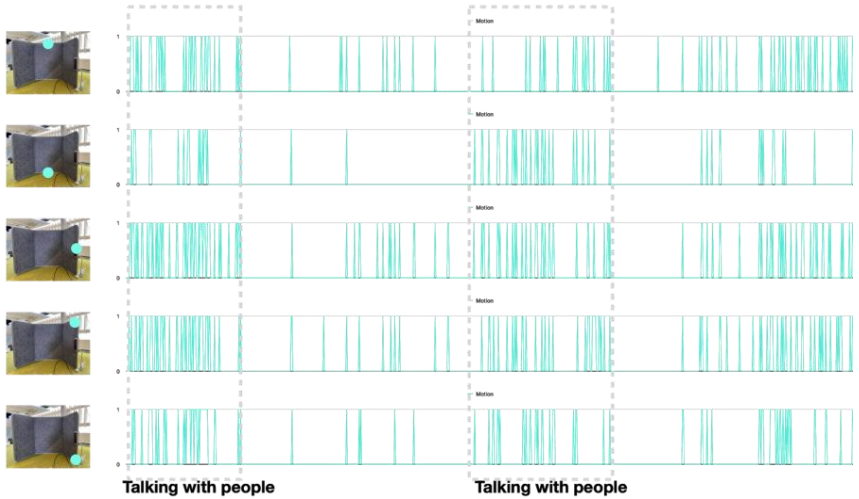
1. What do youthink of the heating panel?
2. What do you thunk of the control unit?
3. WHat do you think of the smart more during the use?

Appendix G

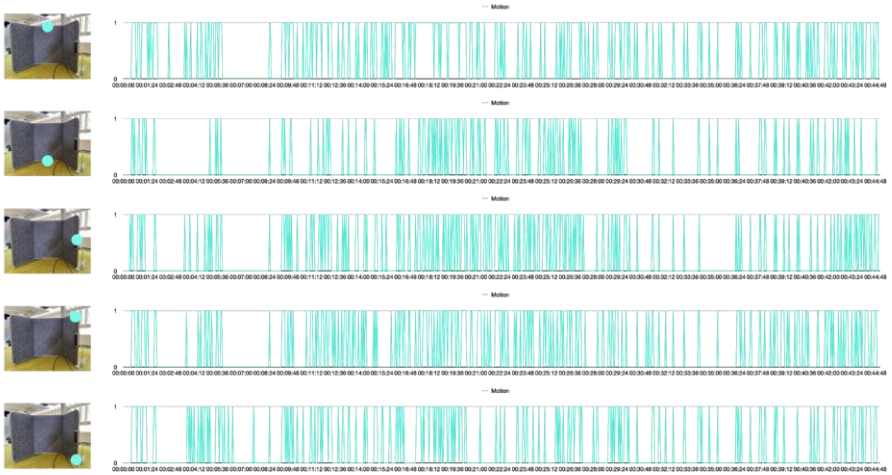
P1



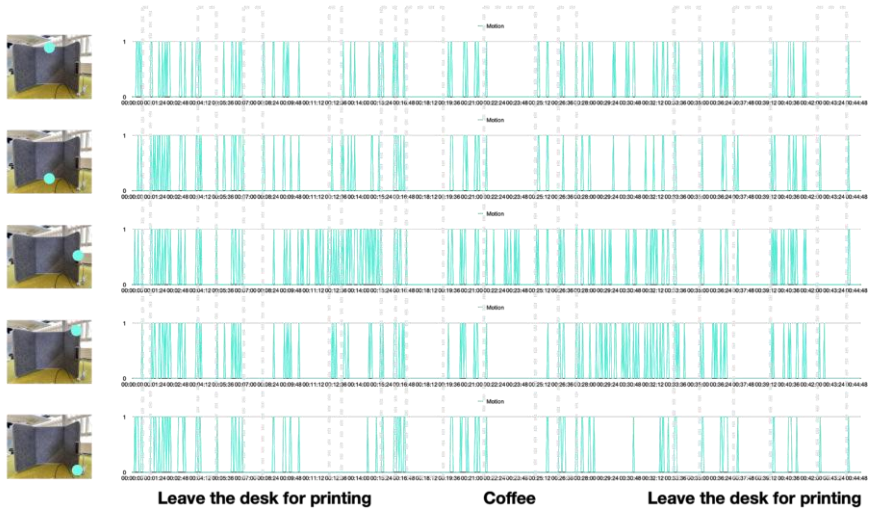
P2: Seat all the time



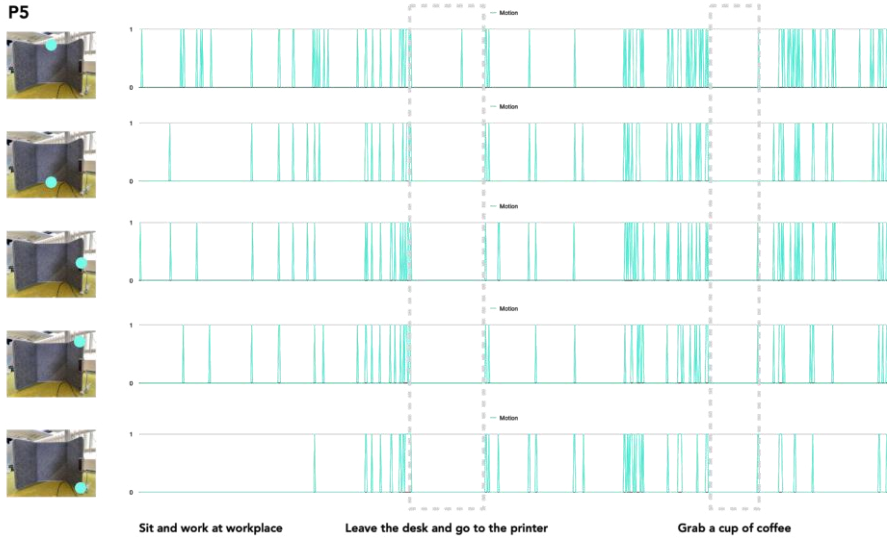
P3: Seat all the time



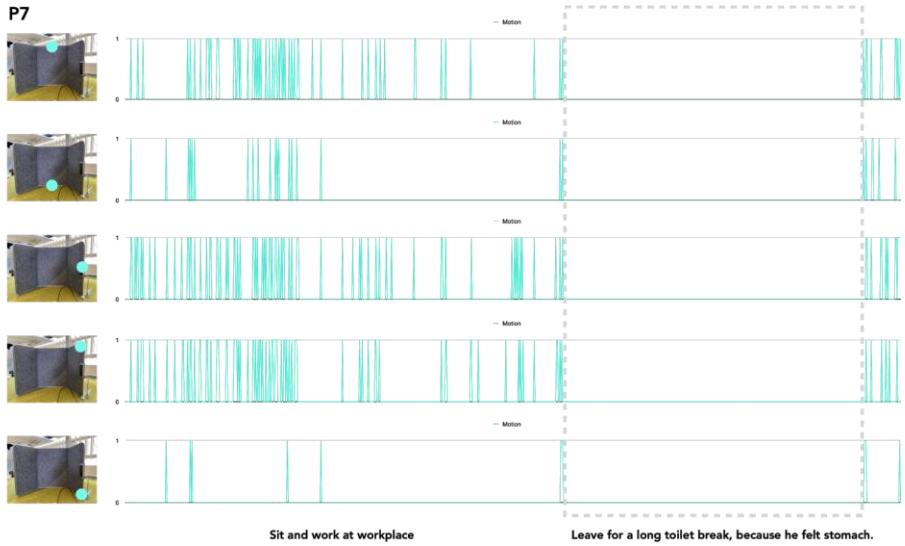
P4



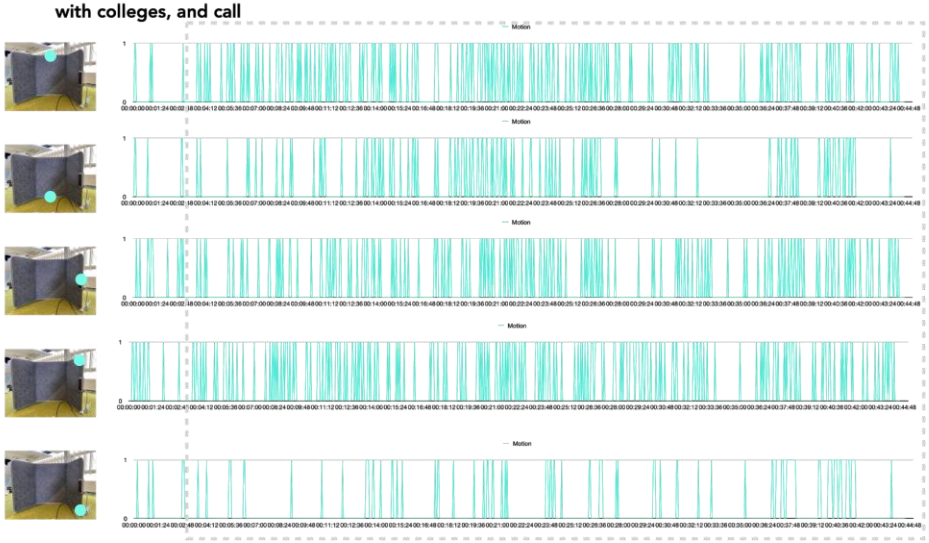
P5



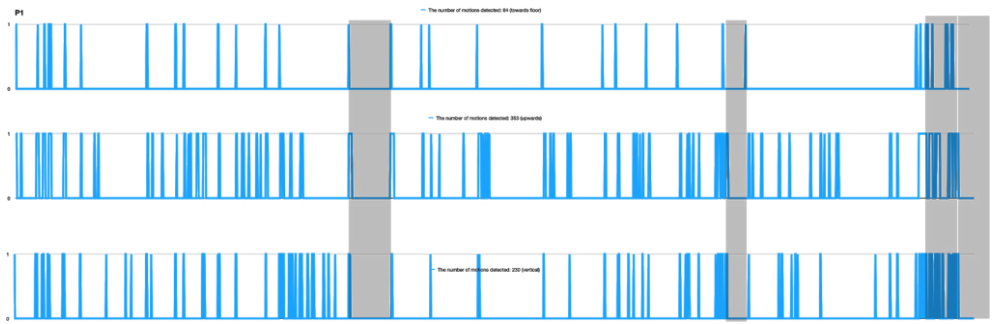
P7

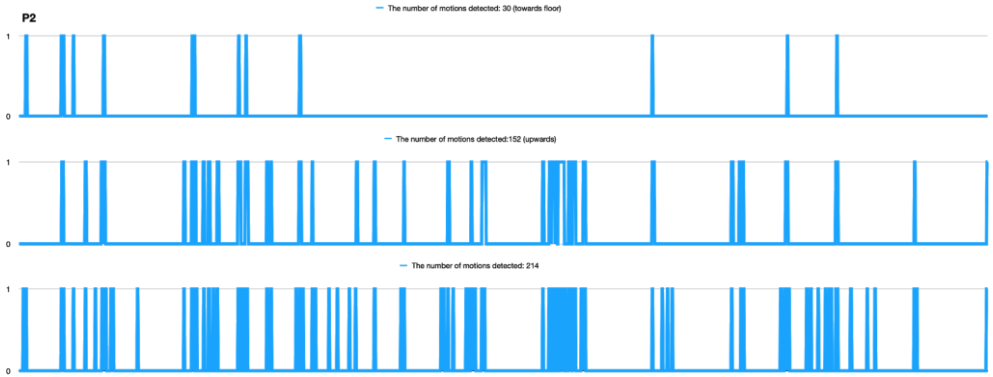


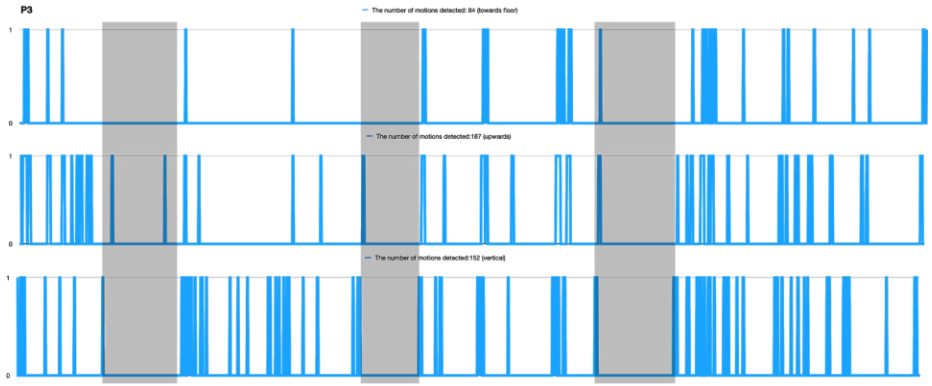
P6: Seat all the time, keep talking with colleges, and call



Appendix H







Grey blocks represents the leaving time

Appendix I

Name		
PIR Seeed motion sensor	https://www.kiwi-electronics.nl/grove-pir-motion-sensor?gclid CjwKCAjwh7H7BRBBEiwAPXjadi3wUXIaCZ2nzWu22K9NivS2TiA0pO8YHZhXp3nVvjLbNXX4hPbgEhoC5DoQAvD BwE	https://iles.seeedstudio.com/wiki/Grove PIR Motion Sensor/resources/Fresnel lens 8120.pdf
SparkFun OpenPIR	https://www.sparkfun.com/products/13968	https://cdn.sparkfun.com/datasheets/Sensors/Proximity/SparkFun-OpenPIR.pdf
Mini PIR sensor	https://www.kiwi-electronics.nl/grove-mini-pir-motion-sensor?lang en	https://www.seeedstudio.com/Grove-mini-PIR-motion-sensor-p-2930.html
Human Presence Sensor (AK9753)	https://www.sparkfun.com/products/14349	https://cdn.sparkfun.com/assets/6/7/9/8/e/AK9753 DS.pdf
D6T-44L-06	https://www.tme.eu/nl/details/d6t-44l-06/temperatuur-convertoren/omron-ocb/?brutto 1&gclid Cj0KCQjwnqH7BRDdARIsACTSAdu5o4M31CAte-Y7qBnexBsTtLQev82PzFJuK4xNNym avV2TX76GtIaAh44EALw wcB	https://www.tme.eu/Document/edb9623823e19c6cb5d4c347526748a1/D6T.PDF https://omronfs.omron.com/en US/ecb/products/pdf/en D6T users manual.pdf
AMBA210207 Middle type	https://nl.farnell.com/panasonic/amba210207/motion-sensor-5-5-to-27vdc-70cm/dp/2473758	
AMN33112J Spot PaPIR Panasonic	https://nl.farnell.com/panasonic-electric-works/amn33112j/sensor-motion-5m-38-22-white/dp/1373715	http://www.farnell.com/datasheets/73642.pdf? ga 2.19647992.1563706293.1600847673-2133126637.1599727444& gac 1.182534612.1600204102.CjwKCAjwzIH7BRAbEiwAoDxxTlCRv24-KQ8IuRCYr2yZer3 UoMPlvyTHH1wZyjYwLi2RxYdGiC7-BoC-zsQAvD BwE
Standard 3112sensor	https://nl.farnell.com/panasonic-electric-works/amn31112j/sensor-motion-5m-100-82-white/dp/1373711	
AMN32112J	https://nl.farnell.com/panasonic-electric-works/amn32112j/sensor-motion-2m-91-91-white/dp/1373713	
Ultrasonic sensor		https://wiki.seeedstudio.com/Grove-Ultrasonic Ranger/

Appendix J

16 responses

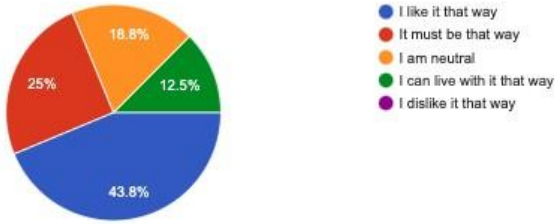
Accepting responses

Summary | Question | Individual

1. Heating speed

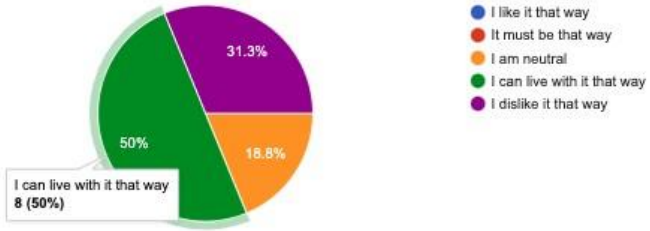
If the heater is able to heat up within 5 mins at your workplace when your workplace is cold, how do you feel?

16 responses



If the heater is not able to heat up within 5 mins at your workplace when your workplace is cold, it might need 10 mins to heat up, how do you feel?

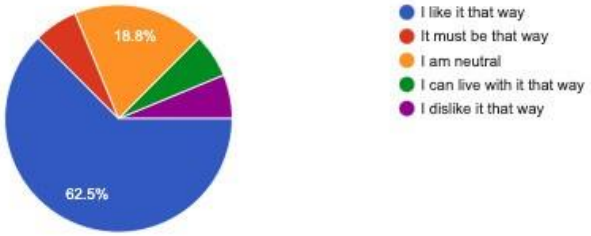
16 responses



2. Auto-off

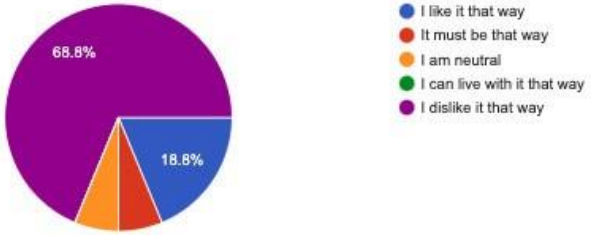
If the heater will only auto switched off when you leave your office personal workplace for meetings / go to the lunch / go home (15 mins leaving), the heater is still on and warm when you go back from coffee machine / toilet break / a short leaving (5 mins leaving), how do you feel?

16 responses



If the heater will always auto switched off when you leave your office personal workplace after 5 mins (coffee machine / toilet break), when you go back, you need to wait 5 mins for the heater to reheat up, how do you feel?

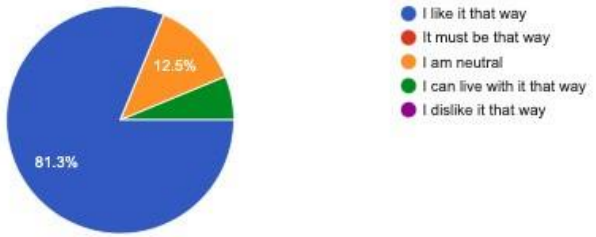
16 responses



3. Interval time for auto-off

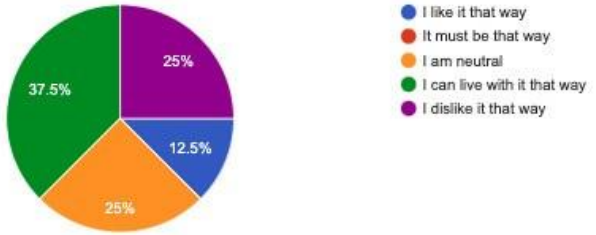
If the heater provided you options that you can adjust the interval time of automatically turning off the panel form 5 mins, 10 mins or 15 mins, how do you feel?

16 responses



If the heater does not allow you to adjust the interval time of automatically turning off the panel, it will always turn off after 5 mins, how do you feel?

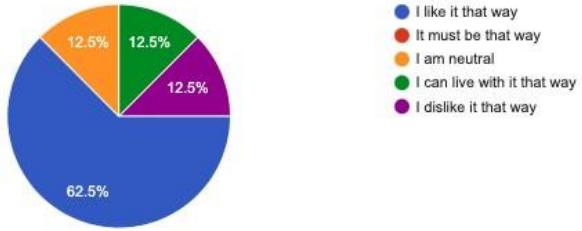
16 responses



4. Auto-on

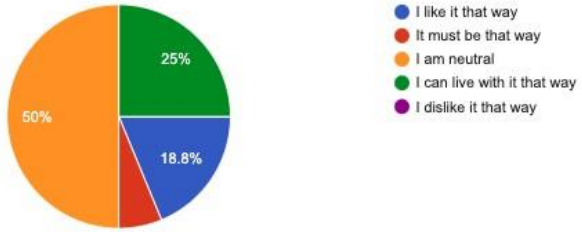
If the heater will be automatically switched on when you enter your personal workplace, how do you feel?

16 responses



If the heater will not be automatically switched on when you enter your personal workplace, how do you feel?

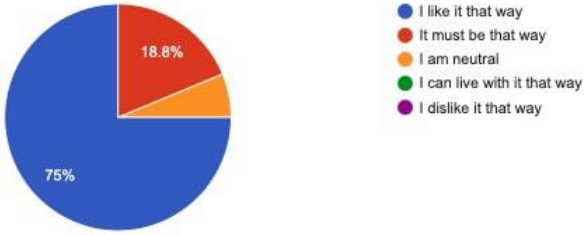
16 responses



5. My setting

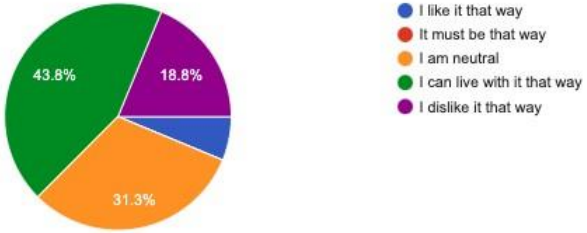
If the heater is able to remember your last setting, how do you feel?

16 responses



If the heater is not able to remember your last setting, how do you feel?

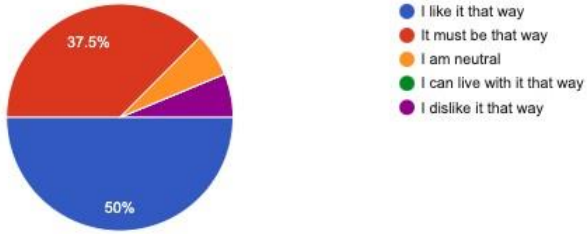
16 responses



6. Manually switch off

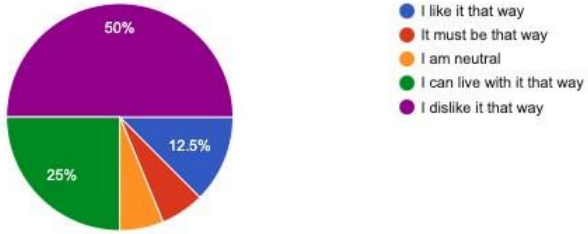
The heater is able to be off when you leave and on when you are back at the workplace automatically, If the heater also allows you to manually switch it off, how do you feel?

16 responses



The heater is able to be off when you leave and on when you are back at the workplace automatically, If the heater does not allow you to manually switch it off, how do you feel?

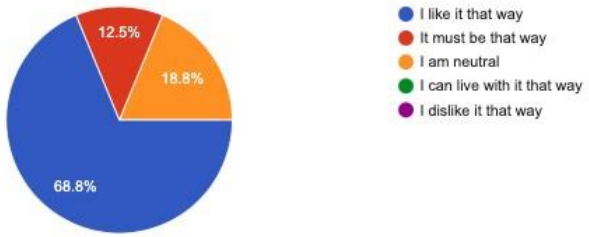
16 responses



7. Preheat

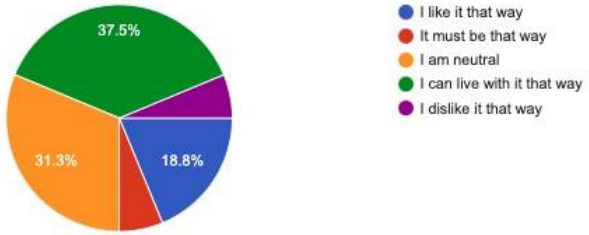
The heater is able to heat up within 5 mins, if it allows you to preheat your office workplace as well, how do you feel?

16 responses



The heater is able to heat up within 5 mins, if it does not allow you to preheat your office workplace, how do you feel?

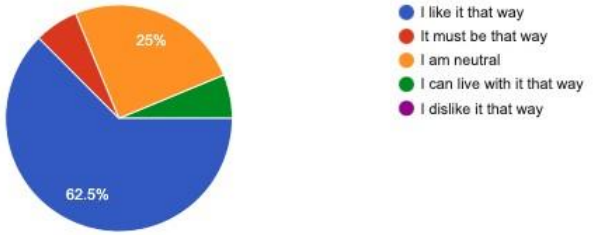
16 responses



8. Notification

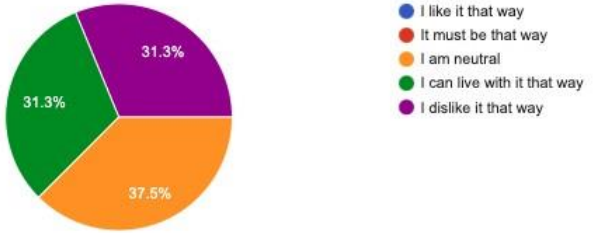
If the heater allows you to check the heater is working well, how do you feel?

16 responses



If the heater does not allow you to check the heater is working well, how do you feel?

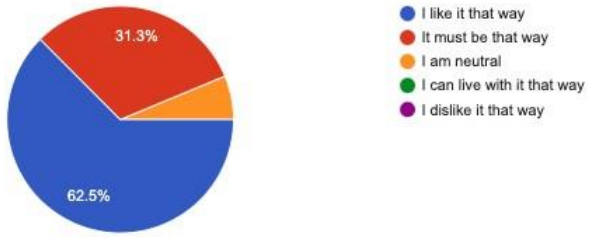
16 responses



9. Notification

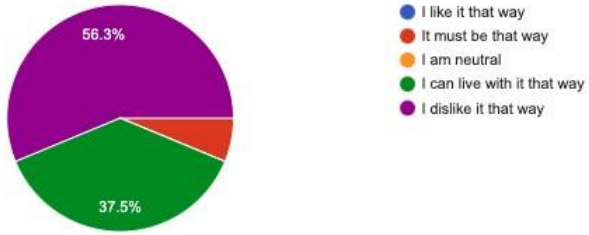
The heater is auto-off when it is broken. If the heater will notify you that there is something wrong with the heater, how do you feel?

16 responses



The heater is auto-off when it is broken. If the heater will not notify you that there is something wrong with the heater, how do you feel?

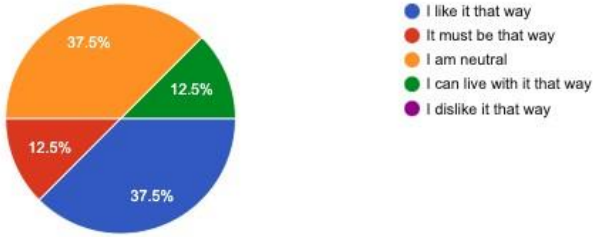
16 responses



10. Temperature setting

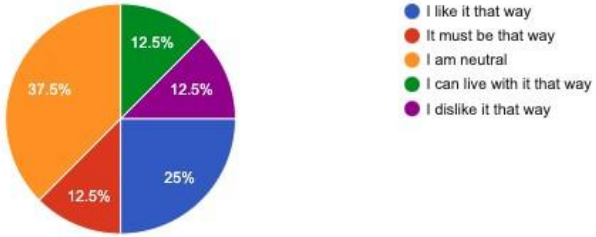
If the heater allows you to adjust the heater temperature by three different levels, not by degrees how do you feel?

16 responses



If the heater does not allow you to adjust the heater temperature by three different levels, but by degrees how do you feel?

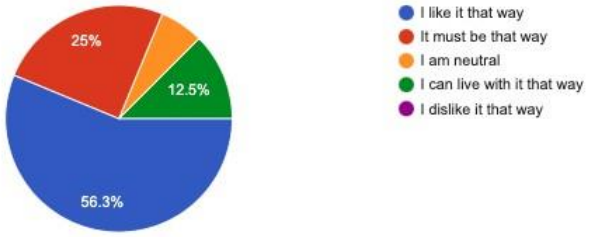
16 responses



11. Other information

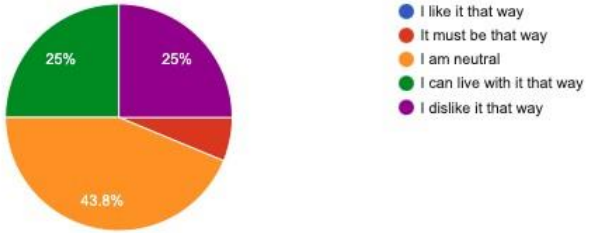
If the heater allows you to know your workplace local air temperature, how do you feel?

16 responses



If the heater does not allow you to know your workplace local air temperature, how do you feel?

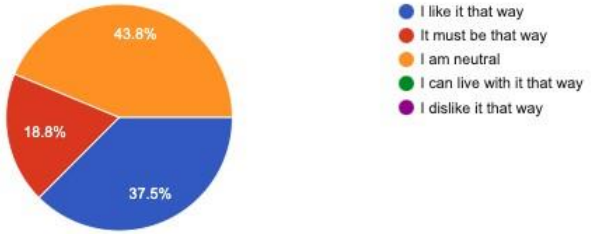
16 responses



12. Other information

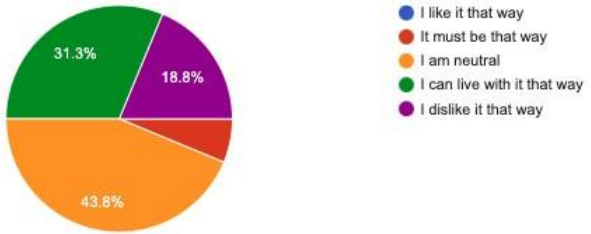
If the heater allows you to know your heater current heating temperature, how do you feel?

16 responses



If the heater does not allow you to know your heater current heating temperature, how do you feel?

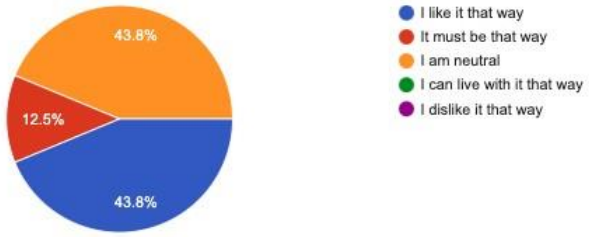
16 responses



13. Timer

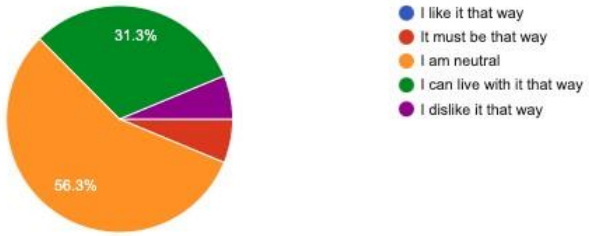
If the heater allows you to pre-set the heating time slot you need, how do you feel?

16 responses



If the heater does not allow you to pre-set the heating time slot you need, how do you feel?

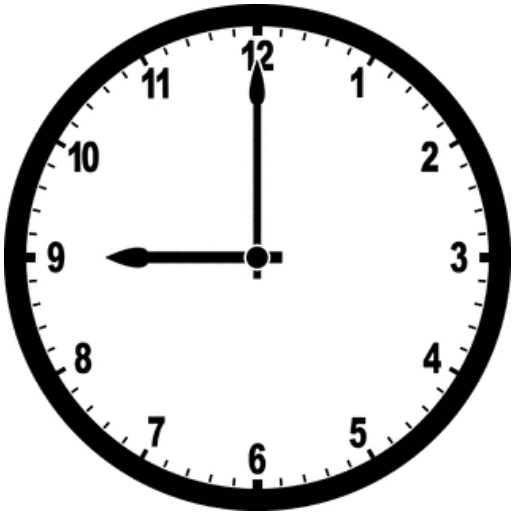
16 responses

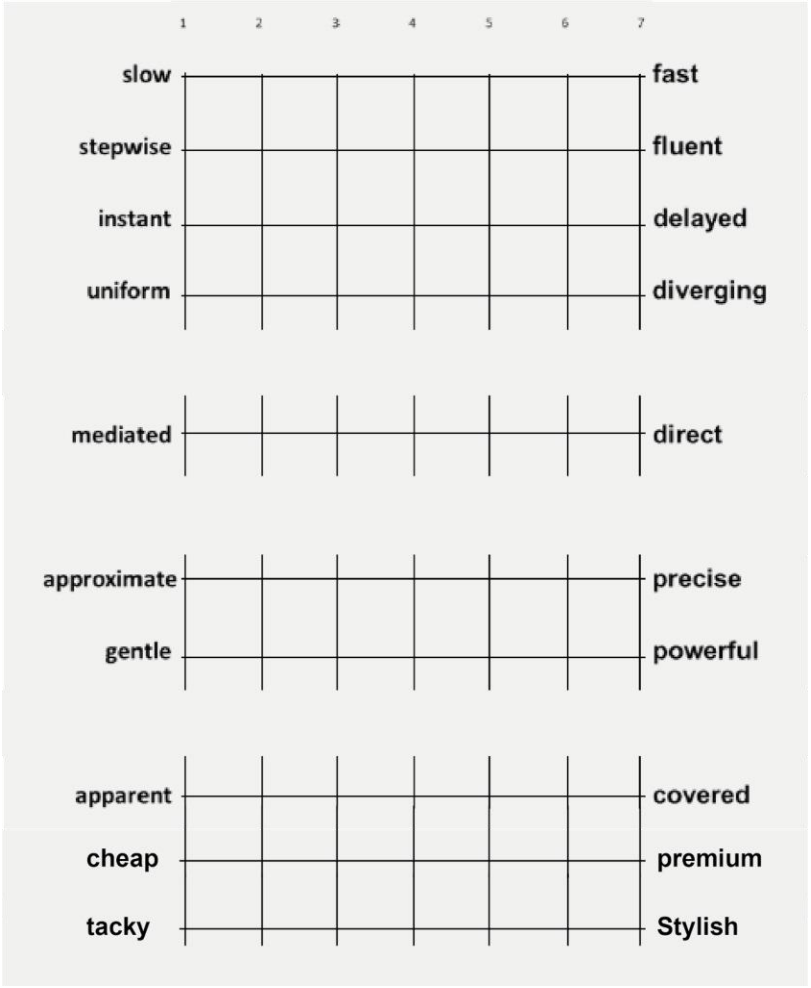


Appendix K

It is Thursday, at nine o'clock in the morning, you just arrived at the office, and you found that the company offered a new heater placed at your workplace under your desk. You would like to try it.

First please experience the heater's position and try several different adjustment methods. Then based on your adjustment feeling, please fll out the interactive quality forms.





Buttons	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	average
slow/fast	6	5	7	7	6	4.5	5.92
stepwise/ uent	3	2	7	7	2	2	3.83
instant/delayed	2	5	2	6	2	1	3.00
mediated/direct	5	2	7	4	6	4.5	4.75
approximate/precise	6	3	6	6	6	6	5.50
gentle/powerful	6	3	2	7	2	5.5	4.25
apparent/covered	2	6	2	5	2	4	3.50
cheap/premium	2	2	5	6	5	5	4.17
tacky/stylish	1	2	4	6	5	4.5	3.75
Touch buttons	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	average
slow/fast	6	6	6	7	6	6	6.17
stepwise/ uent	5	5	6	7	6	6	5.83
instant/delayed	2	2	1	3	2	4.5	2.42
mediated/direct	2	6	7	5	6	4.5	5.08
approximate/precise	6	6	7	6	6	5	6.00
gentle/powerful	1	2	1	7	2	2	2.50
apparent/covered	6	2	3	5	2	4	3.67
cheap/premium	5	2	5	6	6	6	5.00
tacky/stylish	5	2	2	6	6	5.5	4.42
knob by degrees	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	average
slow/fast	5	6	6	5	6	6	5.67
stepwise/ uent	7	6	4	6	6	6	5.83
instant/delayed	4	2	2	4	2	1	2.50
mediated/direct	3	6	6	5	6	6	5.33
approximate/precise	2	3	6	2	6	5	4.00
gentle/powerful	2	3	3	2	2	2	2.33
apparent/covered	2	2	3	5	2	1	2.50
cheap/premium	3	2	3	5	4.5	3	3.42
tacky/stylish	4	2	4	6	4.5	2	3.75
knob by levels	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5	Participant 6	average
slow/fast	5	5	4	5	5	6	5.00

stepwise/ uent	1	2	2	4	2	3	2.33
instant/delayed	1	2	2	4	2	2	2.17
mediated/direct	6	5	6	6	6	4	5.50
approximate/precise	2	6	6	6	2	3.5	4.25
gentle/powerful	7	4	3	6	4	6	5.00
apparent/covered	2	2	3	6	2	2.3	2.88
cheap/premium	4	2	3	4	4.5	5	3.75
tacky/stylish	3	2	4	5	4.5	5.5	4.00

tacky/stylish	3.75	4.42	3.75	4.00

	Buttons	Touch buttons	knob by degrees	knob by levels
slow/fast	5.92	6.17	5.67	5.00
stepwise/ uent	3.83	5.83	5.83	2.33
instant/delayed	3.00	2.42	2.50	2.17
mediated/direct	4.75	5.08	5.33	5.50
approximate/precise	5.50	6.00	4.00	4.25
gentle/powerful	4.25	2.50	2.33	5.00
apparent/covered	3.50	3.67	2.50	2.88
cheap/premium	4.17	5.00	3.42	3.75

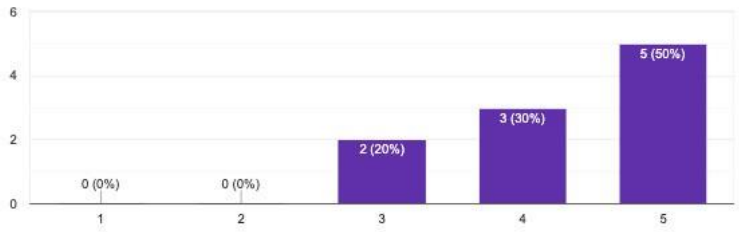
Appendix L

Meaning 1: Three different heating temperature levels

Meaning description: The personal temperature adjustment function allows you to adjust the heater heating temperature by three different levels. The heating temperature varies from 45 degrees Celsius to 60 degrees Celsius. Increase one level, increase the temperature by five degrees. A higher level means warmer the heater will be.

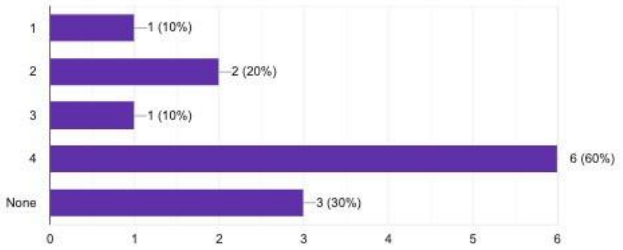
How much do you think the standard (datum) matches its meaning? (circles represent touch buttons)

10 responses



Here are other designs, (circles represent touch buttons). Which ones do you think represent this meaning better compared with the datum icon?

10 responses



Please shortly describe WHY you think it is better.

10 responses

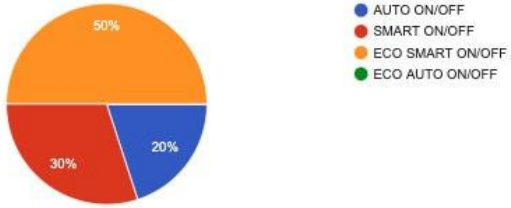
- Number 2 is faster to read once you know the settings. Number 4 is best because of the visual, red means hot and also visually becoming "bigger" (ramping up).
- 3 and 4 are more likely a touch bar for scrolling up and down
- It's clear and fits minimalistic design. I like it to be symmetrical
- More visualized, more intuitive
- shows colour and amount, I think it is very clear what it means (expecially with the icon)
- Number 4 is also clear. High, medium, low just clearly explains on which section of the heating spectrum is used.
- The words high mid and low describe the working perfectly. With numbers or colors you could argue about the order of hot and cold
- Colours are better.

Meaning 2: Save energy mode.

Meaning description: The heater is saving energy by automatically off when you leave the work desk after a while. And when you go back, it will be on automatically.

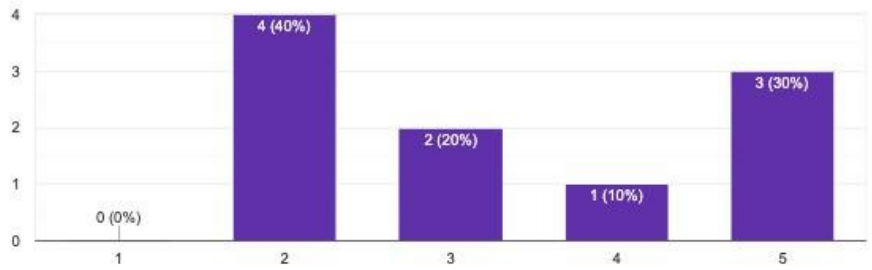
Which of four "name"s can represent this meaning better?

10 responses



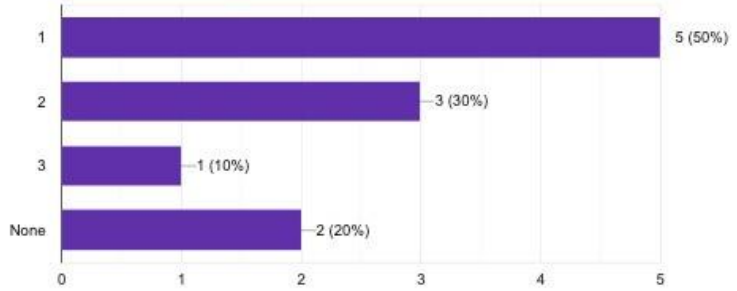
How much do you think the standard (datum) icon matches its meaning?

10 responses



Here are other icons, which icons do you think represent this meaning better compared with the datum icon?

10 responses



Please shortly describe WHY you think it is better.

10 responses

A leaf could mean environment friendly material. With a plug it become more clear that it means energy saving

1, 2 and 3 are more likely for charging

First one looks like green energy to me. The gap of the second one makes me feel like it's using less energy.the third one only means electric for me.

Easy to get the idea and also easy to understand

green and energy combined, for me it shows an sustainable save mode

In combination with the icon on the next page this clearly shows movement is detected to reduce energy use. The leave is a clear sign the product is set to energy saving mode

This icon really shows what the energy saving is about in this case

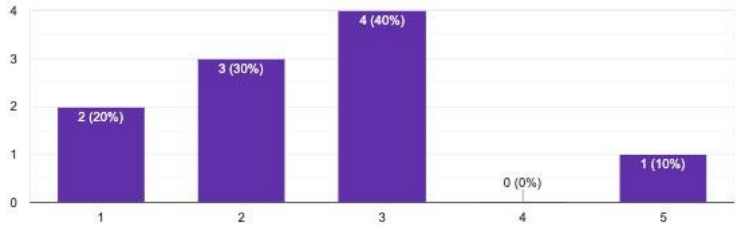
It's better because of the power cable. It connects energie to the logo.

Meaning 3: Detect workplace occupancy

Meaning description: When the automatically turn on/off function is on. The heater will sense your motion so as to detect your workplace occupancy.

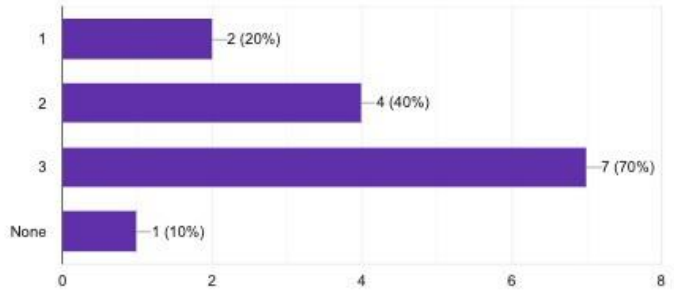
How much do you think the standard (datum) icon matches its meaning?

10 responses



Here are other icons, which icons do you think represent this meaning better compared with the datum icon?

10 responses



Please shortly describe WHY you think it is better.

10 responses

Shows that you are moving away from your workplace.

Datum, 1 and 2 are more likely for detecting if the person is leaving

I think I only notice it when I'm working there, so the third icon matches. The other icons represent that I'm away from the workplace, when I will not see the product or the interface.

It says it's on when I'm here, but the others doesn't give me the feeling that it's off when I leave

It shows me working at the desk, I occupy the desk. For me the others are people passing by

This clearly shows movement, the other symbols might be a bit too much. Number three might be a bit more clear on showing movement at the desk.

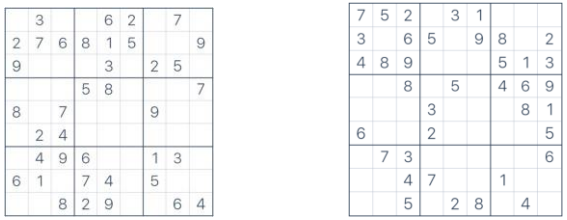
You have to show where these movements take place so that you understand the working of it

The table makes it better.

I think i will only notice the icon when I am sit at the desk, so the third one matches better the meaning

Appendix M

S K



(reset from caution page to the main starting point by pressing the right top button)

Scenario 1 You just saw a new product at ofice

"This morning, you just saw a new heater placed under your personal workplace and did not yet try it out.

Task And now please plug the heater into the socket (I need to ress the screen when plug the heater into the socket)

Scenario 2 After you plugged the heater in to the socket, you sit down and want to start to work (give the suduko)

Task 1 lease turn on the heater and set the temperature to the highest level, and you notice the eco smart mode is already on, but please to try to turn it off and turn it back on on as your try out (I need to turn on the heater and high temp, after ive mins stop the heating animation)

Goal: Let the participant set his/her temperature with the touching system and see if they can understand the "still heating" meaning.

Hidden task: when switch to the highest temperature and see the temperature is rising.

Task 1 2 After a while, you feel the heater is too warm, please switch it to a lower level (I need to switch to the mid temp, after S mins and stop the heating animation)

Goal: If it is easy and reachable to change the heater when the user is working

Scenario3 When you almost inished your current task, you would like to go to the toilet you leave the heater without turn it off

Goal: Satisfaction level when the heater is still on when they back from the short break/The understanding of the smart detection

Task 2 lease leave the desk for a toilet break (go to the print room and go back) (I do nothing)

Scenario 3 2 When you are back, you can still feel the warmth, the heater is maintaining your setting when you check the control interface

Scenario 4 ow you just remember that you will have an hour meeting within 1S mins, so you leave your desk again without turn it off

Goal:

Hidden task:

- Turn it on, the heater still remember my settings

Task leave the desk and go to the room next to us and watch the video(I need to lead participant to another room, play the video, and go back the room, turn off the eco smart button, turn off the power of heating)

Scenario 4 2 When you go back to your seat(Task) the heater turn it on automatically and remember your setting (I need to press the eco icon place again, and after S mins turn off the animation)

Scenario S After the meeting, you left the ofice without turn the heater off ow it is next morning, you entre the oice and notice the heater is completelyoff

- When you seat down, the heater turns it on automatically, the heater still remember my settings

Task You turn on the heater again manually, after a while, you feel the heater is still cold, you feel strange, so you check the interface And no matter how you touch, the heater is not working anymore (press the secret button on the right button to the caution page)

Introduction

Participant Number:
Gender:
Age:
Nationality:
Occupation:
Do you have experience of working in an open offce?

How do you feel about the thermal environment in this room when you sit'?

Scale value	Thermal comfort descriptor	Thermal sensation descriptor
+3	Much too warm	Hot
+2	Too warm	Warm
+1	Comfortably warm	Slightly warm
0	Comfortable	Neutral
-1	Comfortably cool	Slightly cool
-2	Too cool	Cool
-3	Much too cool	Cold

Score of thermal comfort
Score of thermal sensation

How do you feel about the thermal environment in this room with the heater'?

Scale value	Thermal comfort descriptor	Thermal sensation descriptor
+3	Much too warm	Hot
+2	Too warm	Warm
+1	Comfortably warm	Slightly warm
0	Comfortable	Neutral
-1	Comfortably cool	Slightly cool
-2	Too cool	Cool
-3	Much too cool	Cold

Score of thermal comfort
Score of thermal sensation

ikert scale questions

lease rate the control unit based on your experience

You could add your explanation next to your score if necessary

l = Totally disagree

2

3

4 = Neutral

_

6

7 = Totally agree

l) I found it is easy to reach the control unit when I want to adjust it.

2) I can easily understand all basic functions with the interface.

- Manually on/off of main power
- The ECO SMART is on as an default setting, but I can still manually turn on/off of the ECO SMART
- Manually select your personal temperature

3) I can quickly focus again on my task after I readjust the settings.

4) I found it is easy to switch temperature from one to another.

) I found it is easy to read information on the control unit as follows:

- the heater is heating when the lighting is blinking
- The heater reached my selected temperature
- The caution information
- The heater is detecting my occupancy

6) It is easy to distinguish different functions with colour code lightings.

7) The icons positively give me enough information to interact with the control unit.

8) I am satisfed that I can have my personal preferred temperature in a shared offce with the local heater in a cool environment.

) Having a local heater with a personalisable heating temperature, I am satisfed that I have a stronger feeling of control my working environment.

l0) I am satisfed about the heating speed.

ll) With the auto ON/OFF function, I will not often touch the control unit once I fnd my prefect settings during the day.

l2) I do not mind that I need to turn on the heater manually after a longer leave and in next morning once I entered the offce.

l3) I like that I can override the ECO SMART when I do not want to have it.

l4) I can easily understand that when "ECO SMART" is on, it means that:

- The heating will be on automatically when I am at my workplace
- When I leave for a longer time, the heater will be off automatically
- If the main power of the heater is on, It can remember my settings after my frst setting

l) ECO SMART ON/OFF mode positively help me understand the heater is saving energy for the environment.

l6) I will always keep the ECO SMART mode on when I am using the local heater.

l7) When the ECO SMART mode is on, it is not reducing my thermal comfort level a lot.

l8)I fully understand the working status of the heater as follows:

- Please select your temperature
- Heater is heating
- Heater reached the target temperature
- Safety caution

1) To fnd a suitable personal temperature, the number of selections of temperature levels are..... (from l to 7, the current one has 3 levels, which means the score is 3)

20) What other information would allow you to feel the product is contributing to the environment? (for example colour, texture, icon, material, certifcates, etc.)

2l) Do you have any suggestions or questions that have not yet been covered?

Without heater	P1	P2	P3	P4	P5	P6	Average
Thermal comfort level	-1	-2	-1	-1	0	0	-0.83
Thermal sensation level	-2	-1	-1	-1	-1	-1	-1.17
With heater							
Thermal comfort level	1	-1	0	1	1	1	0.50
Thermal sensation level	2	0	0	2	0	1	0.83
Likert scale questions							
1	6	6	3	7	5	3	5.00
2	6	7	5	7	6	2	5.50
3	6	7	6	6	7	6	6.33
4	7	7	6	7	7	5	6.50
5	5	5	6	6	6	3	5.17
6	6	6	6	6	7	6	6.17
7	6	6	5	6	7	6	6.00
8	7	6	6	7	7	5	6.33
9	7	7	6	7	7	5	6.50
10	5	7	5	6	6	6	5.83
11	6	7	6	7	7	6	6.50
12	6	7	6	7	7	7	6.67
13	6	5	4	7	4	7	5.50
14	6	5	6	6	7	2	5.33
15	7	6	6	6	7	5	6.17
16	6	7	6	7	6	5	6.17
17	4	7	6	7	7	5	6.00
18	6	7	5	7	5	3	5.50
19	5	3	3	5	3	5	4.00

Appendix N

O

articipant consent

I am voluntarily taking part in a research study conducted by Yin Shen for the purpose of analysing the usability of the product design. I understand that my participation will be recorded on digital audio and that I will be photographed.

I understand that the data and information I share today will be handled conidentially and anonymously

I understand that the audio recordings and photographs will not be used for any commercial purposes whatsoever. The audio recordings and photography be part of the information presented at professional conferences.

I will not be identifed by name or by showing my face. My personal information will be protected; taking part in this study and the results from the study are not part of my performance review; my manager won't have access to the notes or data you help us gather. My information will be rolled up with the rest of the data from the other study participants.

I waive any right that I may have o inspect or approve the fnal recordings, photo, and report. I discharge Yin Shen from any liability for making, editing, or using the recordings and photographs from this study according to the uses outlined above.

Signature:

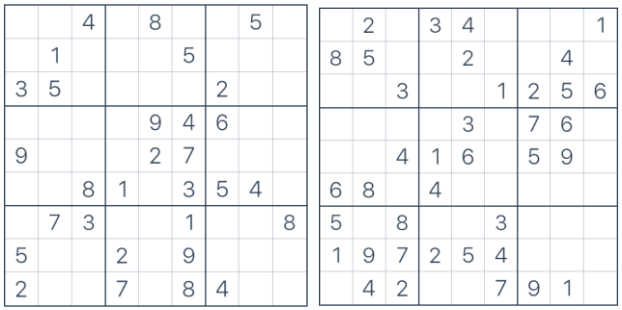
Name:

Date:

Participant Number:
Height:
Gender:
Age:
Nationality:
Occupation:
Do you have experience of working in an open offce?

I

Sudoku



		4		8			5	
	1				5			
3	5					2		
				9	4	6		
9				2	7			
		8	1		3	5	4	
	7	3			1			8
5			2		9			
2			7		8	4		

	2		3	4				1
8	5			2			4	
		3			1	2	5	6
				3		7	6	
		4	1	6		5	9	
6	8		4					
5		8			3			
1	9	7	2	5	4			
	4	2			7	9	1	

Protocol

Scenario 1 (SmartHeco name on the top)

In a cool winter, you just arrive at your office, the general heating system is off, you found there is a product on your desk, you have a look at the product, you remember that it is a local heater that the company provided for each employee. Please assemble the stands to the product and place it under your desk.

After you found a proper position, please let me know.

Scenario 2

l. After you plugged the product into the socket, you sit down and want to start to work.

(Give the Suduko)

(2SS, 4 , ,) orange

2. Please turn on the product, and you go back to work, you feel the product is **getting warm**

3. After minutes, **(3 seconds)** you check the product, you feel the temperature is not warm enough,

(2SS, , ,) red

4. So you switch it to a level higher.

. After another minutes, **(3 seconds)** **you feel warmer**, you are satisfed with the temperature, you check the product.

Scenario3

l. When you have almost fnished your current task, you suddenly would like to go to the toilet. So you leave the product without turn it off. **(please leave your desk)**

2. And when you go back, you check the product, and when you sit down, the product is **still warm**.

Scenario 4

(blue standby lighting)

l. Now you just remember that you will have an hour meeting within mins, so you carelessly leave your desk without turn it off.

2. Now you fnished an hour's meeting. When you go back, you check the product from a long distance, when you sit down, you feel the product is **cold**. **(change to heating interface and colour wipe animation 2SS, , ,)**

3. You check the product again.

4. After a while, you feel **the same warm** level as you have selected before you leave.

Scenario S

l. At the end of the day, you left the offce without turn the product off accidentally. **(please leave your desk)**

2. Now it is the next morning, you enter the offce and notice the product is completely **off** and **cold**.

(ress the hidden button to the caution information and yellow flashing)

3. So you sit down and turn it on again, but when you check the product.

2

lease rate the control interaction based on your experience, You could add your explanation next to your score if necessary

I = Totally disagree
2
3
4 = Neutral
_
6
7 = Totally agree

- I found it is easy to reach the control unit when I want to adjust it.

Text:

- I found it is easy to move in and remove it under my offce desk.

Text:

- I found the product shape is ergonomically comfortable which fts a standard sit working position in a short time.

Text:

lease ill the next question with "x" and "v"

- I found it is easy to understand the information on the control interface as follows:
  - The brand of the product is called "smartHECO".
  - The main power on/off option.
  - Five different heating levels for selecting.
  - My real-time presence detection information.
  - The product starts heating to the targeted temperature when the reddish strips indicators are flashing and increasing.
  - The product reached the targeted temperature, and is maintaining the temperature when the reddish strips stop flashing
  - The caution information: I need to unplug the product and call maintenance when the product is broken.

3

Semi questions for interview

1. Was the prototype clear?
2. Can you understand the smartness of the product?
3. Please describe the smartness of the product in your mind.

(check if the participants mentioned these features)

- I can easily understand the smartness of the product:
  - The product starts detecting my occupancy of the workplace after I turned on the main power.
  - When I leave for a short time (toilet break), the product maintains the temperature I have selected.
  - When I leave for a longer time (an hour meeting), the heating will be off automatically during that time. When I come back to my workplace, the product starts to be warm again while remembers my previous setting.
  - If I forget to turn the product off when I leave the office, the product will be completely off automatically.

4. Was the lighting clear? Can you distinguish the different working statuses of the product based on lightings?

. Do you think it helps you to distinguish the working status of the product quickly?

(check if the participants mentioned these features)

- I fully understand the LED indicates the status of the product as follows:
  - When the LED lighting is wiping in reddish, it means the product is heating to the targeted temperature
  - When the LED lighting stays in reddish lighting, it means the product is maintaining the temperature at the selected temperature level
  - When the LED lighting is cyan, it means the heating is off and the product turns cold when I leave for a long time.
  - When the LED lighting turns from cyan to reddish and starts to repeat the wiping animation it means the product detected my presence and restart to heat.
  - When the LED lighting is flashing in yellow light, the product is broken.

4

lease score your interaction experience based on these qualities

Pragmatic qualities

Complicated Simple	-3	-2	-l	0	+l	+2	+3
Confusing Clearly structured	-3	-2	-l	0	+l	+2	+3
Unruly Manageable	-3	-2	-l	0	+l	+2	+3

Hedonic qualities

Cheap Premium	-3	-2	-l	0	+l	+2	+3
Challenging Undemanding	-3	-2	-l	0	+l	+2	+3

Attractiveness

Ugly Attractive	-3	-2	-l	0	+l	+2	+3
Repelling Appealing	-3	-2	-l	0	+l	+2	+3

5

System Usability Scale Questionnaire	Strongly Disagree				Strongly Agree
1. I think that I would like to use this product frequently.	1	2	3	4	5
2. I found the product unnecessarily complex.	1	2	3	4	5
3. I thought the product was easy to use.	1	2	3	4	5
4. I think that I would need the support of a technical person to be able to use this product.	1	2	3	4	5
5. I found the various functions in the product were well integrated.	1	2	3	4	5
6. I thought there was too much inconsistency in this product.	1	2	3	4	5
7. I imagine that most people would learn to use this product very quickly.	1	2	3	4	5
8. I found the product very awkward to use.	1	2	3	4	5
9. I felt very confident using the product.	1	2	3	4	5
10. I needed to learn a lot of things before I could get going with this product.	1	2	3	4	5

		2	3					Average
2								
								33
2								
3								3
3								
or ✓	0	0			0	0		
Comp i cated	3	2	2	3	2	2		2 33
Confusi ng	2	3	0	3	2	2		2 00
Unruly	3	2	2	3	2	3		2 0
Cheap		0	3	2		2		0
Challen ging	2	3	2	3	2	2		2 33
Ugly		0	2	2		2		33
Appeali ng	0	0		3		2		

		2			2		3	2
2		2		2		2	0	3 0
3								3
							00	00
								3
	2	2	3			2	3	3
								3
	2					2	3	3
								3
0			2					3 3
								3 00
SUS score								00

Appendix O

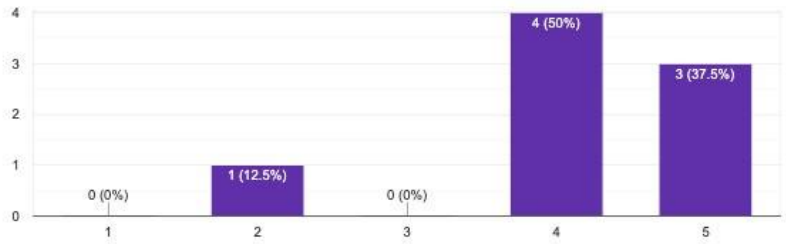
8 responses

Accepting responses

Summary | Question | Individual

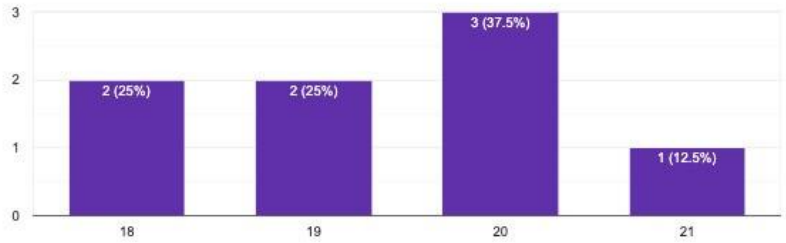
In winter, please assume that you can lower your office temperature to reduce the use of fossil fuel and co2 footprint of the building, would you be willing to use a personal local heater for your local heating, and reduce your office temperature? (The looking and the position of the heater as shown in the foto: a foldable/movable heater which will be placed under your office desk)

8 responses



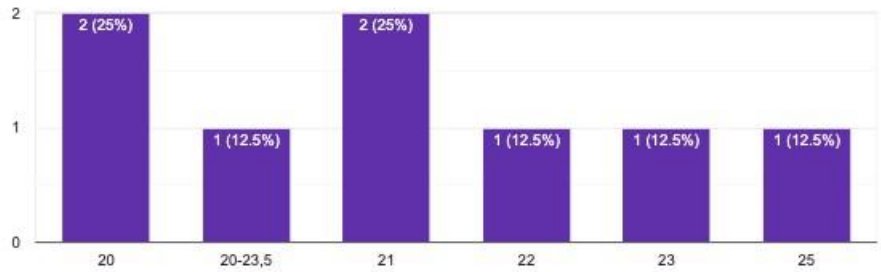
In winter, in your office, how many Celsius Degrees would you be willing to accept for the ambient environment when knowing you can feature a personal temperature locally?

8 responses



Following the previous question, under that ambient temperature, how many Celsius Degrees would you like to personalize locally (at your personal workplace in the office)?

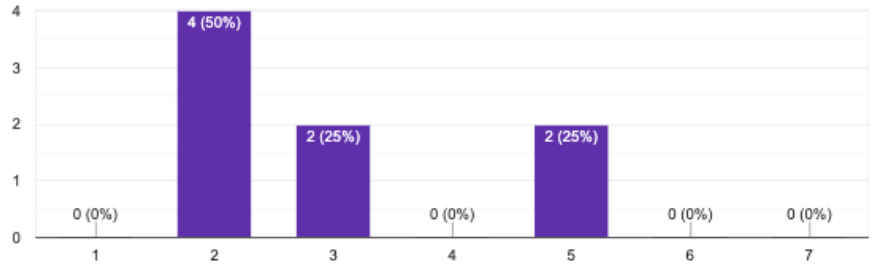
8 responses



Attractiveness quality validation

What score would you be willing to give about its attractiveness quality in the modern office environment, based on its rendering? (1 means unobtrusive, 7 means obtrusive)

8 responses



Appendix P

Appendix Q

10mm x 2mm Magnetic
https://www.amazon.nl/Magenesis-neodymium-magneten-extreem-hechtsterkte/dp/B06X977K8L/ref asc df B06X977K8L/?tag nlshogostdde-21&linkCode df0&hvadid 430598091305&hvpos &hvnetw g&hvrand 12407914627575036366&hvpone &hvptwo &hvqmt &hvdev c&hvdvcmdl &hvlocint &hvlocphy 1010704&hvtargid pla-303855520501&psc 1

Grey ireproof fabric
https://www.stoffenshop.eu/nl/stof/1989/texture-lichtgrijs-280cm-breed-brandvertragend-certiicaat-30mtr

PC light cover
https://www.techniekwebshop.nl/ledvance-ledv-tbh-v-led-driver-4058075305793-ledvance-toebehoren-voor-led-driver-lengte-1000-mm-kleur-wit.html

Capacitive switch
https://www.banggood.com/nl/10Pcs-2 5-5 5V-TTP223-Capacitive-Touch-Switch-Button-Self-Lock-Module-p-1132674.html?utm source googleshopping&utm medium cpc organic&gmcCountry NL&utm content minha&utm campaign minha-nl-nl-pc&currency EUR&cur warehouse CN&createTmp 1

3.5 inch LCD screen
https://www.amazon.com/dp/B07HFBF221/ref sspa dk detail 5?psc 1&pd rd i B07HFBF221&pd rd w DidnR&pf rd p 7d37a48b-2b1a-4373-8c1a-bdcc5da66be9&pd rd wg ZDZtJ&pf rd r RHPMYA4P8YPFV2QDDPE9&pd rd r bac50735-4baf-4548-ad4d-1532228b8e8a&spLa ZW5jcnlwdGVkUXVhbGlmaWVyPUExSFk0UEZaVEZKUzlLJmVuY3J5cHRlZElkPUEwNTA3NjY3M09GRVdXN1dPMUczQyZlbmNyeXB0ZWRBZElkPUEwNzg0OTIyMVJVTzdYNjlZU1ZVTyZ3aWRnZXROYW1lPXNwX2RldGFpbCZhY3Rpb249Y2xpY2tSZWRpcmVjdCZkb05vdExvZ0NsaWNrPXRydWU

Insulation/relective layer
https://www.hornbach.nl/shop/MACLEAN-Radiatorfolie-Therm-zilver-breedte-500-mm-lengte-2-50-mtr/4111059/artikel.html

165 W Carbon infrared heating ilm
https://infrarot-fussboden.de/Comfort-PTC-heating-ilm-160Watt/m-50cm-wide-fully-assembled-1-6m

NTC temperature sensor
https://nl.grandado.com/products/5-pcs-1m-ntc-thermistor-nauwkeurigheid-temperatuursensor-10k-1-3950-waterdichte-sonde?variant 3219603442898

Ball tilt sensor
https://www.otronic.nl/a-60901542/sensors/sw-520d-helling-tilt-sensor/?gclid Cj0KCQiAqdP9BRDVARIsAGSZ8AlbES6jtb2 VuKOiLs8GUSOSsZc49i6nqgMHX-TWQKdQfa00zCmvyYaAlcgEALw wcB

WS 2811 LED light strip
https://www.amazon.nl/pixelstriplicht-kleurrijke-stripband-adresseerbare-IC-besturing/dp/B07V5NMRGJ/ref asc df B07V5NMRGJ/?tag nlshogostdde-21&linkCode df0&hvadid 454881644048&hvpos &hvnetw g&hvrand 10044364938885487711&hvpone &hvptwo &hvqmt &hvdev c&hvdvcmdl &hvlocint &hvlocphy 1010704&hvtargid pla-947208423513&th 1

The background

By 2050 all office buildings according to EU plans should be energy neutral. This implies a large potential for more efficient solutions, such as occupancy-aware local heating. Based on this idea, OfficeVit ae developed a vertical heating panel for use in offices using infrared foil. As imagines show below, the initial prototype has a wooden structure and covered by fireproof textile for the safety reason. And the prototype has wired communication and controlled at a distance. By using the infrared heating units to heat workspaces, CO2 building emissions can be reduced, while reducing to a minimum the need for natural gas-powered central heating. The central heating can be kept low to maintain the ambient temperature at 18.SC. In the early pilot phase, OfficeVitae also validated that the temperature and overall quality of comfort was slightly higher in the areas with local heating. The sense of control was also higher, which can be attributed to individual control of heating afforded by the infrared heating panels. (Conclusions from the report- EIT-BP2019 UCBI)

Therefore, the sustainable design principle and infrared foil heating technology are reliable and validated. However, the main problem right now is that the simple switch does not enable the user to personalise temperature control and the physical product design needs to be further developed. Therefore, in this graduation project, OfficeVitae wants to provide an integrated infrared heating panel with a personalised temperature control experience. The potential contexts have been limited in two: the office and the home. The assignment of this project is to develop a working standalone portable unit with embedded electronics, presence aware sensors, and a physical user interface to enable personalise temperature control.

In this project, I work with OfficeVitae within an agile team where I can get research support from Floris and technical support from Martin. Since the company is located in Delft, design and prototyping support will be locally provided.

The current physical product design with wires and cables. (Left) The primary structure is in wood and the appearance is covered by a fireproof textile for the safety reason. (Right)

The panel is be positioned below the desk. (Left) Workstation showing local heating switch (high light with a red circle in the image)to the right of the monitor. This location also housed the LoRa gateway on the desk and antenna mounted on the wall. (Right)

Problem statement

As mentioned in the background, there are two prioritised aspects of the infrared heating panel that need to be enhanced: the physical product design and the personalised temperature control design.

The physical product design

the expected infrared heating panel should be portable, pleasing look, integrated. Instead of the current bland appearance of the product, an aesthetic appearance that aligns with the desired market needs to be determined and designed. The ergonomic design of the portable unit needs to be solved as well. The size of the panel could vary in size to serve from different contexts.

The main research question is: In what envisioned contexts that the product will be used?

The design challenge is: The size, product' look & feel style definition, the portable design.

The control interaction design

During the test, the existing physical controller was only a single control switch and did not allow users to adjust the temperature by themselves. if o improve the sense of control, an intuitive, and understandable, personalised temperature control system is expected. The basic control requirements include: switch on and off the heating panel, several modes selection, a dial of adjust the temperature. More actual control requirements will be defined during the project.

The main research question is: what are actual smart control requirements for personalising local temperature?

The design challenge is: The control method selection and the interaction design

Other design issues

Although it is now possible to reduce CO2 emissions technically, the design needs to be improved during the use to reduce unnecessary energy waste. Thus, the heating panel is better to be context-aware. A presence-aware smartness will reduce energy waste caused by people's carelessness, such as forgetting to turn off the energy switch when people leave seats to have lunch. Presence aware sensors and other electronics are going to be embedded into the heating panel. Apart from the product design and the control interface design, Safe is another essential issue that should take into account during the project. Such as the materials used need to be fireproof, the panel should endure a certain wet and dust, and the product design should be based on safety requirements. The end result would be a combination of physical design and interface design.

The assignment

Design an integrated infrared heating panel that can be used to heat people's workspaces locally. The heating panel is portable, has an appropriate appearance for the user context. People will be able to personalised local temperature with the physical interface.

In order to have this result, I divided the project into two parts, the physical product design and the control interaction design.

The physical product design

- First, analysing and defining the most potential and interesting contexts based on market research result from Floris. I will use storyboards to illustrate them.
- Making mood boards to present several possible aesthetics directions aligned with contexts.
-A survey to evaluate the mood boards.
- Once I finish determining the user contexts and a general style. I will generate several portable product ideas for the first testable prototype. I will work with the client to develop the most feasible concept further.
- The first rough prototype (week 7) is able to be tested with a physical control, has the standalone portable design, can be tested for a usability test.
- more completed appearance will be finalised in the second client-presentable prototype including shape, colour and material selections. Aesthetics design decisions will be made based on the mood board set in the beginning.

The control interaction design

- The problem of the current control experience can be determined by analysing the data from previous pilot tests of physical switch.
- And more requirements can be clarified by communicating the different needs of users of personal temperature control. Thus I would like to organise a co-creative session with target people, to validate client' insights and user actual requirements of personalising local temperature.
- A survey to validate the importance of different functions.
- After determined the actual essential needs from the user, I will start to design and make the physical control with Martin for the first rough prototype. With user tests, pros and cons of using physical switch can be found out.
- With the validation insights of the first rough prototype, the next step is to improve the interaction aesign and fine tuning the UI interface for the advanced-presentable prototype.

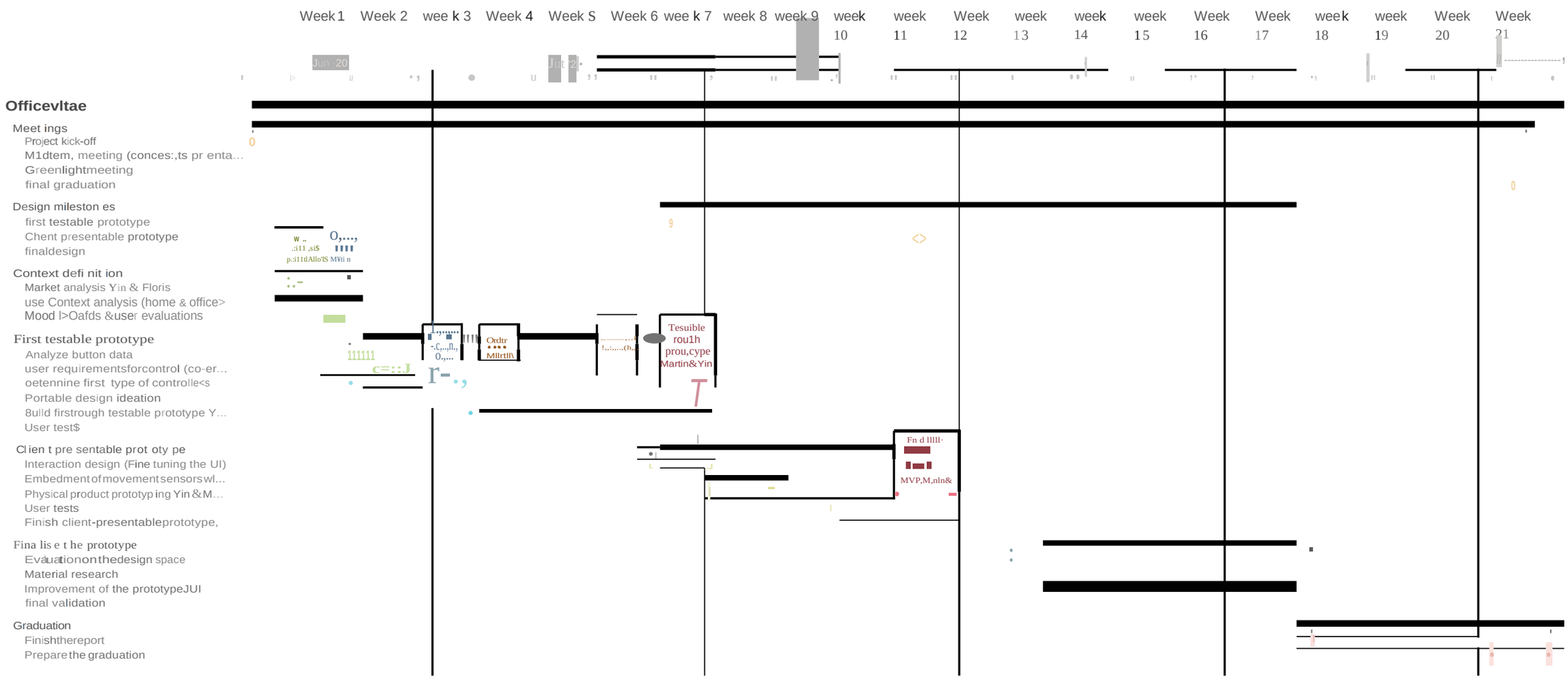
Both product physical and interaction areas shouldn't be viewed as being separate parts, but should be intertwine and explored at the same time.

Other design issues: Safety and context-aware

A selection list of possible materials needs to be conducted based on aesthetics decisions and safety requirements.

The context aware is the novel part of the project, in order to develop it, the first step is implementing PIR movement sensor into the demonstrable/presentable prototype, after the user tests, with client feedback and tests insights, I will decide how to develop it further with the supervisor team.

The planning



Instead of the more traditional waterfall flow, this project will follow the semi agile design method, and the MVP method. The goal of this workflow also allows me to work closely with the team between designing and prototyping.

if he first two weeks are about exploring the market of personal heating with the help of Floris to define potential user contexts. Analysis the switch data to understand the current problem. Catch user real control requirements of personalising local temperature through co-creative session. And map out actual product and control needs for further development.

1. The rough testable prototype (week 7)
In week 7, the first rough testable prototype needs to be built as a proof of the concept. The mid-term evaluation will take place in week 8 to verify if this workflow is achieving its goal.

2. The presentable prototype (week 11)
In week 11, the client presentable prototype needs to be accomplished which is a minimum viable product. After that, I would like to have a week off to have a break during the project and be recharged for the next stage.

In week 13, an evaluation will take place which takes previous client's feedbacks and user tests' results into account. The goal of this larger evaluation is to come up with a further development space of the final design, such as a more advanced context-aware design, or dive into the interface design and so on.

A final prototype will be finished in week 17 with a final validation test. The results and conclusions will be discussed during the green light meeting. Research, iteration, and testing results will be continuously documented.

ifhe last 4 weeks will be used for the preparation of all deliveries and graduation.