Master Thesis
Department of Industrial Design - Future Everyday Research, TU/e

The Coolingstat -
A tangible user interface for a personal cooling system for a shared workspace

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ABSTRACT

This report presents the design processes of a tangible user interface for a personal cooling system in a shared office environment. Through two iterations of design, a set of design criteria and qualities were concluded, which were applicable and also important for the design of the interface.

We also argued the importance and necessity of human input for the development of machine learning. Furthermore, we explored the design possibilities through qualitative methods to learn what motivate users to give their personal input to the smart agent. As results, we learned that the motivations from users heavily based on their personal interest and level of commitment and convenience of the interaction offered by the interface.

ACKNOWLEDGEMENT

I would like to express my special appreciation and thanks to my graduation mentor Prof. Loe Feijs and project expert Dr. Lennek Kuijer. Thank you for your kindly support and patience during the entire project. Also, I would like to thank Prof. Wim Zeiler and Jacob Verhaart, thank you for giving me this opportunity to work on this cross-faculty project. Thanks to all of my friends who have been with me throughout this graduation project. Also, I would like to give my special appreciation to the participants who took part in this project. Last but not least, I would like to extend my deep gratitude to my family: thank you all for your support.

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INTRODUCTION

Creating a comfortable indoor climate is an essential requirement of a shared workspace. However, still, a large portion of office workers suffer from thermal discomfort on a daily basis (Fjeld et al, 1998). Working in a shared environment that is hotter or cooler than the personal optimum preference is shown to impact their satisfaction (Tanabe, 2015), health and productivity (McCartney & Humphreys, 2002).

The indoor climate is usually regulated by the Heating, Ventilation and Air Conditioning (HVAC) systems. Most modern HVAC systems are programmed by following the rule-based methods (Wens & Mishra, 2018) to regulate the indoor temperature throughout the day when the workspace is in use. This approach enables engineers to apply their best practices, experience and knowledge of HVAC systems into a set of rules (e.g. pre-cooling) to maintain a comfortable indoor climate (Wens & Mishra, 2018). However, according to Kim (Kim, 2018), only 44% of buildings succeed to accomplish this goal that delivers a standard thermal condition that satisfies a majority 80% of occupant's preference. Therefore, it seems this approach is only capable of controlling the HVAC system in a suboptimal way. More advanced or individual systems shall result in a higher energy consumption and operation costs.

An optimal solution for addressing the above limitation is represented by the MPC (model predictive control) strategy (Afram & Janabi-Sharifi, 2014), driven by the technological development in Big Data and Machine learning. Engineers and designers are able to collect both environmental and personal data by deploying multiple sensors in office rooms to learn about personal thermal preference (Zeiler & Labeodan, 2019). The real-time processing enables the personal thermal comfort prediction to be developed by utilizing machine learning algorithms. However, advanced automation systems and technologies often require appropriately trained technicians or building managers to operate them, most buildings don't have such staff available (Wen & Mishra, 2018).

A smart agent (e.g. Smart thermostat) is designed to be the embodiment of such complex automation systems. By integrating HVAC systems, the user interface and user interaction, the smart agent is able to learn from the occupant's personal input, analyse their inputs and then refine the thermal comfort model in order for the system to make appropriate decisions (Snow et al, 2017). However, most agents are installed to regulate the indoor climate of a big space, and only allow users to change a small range of parameters (Peffer et al, 2011). And most of them are featured with a small digital screen and confusing programming features, and the number of steps needed to be performed to make changes. The ability for users to adjust their local climate is limited, as well as giving their personal inputs is not intuitive or motivative. Sometimes user flaws may even cost more energy.

A personal (cooling or heating) system seems to be a good solution to address the above problem. Researches have shown (Verhaart et al, 2018) (Kim, 2018) that individual control over personal temperature improves the perceived thermal comfort. Personal heating or cooling requires less energy than regulating the temperature of a large space. In this report, we explored and designed a tangible user interface for cooling systems, which not only allows users to change their local climate but also motivate them to give their input in order to refine their optimum personal thermal comfort.

The rest of this report is structured as the following: Chapter 2 explains the theoretical terms for the understanding of this report. Chapter 3 introduces similar works or products that are related to this project. Chapter 4 introduces the earlier research on user interaction of a personal cooling system, as well as FMP overview and stakeholder information. Chapter 5 describes the research questions and methodology. Chapter 6 describes a pilot test including deployment, the first iteration of the user interface and findings. The pilot test helped to generate design implications and define design criteria for the second interaction. Chapter 7 describes the design process of the 2nd interaction, including questionnaire, co-design session and interviews. Chapter 8 explains in detail the technologies and final design, as well as the evaluation and final deployment. Lastly, conclusions and discussion are presented in Chapter 9.

CHAPTER 2

THEORETICAL BACKGROUND

This chapter presents the most fundamental terms related to this project. The chapter is divided into two sections. The first section explains the basic terms related to thermal comfort and indoor climate. Section two describes the terms of Interaction Frogger Framework.

2.1 DEFINITIONS

Airspeed:

ASHRAE standard 2017 defines airspeed as "the rate of air movement at a point, without regard to the direction" (ASHRAE, 2017). The definition of airspeed in this report indicates the setting of fan speed of the personal cooling system.

Thermal comfort:

ASHRAE standard 2017 defines thermal comfort as " the condition of mind expresses satisfaction with the thermal environment and is assessed by subjective evaluation" (ASHRAE, 2017). Thermal comfort is a subjective phenomenon generally based on two categories: environmental factors and personal factors (Katić et al, 2018). Environmental factors include indoor-outdoor temperature, humidity and building insulation etc. Personal factors consist of body weight, age, gender, metabolism rate and physical condition (sick or not).

Acceptable environment thermal comfort:

ASHRAE standard 2017 defines acceptable environment thermal as " the thermal environment that a substantial majority (more than 80%) of the occupants find thermally acceptable (ASHRAE, 2017). Theoretically, combining both environmental and personal factors would potentially deliver an acceptable indoor climate that satisfies most of the people, however, everyone has their own individual preference, therefore, to create a comfortable climate that is able to adopt different individual's thermal preference is yet a practical problem that needs to be addressed.

ASHRAE 7-scale point thermal sensation:

is a subjective expression of an occupant's thermal perception of the environment, commonly expressed by using the categories "cold," "cool," "slightly cool," "neutral," "slightly warm," "warm," and "hot" (ASHRAE, 2017).

When evaluating an interactive product by using the **Frogger Framework**, it is necessary to see whether the actions and functions are naturally coupled. Feedback and feedforward information (action and perception) is needed to be 'displayed' on the interface. Feedback is the information that occurs during or after the user's action. Feedforward takes place before the user's action, it is the information to users when, where and how to start.

Functional Feedforward:

serves to inform the user about the general purpose or overall functionality of the product. Functional feedforward information should give the user a clear idea about what they can do with the product.

Inherent Feedforward:

aims to afford action possibilities (pushing, rotating, sliding) through tangible artefacts, is related to the perceptual-motor skills of the person (Wensveen, 2005), it can also be viewed as a limited interpretation of the concept of affordance (Gibson,1979).

Augmented Feedforward:

gives additional information to the action possibilities. It appeals to cognitive skills, for example, signal lights, words, icons, pictograms and spoken words.

Functional Feedback:

Should be viewed in respect to the needs, intentions and desires of the user. In the PCS, increasing (switching on) the PCS when it is hot and decreasing (switching off) it when it is cold.

Inherent Feedback:

is the information that is returned from acting the action possibilities. When the airflow increases, the sound of the wind is also increasing, when the user rotates the knob to set the desired airflow, the user can feel the physical force and hear the sound of the button.

Augmented Feedback:

from an additional source, augmented feedback appeals more to the cognitive skills of the user. In product design, augmented feedback is usually displayed through the use of an LCD screen, a sound APP like a chatbot or LED lights.

CHAPTER 3

RELATED WORKS

This chapter consists of a literature review into the associated sections in the co-performance (Kuijer & Giaccardi, 2018), an example of a smart thermostat (The Nest), personal thermal comfort researches and personal thermal conflicts in a shared workspace.

3.1 OPTIMIZING SMART AGENT THROUGH USER INPUT AND CO-PERFORMANCE

The PID (proportional-integral-derivative) control and/or on/off control are the most popular and commonly used agents to control indoor temperature via HVAC systems in commercial buildings (Katic et al, 2018). These controls are considered to be an agent that regulates the HVAC systems to maintain an acceptable environment thermal comfort for the building occupants. Most of these agents are programmed by following the rule-based methods (Wens & Mishra, 2018) which require engineers or HVAC experts to apply their best practices and experience into a set of rules. These rules can be translated to schedules and setpoints to determine an appropriate indoor climate, in combination with the current room temperature (Kuijer & Giaccardi, 2018). For example, preheat the office room before the working hour; activate the cooling or ventilation system if the measured CO_2 level is too high etc.

However, these programmed agents cannot interpret what indoor climate is considered appropriate in the messiness (opening windows or doors) of everyday life (Kuijer & Giaccardi, 2018). One common reason is that these agents were not programmed to take the individual's thermal preference and situated circumstance into account. Programmed agents can achieve a better building performance in terms of energy management, but sacrifice individual thermal comfort as the consequence.

With smart devices receiving more and more agency to make decisions about our daily life, in the recent development of Human-Computer-Interaction, smart technologies have pushed the boundaries of the programmed agent to be further developed. The smart agent, which is designed by following the 'human-in-the-loop' strategies (Zeiler & Labeodan, 2019), is capable of learning and performing together with occupants in terms of defining an appropriate indoor climate (Kuijer & Giaccardi, 2018). This design philosophy is expressed in a design perspective called co-performance, coined by Kuijer & Giaccardi ((Kuijer & Giaccardi, 2018). Co-performance offers a new perspective on the role of smart agency in everyday life. In their work, they reflected the development of domestic heating and smart thermostat design, which is inspiring for the design process of the graduation project.

3.2 THE NEST THERMOSTAT

A smart thermostat is considered as an example of the smart agent to regulate the HVAC systems in both residential and commercial buildings. Snow (Snow et al, 2018) defined two typical aims of a smart thermostat are: ‘1) to reduce HVAC energy consumption by simplifying interactions between users and agents and 2) to provide an agreeable thermal comfort to occupants by learning users’ thermal comfort preferences. A classical example of a smart thermostat is the Nest (Nest, 2020), the first-generation design was introduced in 2011, it utilizes machine learning to obtain a predictive model by involving users’ contextual experience as inputs to achieve a comfortable indoor climate. However, a study conducted by Yang & Newman (Yang & Newman, 2012) that a percent of the Nest owners are uncertain about the Nest’s energy savings, furthermore, the interaction steps needs to be performed on its GUI to train and refine machine learning model was considered to be challenging for new users.

3.3 PERSONAL THERMAL COMFORT RESEARCH

An increasing number of studies (Kim, 2018) & (Katic et al, 2018) are investigating how user involvement can be utilized for predicting personal thermal comfort. These studies were conducted in a controlled lab (situated climate chamber). The participants were often asked to use wearable devices such as a wrist to measure skin temperature and collect accurate real-time thermal comfort information. Additionally, a personal heating or cooling system is also installed to change their local climate. The convenience by using such systems allows researchers to collect accurate individual data on thermal comfort at a personal level. However, the practicality in using such systems in a shared working environment may be limited due to the higher number of users and the messiness of everyday life and unrealistic costs.

3.4 PERSONAL THERMAL PREFERENCE AND CONFLICT IN SHARED WORKING ENVIRONMENTS

Personal thermal comfort is a subjective experience that can be influenced by both personal and environmental factors. In a control climate chamber, it is far easier for a smart agent to learn the thermal comfort preference of 2 people than it is an office of 20-40 people (Snow et al, 2018). To design an agent to control the local climate in shared working environments faces more challenges. This is because a new category of factor is added in this context, which are social factors. In a shared working place, people are willing to tolerate the discomfort until a certain level. In conclusion, there are mainly three different categories of factors that influence a person’s thermal preference, most researchers only consider the environmental factors, (such as temperature, humidity) and personal factors (like height, age, metabolism rate.) The 3rd category, which is the social factor, should be given more consideration.

CHAPTER 4

CLIENTS & EARLIER RESEARCHES

PROJECT PLANNING

The project started by following a master elective namely Intelligent Buildings, offered by the Building Services Research Group in Q1, Sep 2019. Two subjects were taught: data analysis and machine learning. The FMP proposal started in Q2, Nov 2019. The official starting day of FMP was in Q3, Feb 2020, an extra master elective related Smart HVAC systems and energy management system offered by Brainport Smart District in Helmond, was also completed in order to gain more field insights. A pilot test and design process were performed in Q3 and Q4.

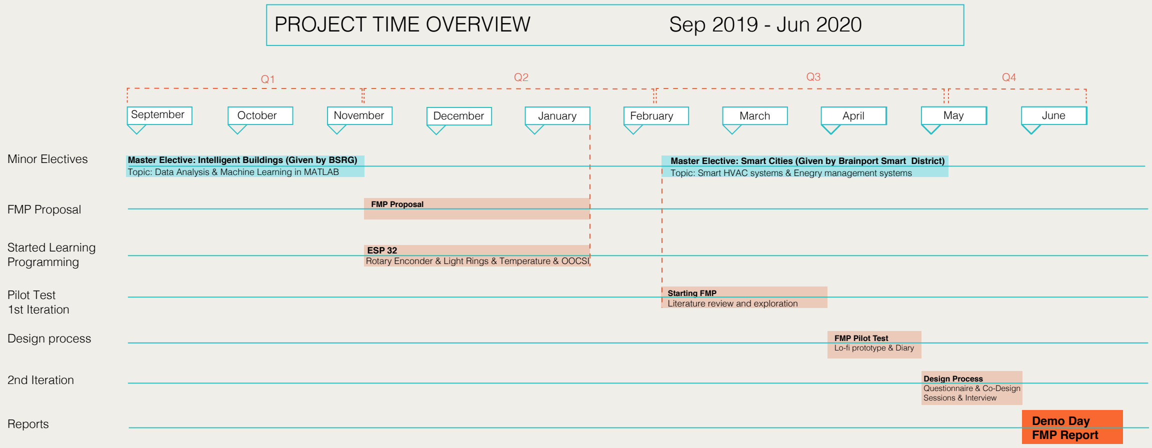


Figure 1. Project planning overview

CLIENT INFORMATION

This project is a cross-faculty project that stands in between the Department of Industrial Design and the Built Environment at the Eindhoven University of Technology. The project is based on the early work conducted by BSRG (Building Service Research Group), which is a research group of the Building Physics and Services unit. The research group focuses on two main research directions (Building Services, 2020): 1) The concept of 'individual' comfort system whereby each occupant has control over the local climate. 2) Design future proof buildings with sustainable energy by seamlessly integrating building services and technologies.

The final experiment will be deployed at Kropman Installatietechniek, in Breda Office, which is a Dutch installation company with several branches in the Netherlands. The company is specialised in smart building automation systems and sustainable solutions in the field building services and system design. Their mission is to make buildings greener, healthier and more efficient. This project involves two experts in the field of thermal comfort from two different departments. Which gives different design perspectives for the development of the user interface.

STAKEHOLDERS

- Prof. Wim Zeiler: The chairman of Building Services Research Group and the University Representative of Kropman Installatietechniek company.
- Prof. Loe Feijs: Graduation mentor from Future Everyday Research Group
- Jacob Verhaart: PhD student, expert in thermal comfort and personal cooling system.
- Lenneke Kuijer: Expert in thermal comfort in Future Everyday Research Group.

EARLIER RESEARCH

The research was initiated by the Building Services Research Group in the Department of The Built Environment, TU/e. The earlier research was conducted by Verhaart (Verhaart et al, 2017) in a stable, slightly warm (operative temperature: 27.5 °C) environment in a Climate Chamber. Their research focused on the interaction of the user with a personal cooling system (PCS), participants were required to interact the PCS with a simple interface (figure 2) to change the airspeed in order to create a comfortable indoor climate. Besides that, they are also asked to self-report their thermal sensation on the ASHRAE 7-point sensation scale (ASHRAE,2017) and to answer questions related to perceived air quality.

The research team would like to have **a new interface that facilitates participants to interact with the PCS, as well as collecting their subjective experience and environmental data in an easy and intuitive way.**

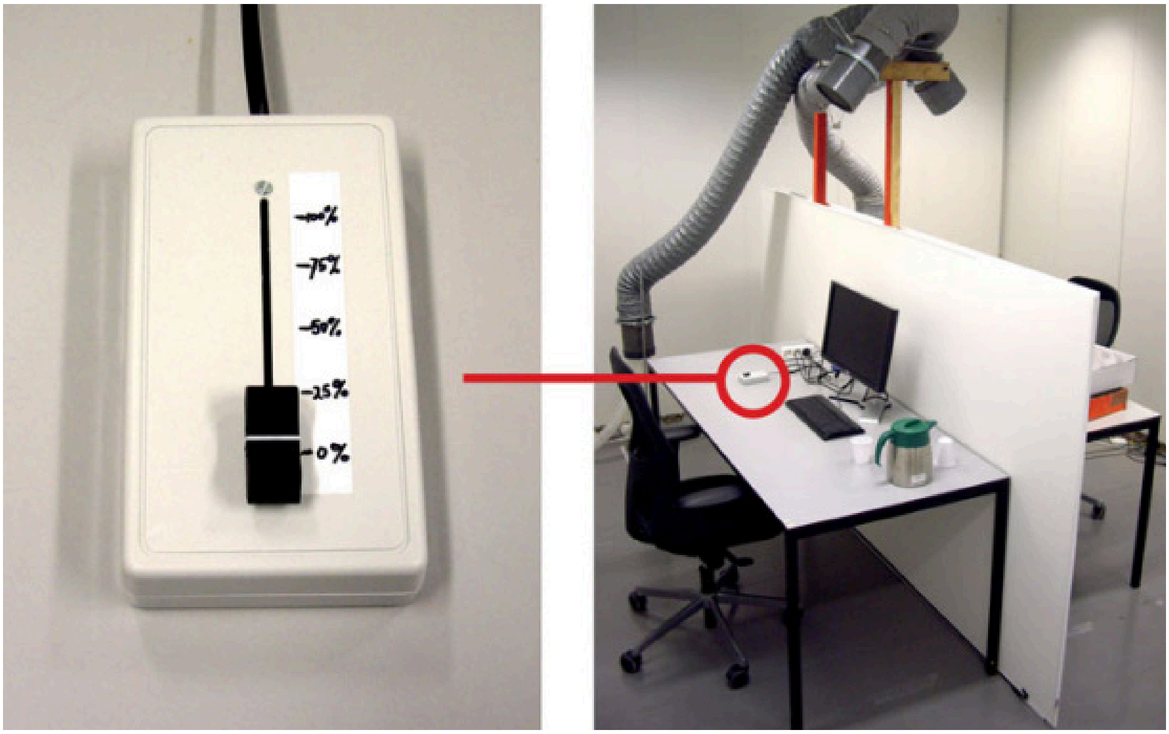


Figure 2. User interface (on the left) used by the user to control the airspeed of PCS (Verhaart et al, 2017).

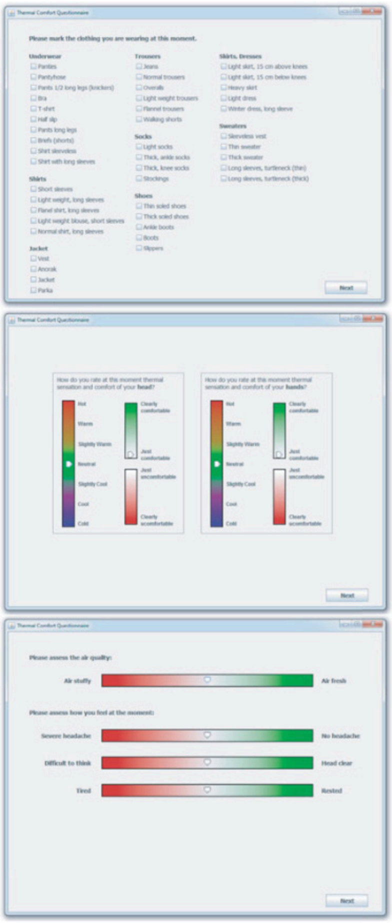


Figure 3. Screenshots from the computer-based questionnaire from the early work (Verhaart et al, 2017).

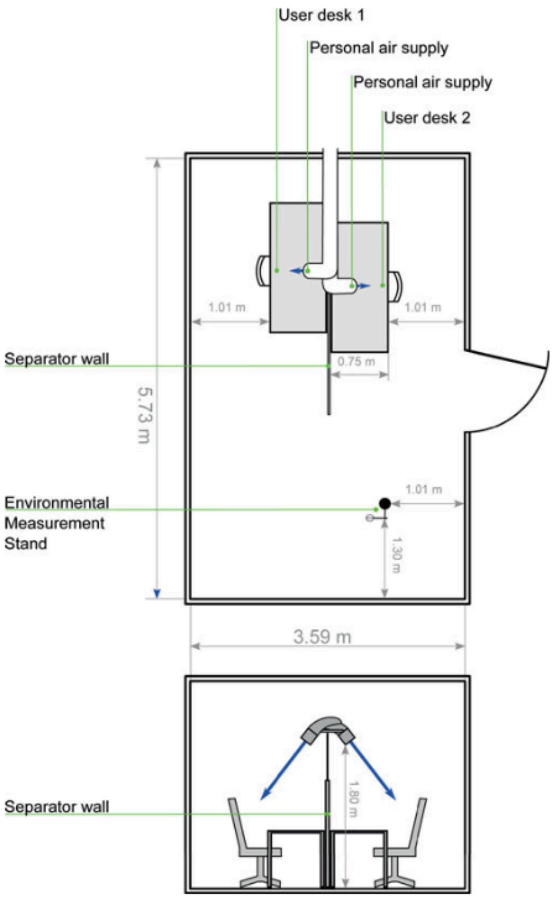


Figure 4. Layout of the climate chamber used in the experiment (Verhaart et al, 2017)

Analysis of the old user interface

User interface: the user interface allows participants to change airspeed in 4 degrees (25%, 50%, 75% and 100%) and a digital questionnaire allows them to report their personal thermal comfort and perceived air quality.

The tangible user interface affords only one action possibility (sliding), the action is coupled in direction with the inherent information, when the user slides up or down, the slider moves in the same direction as the action is performed. The text on the right side of the slider is providing augmented feedforward, which indicates different airspeed of the PCS. After the action is performed, the PCS gives functional feedback by changing the airspeed. The function feedforward and augmented feedback are unclear or missing on this user interface.

Subject	Inherent Feedforward	Functional Feedforward	Augmented Feedforward	Inherent Feedback	Functional Feedback	Augmented Feedback	Total Score (30)
User Interface	Slider	Unclear	Text	Sliding	Change airspeed	Missing	-
Score	1	0	1	1	1	0	5

Table 1. Analysis of the old user interface

Analysis of the Climatebuddy

The Climatebuddy (figure5) is a multisensory toolkit that is developed by the Client company (Kropman Installtietechniek, 2019), which collects real-time environmental data including temperature, humidity, light intensity and CO_2 level (Kropman, 2019). The ClimateBuddy was developed for to facilitate researchers to collect environmental data in the situated place for the development of the machine learning model.

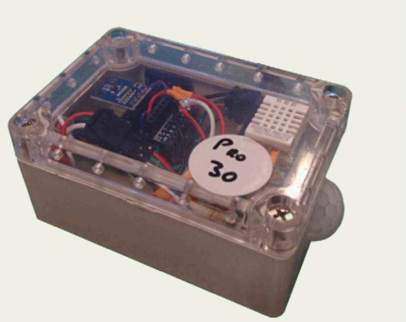


Figure 5. The Climatebuddy (Kropman, 2019

However, Climatebuddy excludes the necessity of user involvement. As Snow (Snow et al, 2018) states in their work, machine learning approaches involve collecting user contextual information and learning these parameters through user input. User feedback is used to train and refine the thermal comfort, with an aim to deliver an agreeable temperature for individual user's preferences. Therefore, designing for user involvement in the development of a machine learning model is essential.

Final deployment

The envisioned final deployed place will be in a shared office room at Kropman, in Breda. All the previous research works were conducted in a controlled climate chamber. In this project, we would like to apply a field study by deploying the prototype in a real shared environment in order to explore design possibilities and insights for the development of the user interface.

CHAPTER 5

METHODOLOGY

DESIGN CHALLENGE

End-users: there are two types of end-users in this project:

Type1: regular participants that only operate the PCS to achieve their optimum thermal comfort.

Type2: researchers that aim to study participant's cooling behaviour and collect their data for the development of a personal comfort model.

The clients would like to collect both environmental data and personal data for the development of personal thermal comfort models. However, we assume, also mentioned in the early work, that participants would like to have a simple interface. A complicated interface tends to distract them, frustrate and induce abuse (Verhaart et al. 2017). On the other side, in order to motivate participants to self-report their personal input, rather than being required to fill in a questionnaire every 15 minutes. We aim to design an interface that motivates them to report their thermal sensation and perceived air-quality in an easy and intuitive manner.

RESEARCH QUESTIONS

The main research question associated in this project is:

How can a tangible user interface be designed to facilitate users to interact with PCS in an easy and intuitive way?

To answer the main research question, the following sub questions are developed:

1. What are the expected functions of the user interface?

2. How to motivate users to self-report their thermal sensation to the system in order to facilitate the machine learning?

3. What criteria are important for a user interface for a PCS?

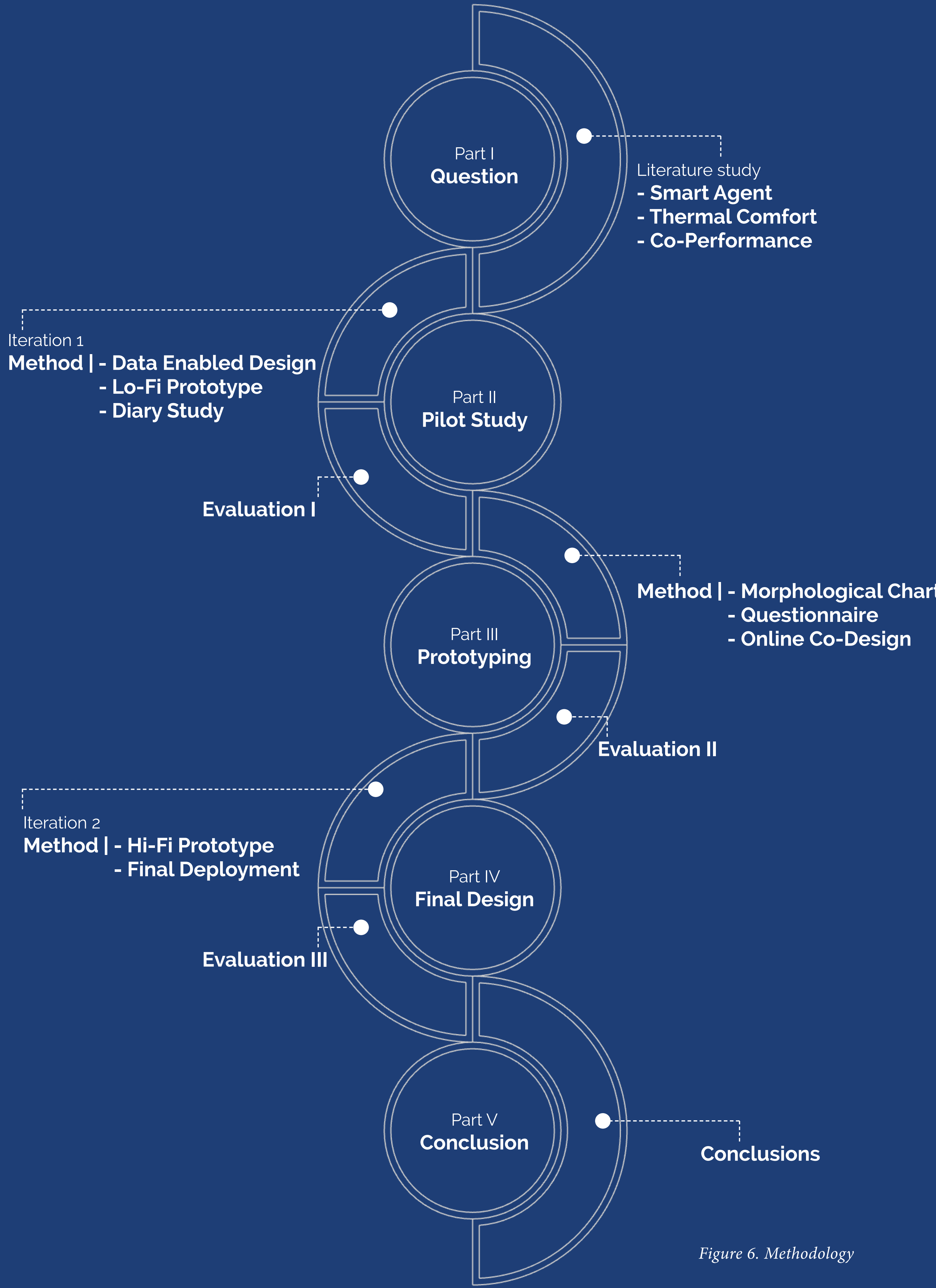


Figure 6. Methodology

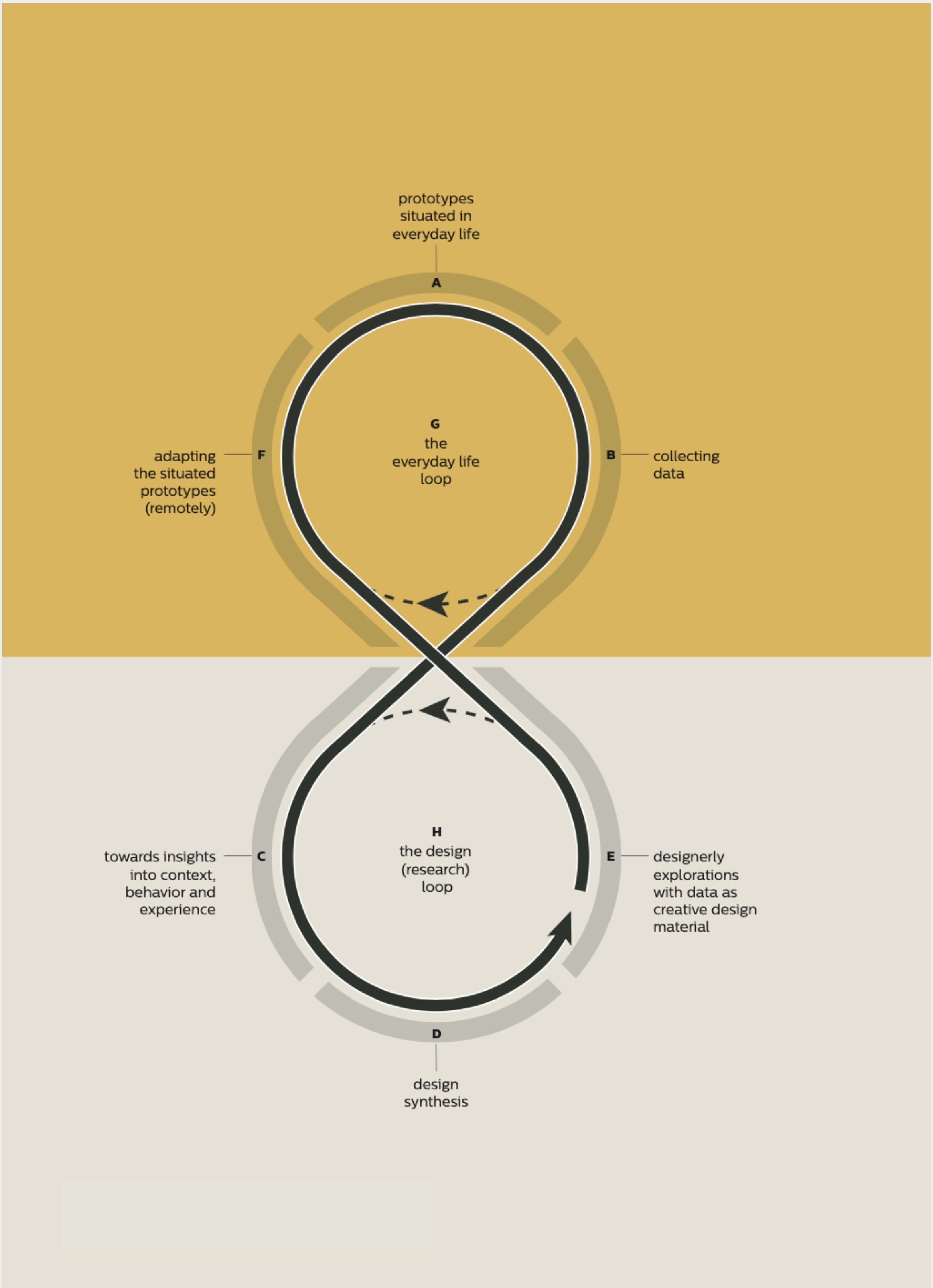


Figure 7. Data Enabled Design Framework (Van Kollenburg & Bogers, 2019)

In this report the method is visible in Figure 6 will be used. The first step is to investigate the possible solutions and related works. This stage will be conducted regarding a literature review of thermal comfort, co-performance and smart thermostat.

In the second step, a pilot test will be conducted in order to understand the context. The design method undertaken in this pilot study will be Data Enabled Design (Van Kollenburg & Bogers, 2019), proposed by Van Kollenburg & Bogers, which can be seen in figure 7. The design method consists of two steps: the Contextual and Informed step.

The contextual step starts with deploying a data probe in the context of the participant, which serves to gain insights into the daily behaviour of the participant. Other qualitative research methods like interview and dairy study were also used in this pilot test. A lo-fi prototype will be deployed as the interface for the PCS.

In the third step, which is the Informed step, based on the gained insights from the contextual step from the pilot test. The design exploration will be performed by hosting an online questionnaire. Sub question 1 will be answered. After that, a morphological chart will be created to display all the possible functions, online co-design sessions and interviews will be performed with participants to assess the expected functions. They will be asked to make a selection (sketch) of the best combined function(s) on an online platform. Their sketch will be converted to a 3D model, their thoughts and process will be recorded for further analysis. All the concepts will be analysed and therefore the design criteria is completed. Sub-question 2 and 3 will be answered after this stage.

In the fourth step, a museum quality prototype will be created based on the insights and design criteria conducted from the previous stages. The final design will be presented on the demo day, as well as be deployed in the same office room where the pilot test was conducted. Conclusions will be drawn after the final deployment.

CHAPTER 6

FIRST ITERATION

PILOT TEST

A pilot test was performed in order to better understand factors that attribute to a good indoor climate. Especially in cooling. The pilot set-up was organised to mimic the experimental settings mentioned in the work of Verhaart (Verhaart et al, 2017). The goal of this pilot study was to explore the user experience of a personal user interface of a PCS, as well as elicit insights and implications for the future design.

The pilot study was conducted in a shared office room(figure 8). The size of this room is 26 m2. Additionally, the outside wall of this office room is well-insulated by using a 65mm layer of Neopixels in between two layers of brick walls. The windows are installed with double-layered HR++ glass. The roofs are sealed with 120 mm glaswol as the insulation. The overall indoor climate is sound and stable. In this office, a PCS is installed 1.5m above for the participant as the picture shows. The pilot test started in April 2020.

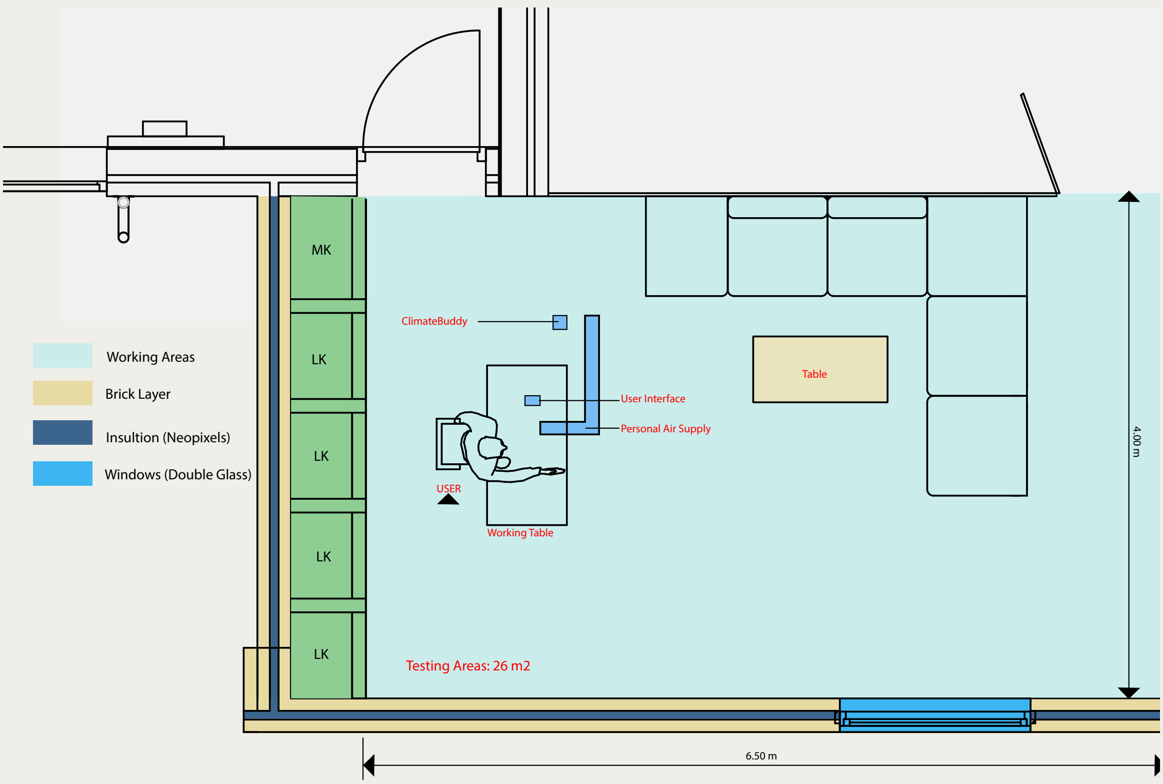
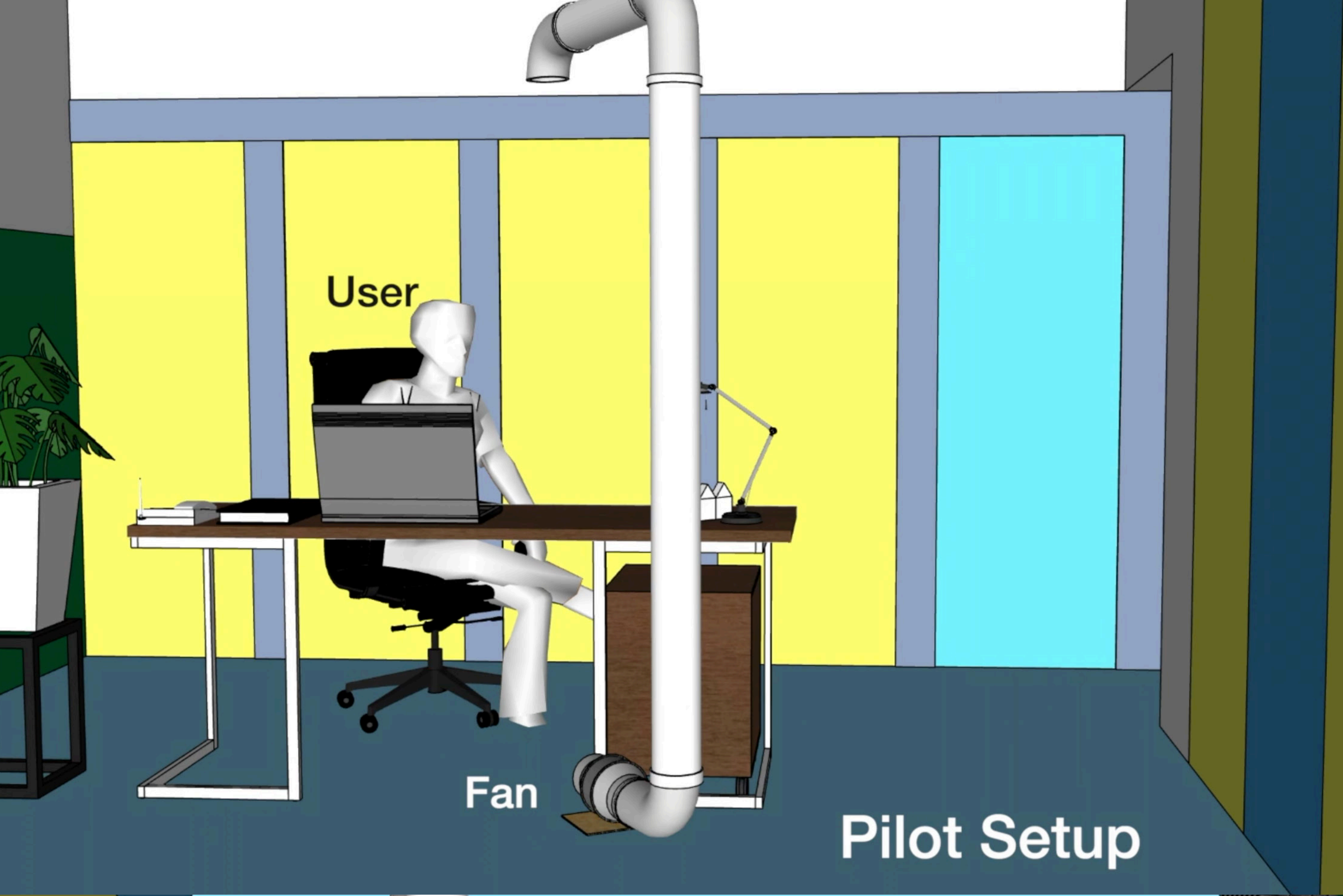


Figure 8. Layout of the shared office room in the pilot test



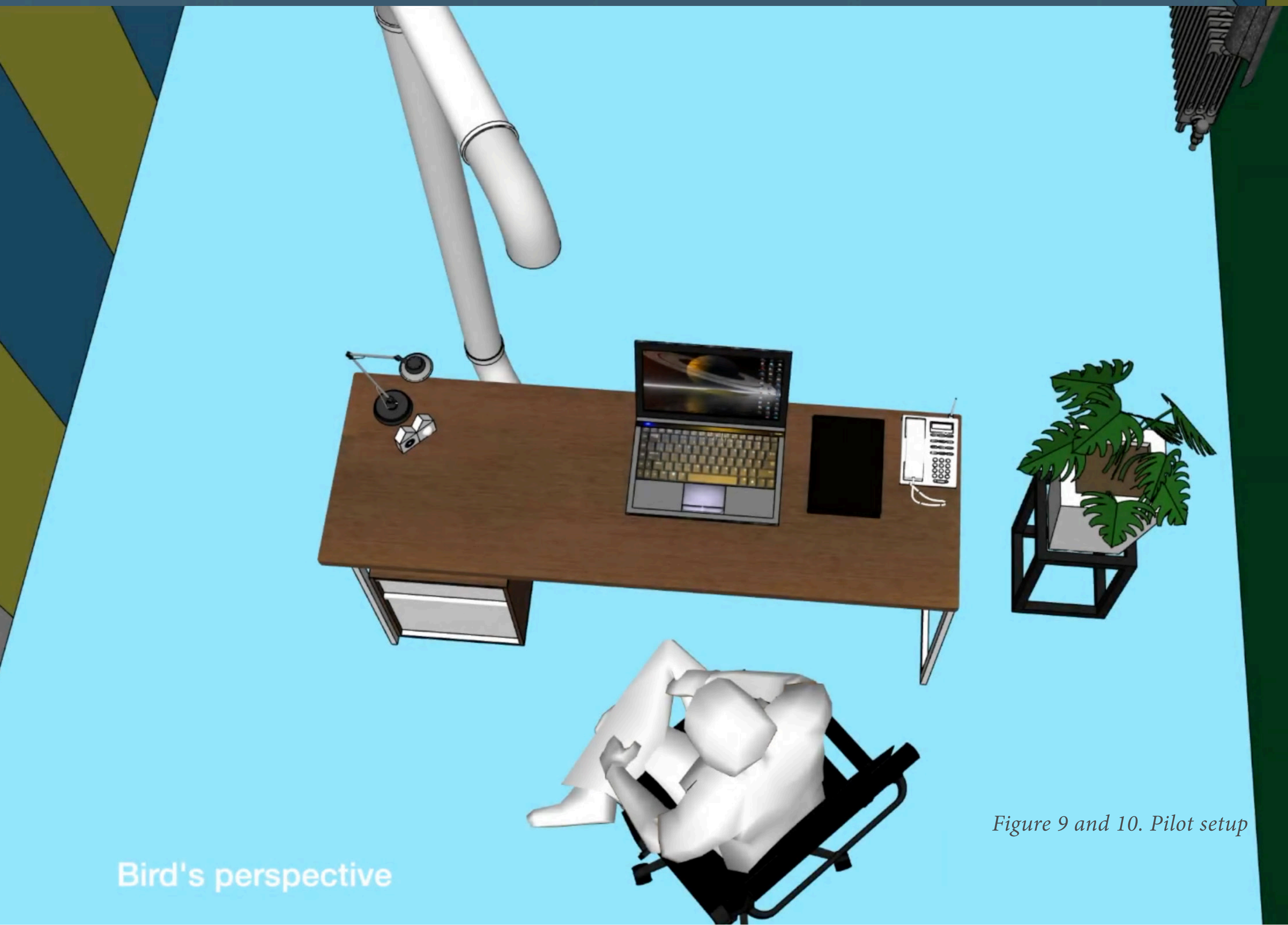


Figure 9 and 10. Pilot setup

PARTICIPANT

One participant took part in this pilot study, who has a technical background. The pilot test lasted for one week, during the pilot test the participant was asked to work on his computer under the PCS, as well as required to give his input on the diary booklet (Appendix 1) in every one hour.

DATA PROBE

The pilot test started by deploying the Data Probe (figure 11) in the office room of the participant. The Data Probe was created by using a micro-controller ESP32, also included sensors that measured CO_2 (GSP30), temperature & humidity (DHT 11), light intensity (SEN-09088), and an electric fan installed next to the sensors to ensure that the airflow was represented the correct room temperature to create accurate measurements. The collected measurements were sent in 8.0 s intervals to the Data Foundry platform (Data Foundry, 2019) by using OOCSI (Oocsi, 2019). The collected data were stored as a.CSV format and then imported in Jupyter NoteBook for data analysis and visualization.

In combination with the data probe, a diary booklet (figure 12) was given to the participant in order to collect his thermal comfort and sensation towards his experience of the indoor climate. The diary also allowed the participant to log their clothing, activities and inputs on desired airspeed. At the end of the deployment, a semi-interview was conducted.

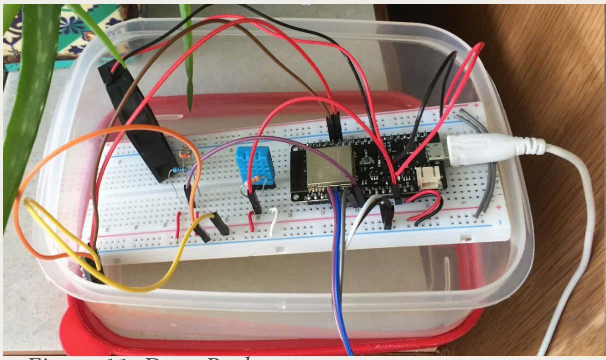


Figure 11. Data Probe

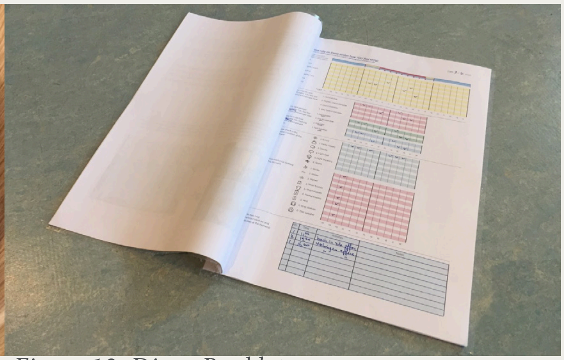


Figure 12. Diary Booklet

LO-FI USER INTERFACE OF PCS

A low-fidelity user interface was created for this pilot test and deployed next to the participant's working computer. This user interface has two modules: the Temp module and the PIR module. Both modules were connected with an ESP32 board. A voltage amplifier was also created for the ESP32 to convert low voltage (3.3V) to high voltage (10V) to control the airspeed of PCS through a frequency Drive (Peter, 2017).

Temp module:

The inherent feedforward is given by the rotary encoder, which offers two types of action possibilities (rotation and pushing). When the participant rotates the knob in a clockwise (counter-clockwise) direction, the PCS gives the functional feedback by increasing (decreasing) the airspeed. The augmented feedforward is given by the text on the Temp module, which indicates the available airspeed options of the PCS. The augmented feedback is displayed by the LED ring around the rotary encoder, which indicates the current airspeed setting. When the user pushes the knob, the desired airspeed will be chosen. The 'house-looking' shape was chosen in order to create a relation with the deployment place (shared office), as well as providing functional feedforward information to give the participant a general purpose of the user interface.

PIR module:

The augmented feedback is given by the LEDs with different colours on this module. Yellow light states that the system is in idle mode, the interface detects the movement of the participant, green light will light up which indicates that the participant can start using the system. Blue light indicates that the system is connected to the Wifi and sending data to the Cloud.

Subject	Inherent Feedforward	Functional Feedforward	Augmented Feedforward	Inherent Feedback	Functional Feedback	Augmented Feedback	Total Score (30)
User Interface	Rotary Encoder	UI for PSC	Text & Light	Sliding &Pushing	Change airspeed	Light	-
Score	2	1	2	2	1	2	10

Table 2. Analysis of the pilot user interface

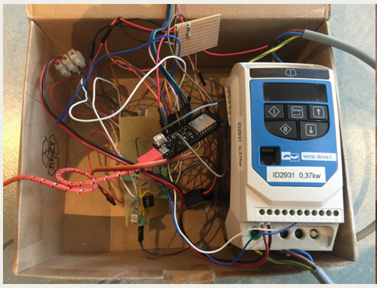


Figure 13.Frequency Drive and ESP connection

Figure 14. Pilot prototype

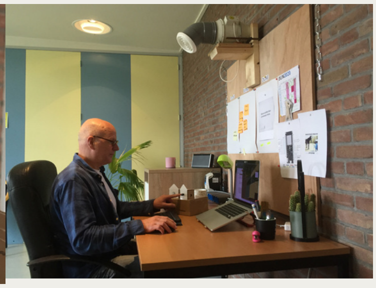


Figure 15. Participant and prototype in use

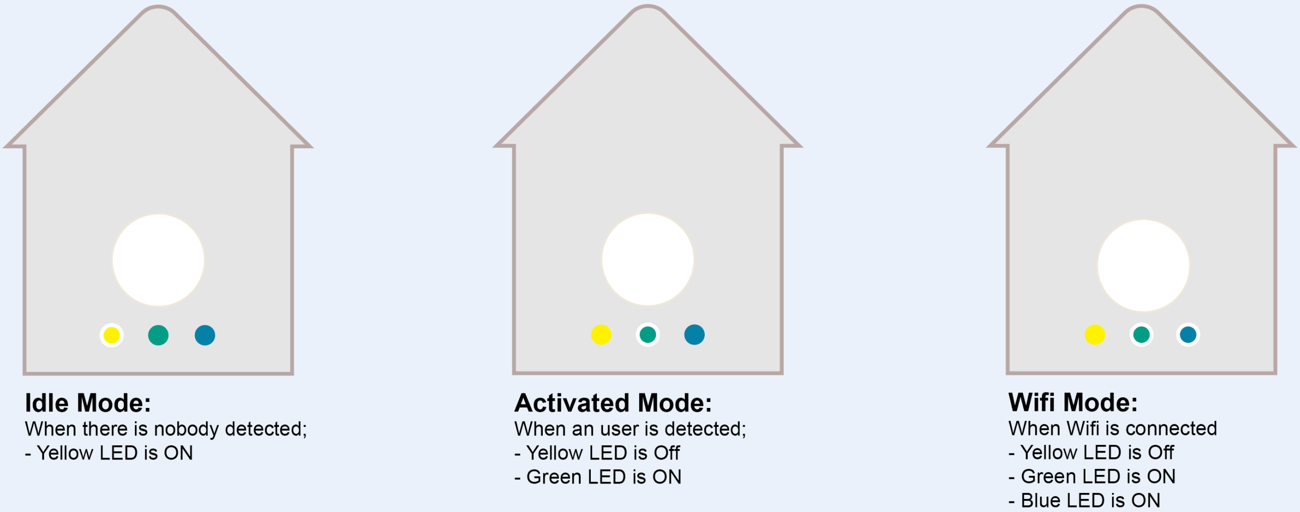


Figure 16. PIR module interaction flow

Interaction Flow- Temp Module

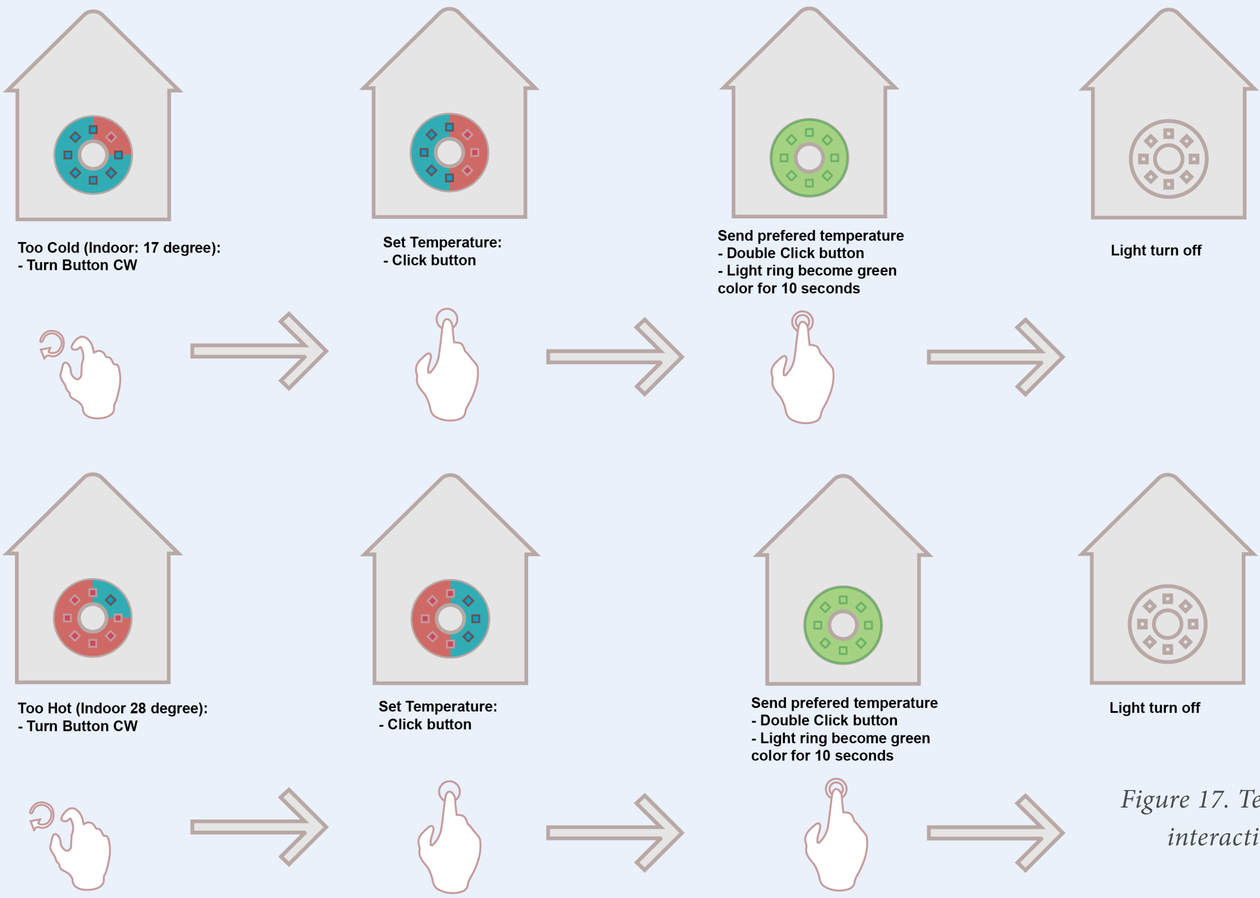


Figure 17. Temp module interaction flow

Given future consideration that collected user input will be used for the development of a machine learning model for the client. The chosen algorithms will be SVM (Support Vector Machine) which requires collected user input be classified into several classifiers. This was also achieved by the rotary encoder. The airspeed was programmed into 8 settings corresponding to the number of LED ring. The step-limit of the rotary encoder was programmed into 8 steps, each step is given a label (1 to 8), which will be used as a classifier (see Figure 18). Every time when the user pushes the rotary encoder, his desired airspeed will be sent to Data Foundry Platform, in combination with the environmental data at that moment.

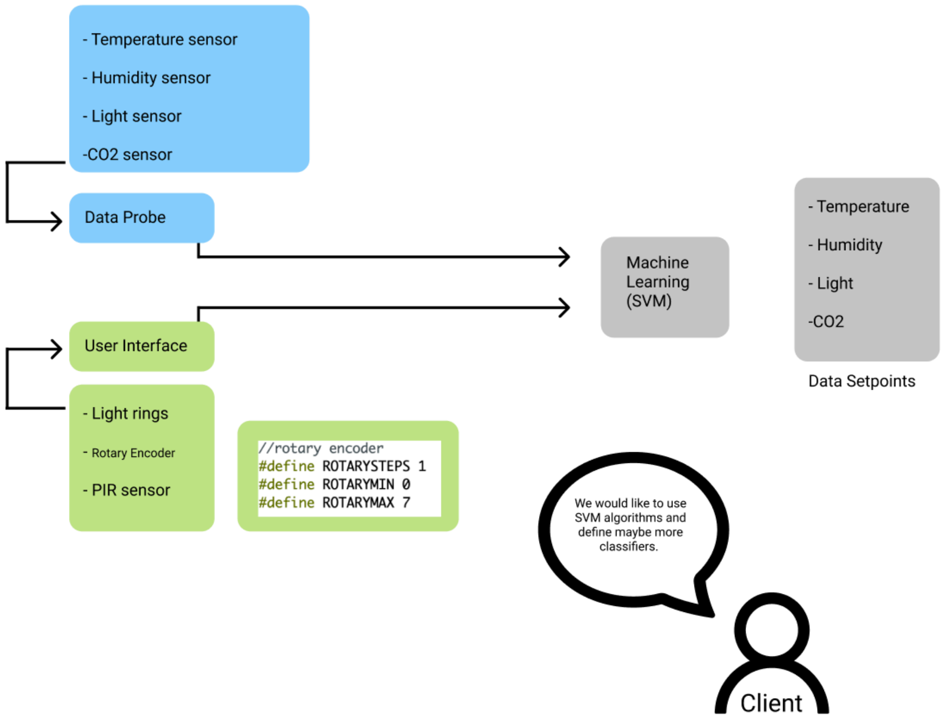


Figure 18. Machine Learning Data Structure

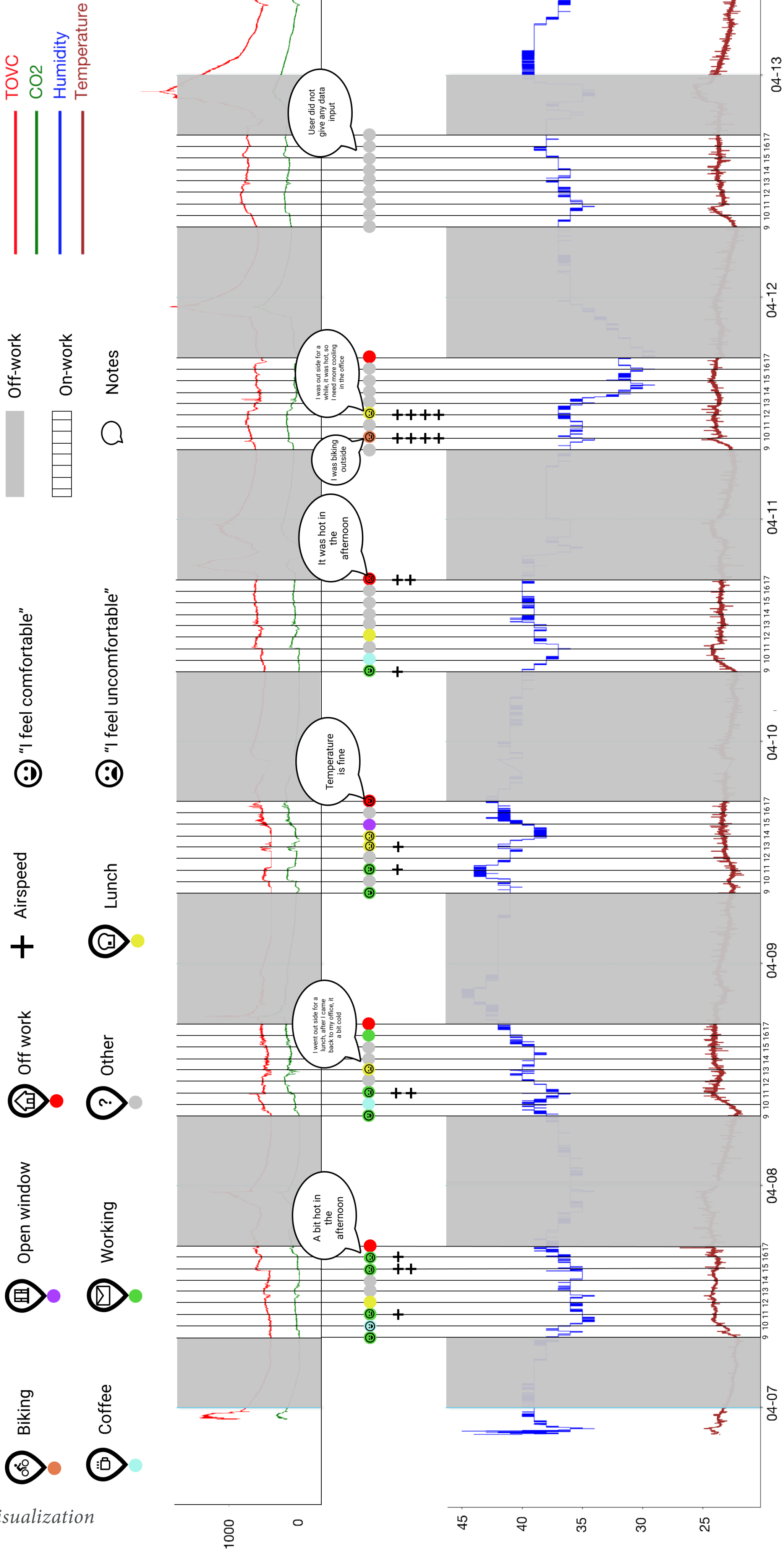


Figure 18. Data Visualization

Data Probe

The data probe was working properly during the entire pilot study. The datasets were visualized in Jupyter Notebook. As the figure 18 shows, the measurement of indoor temperature,CO_2 and TVOC was relatively stable, only the humidity level (blue curve) performed more dynamically. This might be caused due to the fact that this office room is well insulated and almost no activities like open windows occurred during deployment

Diary booklet

The diary booklet was perceived as easy to fill in, most of the time, the participant was satisfied with the current indoor climate. Ideally, the participant was asked to fill his thermal sensation every one hour, however, he was only motivated to give his inputs by his discomfort, he states:

[...]because when I am comfortable, I don't want to change anything, okay when I feel uncomfortable, then I think what can I do to make myself feel comfortable? so the uncomfortable sign makes me want to change the setting...

The performed activities could also influence his personal thermal comfort, he stated:

[...]mainly when I come back from something (biking or physical work) and the office (inside) is warm, and you sit down and then you feel you are hot, and when you need it...

Pilot Prototype

The user interface was perceived as easy to use, the augmented information is presented by using LEDs as an indicator of current airspeed and was interpreted easily by the participant:

[...] Because I don't have to read, I can see it from a distance…

The participant was also curious about if the indoor temperature and CO_2 can be visualized on the interface. He suggested:

[...]maybe you can add another light ring to indicate temperature, if all the lights turn to red colour, it can be that the CO_2 level is very high, which is not healthy...

The Participant also explored different airspeed but he experienced that the settings of airspeed is too dynamic, he states:

[...]if you want to stay at eight settings, the range from 0 to 50% of the fan capacity (is enough). And don't put it on the 1oo% because you will never use it, and the papers will blow from the desk...

Last but not least, the participant also considered social interactions in the shared working environment. He mentioned: *[...] The combination of drive and fan can set a very low airspeed… which has a small exposure, so only one person is exposed, no colleague are affected...*

CONCLUSION

We gained two main insights from the pilot test. Firstly, we found that the participant was only motivated to interact with the user interface by his discomfort. Secondly, the participant was motivated to give more personal inputs if he is able to interpret his surroundings in a visual way for example (temperature and CO_2).

LIMITATIONS

The participant has more experience regarding temperature control than the average users. And more focuses were given on the functions and technical aspect. This can be biased on our design decision, therefore, in the following exploration, it is necessary to recruit participants with a more diverse background.

CHAPTER 7

SECOND ITERATION

The second iteration started with a questionnaire (Appendix 2), which was made based on the design implications and insights concluded from the pilot test. The questionnaire had three parts, the first part collected basic information from the participants, such as age range, gender and professions.

The second part consisted out of a set of questions whereby we took on the role of the participant, assuming their daily routine and behaviours that they might experience in different cooling options in an actual shared working environment. This part served to substitute a role-playing and provided information and context about the project to the participants.

The third part presented a digital mock-up created on Figma Platfom (Figma, 2020) and three different lo-Fi prototypes. Participants were asked to give their opinion of each prototype, which helped to generate better design criteria for the design and development of the interface.

- In addition to the pilot interface, two new prototypes with different shape and interaction styles were also added on the questionnaire in order to collect insights from a large scale of participants. The interactions were performed by one participant and recorded. All the videos were uploaded inside the questionnaire to show participants the interaction.

Figure 19-21. Pilot prototype and other two new prototype

The last part of the questionnaire collected personal data about the expected functionalities of this interface and the participant's opinion about the data collection. In order to help us to distinguish different roles and responsibilities of the systems and users, the co-performance theory was implemented to divide the performances (activities) of a user and the interface.

The questionnaire was filled in by 26 participants(14 female, 12 male), 46% of them are master students from industrial design, the rest of the participants have a diverse background, including four PhD students from different fields. 23% of the participants are office workers. The average age of the participants is between 16 to 30.

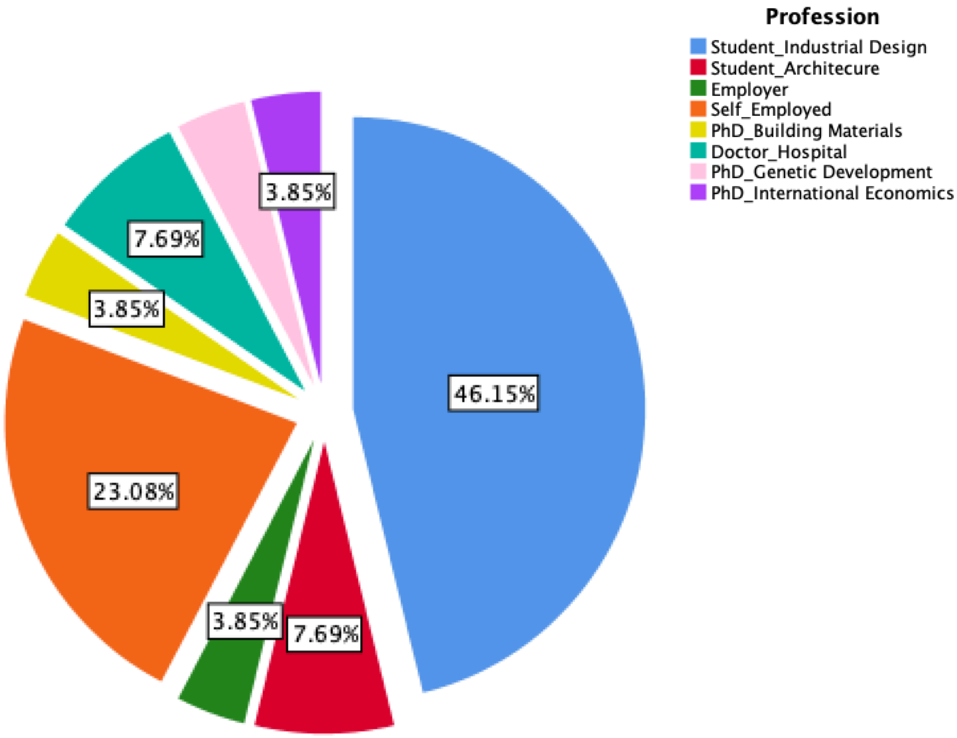
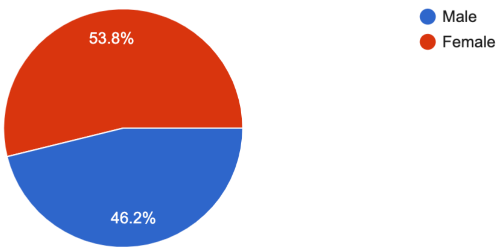


Figure 22. Participants profession in a pie chart



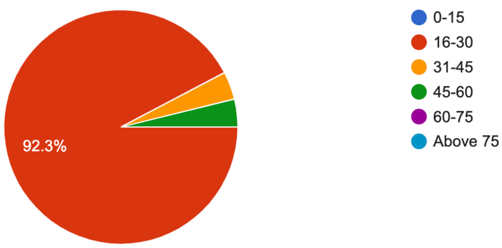


Figure 23. Participants gender in a pie chart

Figure 24. Participants age in a pie chart

The the results from the questionnaire enabled the exploration and developments. The analysis of results can be found in appendix 3. Here we would like to present the most significant findings in terms of different versions of prototypes, expected functions and data collection.

Feedback on the three prototypes:

The three different interfaces received a lot of useful feedback from participants through the questionnaire. Here is an overview of most significant feedback received on each prototype (see all feedback in appendix 3).

Three prototypes

Prototype 1

This prototype was used in the pilot test, which received most negative feedback (4 positive and 20 negative).

- The separation of functions on the interface was perceived negative. Seven participants prefer only one interface with all the functions rather than having two modules with different functions, as they mentioned:

[...] I don't like the design and prefer one item over two...

- The 'house-looking' shape failed to provide both functional feedforward information and aesthetic quality. Five participants did not like the shape of the design. One participant stated:

[...] I don't like the house shape...

- The knob is fabricated with a combined function (rotation and push button), the coupling of action in direction and position was perceived unnatural, one participant stated:

[...] The direction of the button is unnatural, when you push it and I am afraid it will fall from my table... [...]The button is horizontal and hard for the interaction...

Prototype 2

The second prototype received 8 positive feedback and 16 negative feedback.

- Similar to the prototype 1, five participants prefer only one interface rather than one with the separated functions.

- The 'playfulness' quality of this prototype was perceived in two directions. One participant stated:

[...]I think version 2 would be most attractive to use as the interaction seems playful and the most interesting of all....

However, other five participants were concerned that playfulness would not fit the environment of an office room. They mentioned that:

[...] More playful functions will distract me from work…

[...] Normally, I like playful elements but for this purpose, I would like for easy, simple, and still... [...]It can be distractive, too easy to play around with...

Prototype 3

The third prototype received most positive feedback (23 positive and only 5 negative).

- Nine participants liked the fact that this version only has one interface with all the desired functions. They stated:

[...]because it is one-part equipment...and one hand use, no distraction…

[...] I like 1 module instead of 2 since my desk sometimes is full, sometimes messy and I could lose the second module...

[...] It's all-in-one and it wouldn't get lost as easily as the others. Also , if it breaks, you only need to order one…

- The interaction style of this version received more positive feedback. Participants mentioned:

[...] The interaction seems precise, and I was able to get the most insights as to how the prototype worked out of all three versions…

[...] The interaction is better than the first (pilot) one, and more stable than the second one…

[...] Intuitive understanding of the function...

- The ergonomic quality of this prototype was also mentioned by two participants. As they stated:

[...] much ergonomic… seems easier for turning (the knob)…

[...] the button stands vertically, seems easy to control, the interface looks friendly...

Performance in a situated practice can be depicted as a sequence of doings (Kuijer, 2019). When exploring the expected functions, co-performance theory was applied to separate the doings in order to specify which of the doing in the practice are performed by users and which by the interface. A simple overview is created of a division of roles (see table 3). The participants were asked to give their opinion in the 5-point Likert scale: strongly agree, somewhat agree, neither agree nor disagree, somewhat disagree and strongly disagree. Each scale is given a score from 5 to 1 respectively. The total scale is obtained by the using the following formula:

*Score = [(Sum of actual scoring scale)/(Range of Sum of scoring scale)]*100%*

Envisioned performance Questionnaire	User score	Interface score	Performer
1. Changing airspeed	82%	65%	User
2. Making a cooling schedule on based on your office hour	66%	72%	Interface
3. Activate eco-mode in order to saving energy	58%	80%	Interface
4. Sense presences and switching on or off the PCS	60%	70%	Interface
5. Switch on or off Interface	69%	59%	User
6. Display indoor temperature	49%	76%	Interface
7. Display outdoor temperature	50%	82%	Interface
8. Control airspeed when it is needed	75%	69%	User

Table 3. Division of roles and doings

Results	
Top 3 tasks should be performed by Users: 1) Change airspeed 2) Control airspeed when it is needed* 3) Switch on / off the system *We envision that users can still change airspeed in some strict situations (eco-mode) which means the user's cooling demand is above programmed rules.	Top 3 tasks should be performed by System: 1) Display indoor temperature 2) Activate eco-mode and saving energy 3) Display outdoor temperature.

Table 4. Results of performed roles

From the above tables we can conclude that users are the performer of changing airspeed, switch on or off the interface and control airspeed when it is needed, which we assume that user can still change airspeed above the programmed rules

The interface is collecting data for the development of the machine learning. In order to get insights from participants what data they feel 'easy' to share with the system, the 5-point Likert Scale was also applied.

Here is an overview of collected data type and their score:

ID	ID	Score	Agreed Percentage	Rank
A	Temperature & Humidity	121	93%	1
B	Light Intensity	105	80%	3
C	CO_2	111	85%	2
D	TOVC	98	75%	4
E	Presence	85	65%	5

Table 5. Most wanted data

Conclusion: Temperature, humidity and CO_2 data has high acceptance for sharing, the personal presence detection scores lowest acceptance.

In addition to the proposed functions that were analysed from the questionnaire. The client also requested to add some data collection and prediction function on the interface. For example, self-reporting thermal sensations from the user and suggested thermal comfort. Table 6 presents an overview of all the required functions:

Parameters can be set the user	Parameters can be set the user
1) Change airspeed 2) Switch on / off the HVAC cooling fan 3) Report personal thermal sensation 4) Presence detection	1) Display Indoor temperature 2) Display CO_2 level 3) Offering suggested thermal comfort

Table 6. Required functions

ONLINE CO-DESIGN SESSIONS

After the questionnaire, participants were asked to join an online co-design session. Two morphological charts were made by the designer and clients where listed all the necessary functions and data category (see figure 25 & 26). After that, 12 co-design sessions were performed on Figma platform and Skype. They were given a short explanation of each feedforward and feedback concept, all the elements for designing this interface are displayed in the morphological charts. Participants were asked to choose one element from each category and design a user interface for themselves. 12 different concepts were created and 8 designs were selected to be further developed (see appendix 4). The co-design sessions were recorded and significant quotes, participant's inspiration and thoughts were also noted down near the their sketch. All the concepts were being analysed (see appendix 5), in this chapter, 5 different refined concepts were selected due to the fact that they are the most developed concepts that helped in terms of shaping the final design.

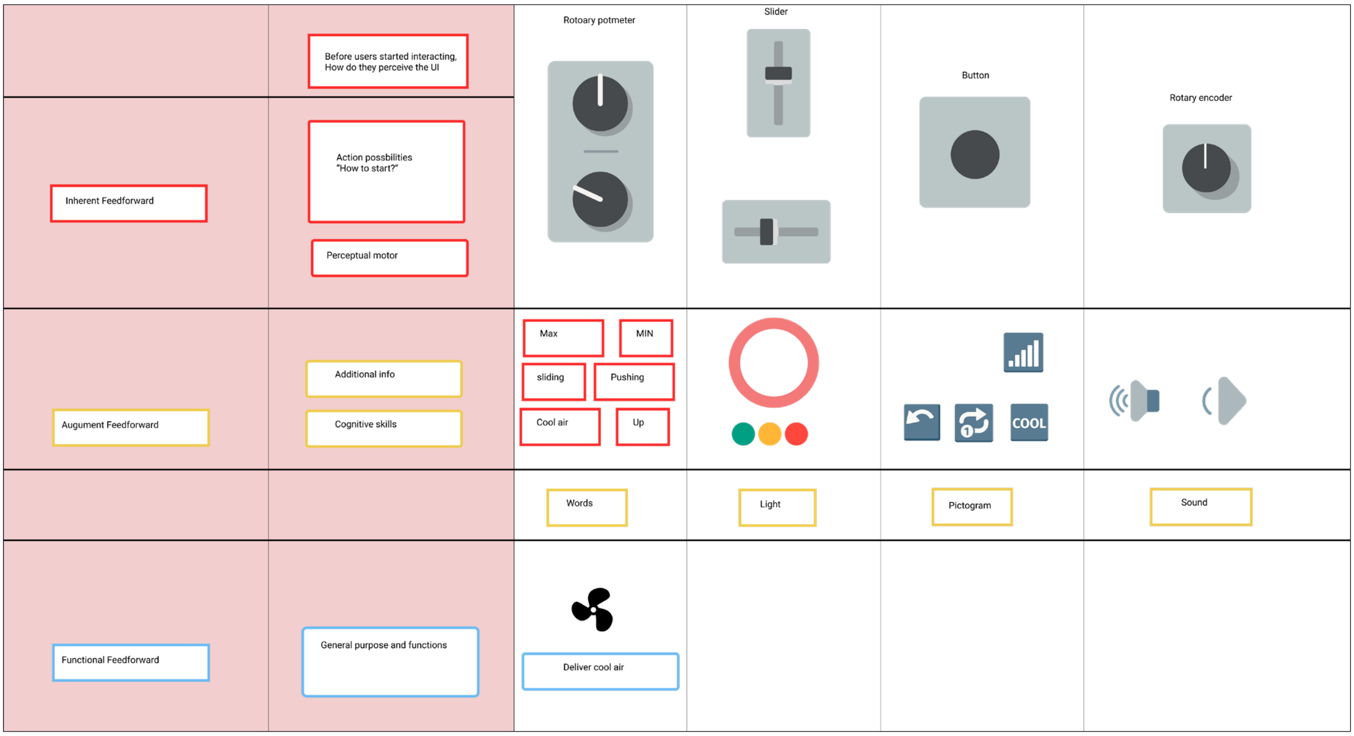


Figure 25: Feedforward morphological chart

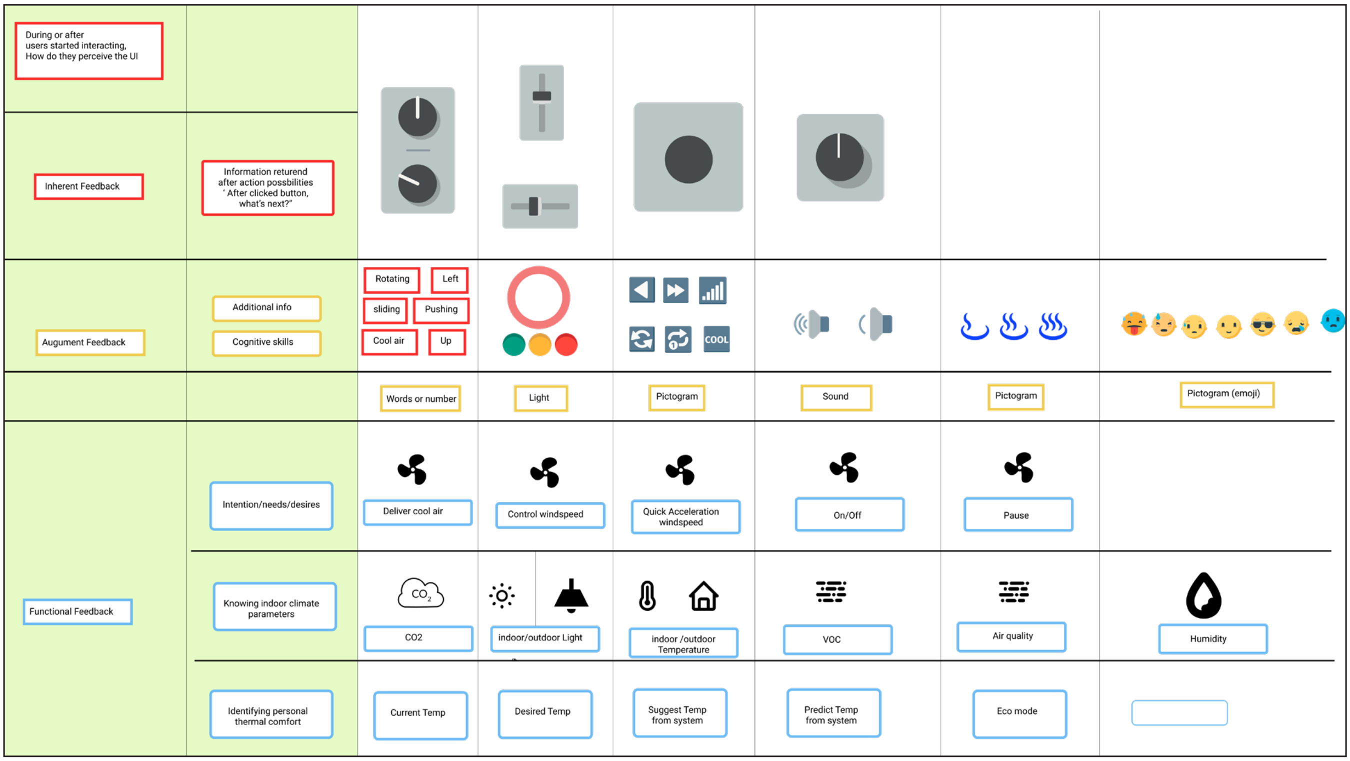


Figure 25: Feedback morphological chart

CONCEPT 1

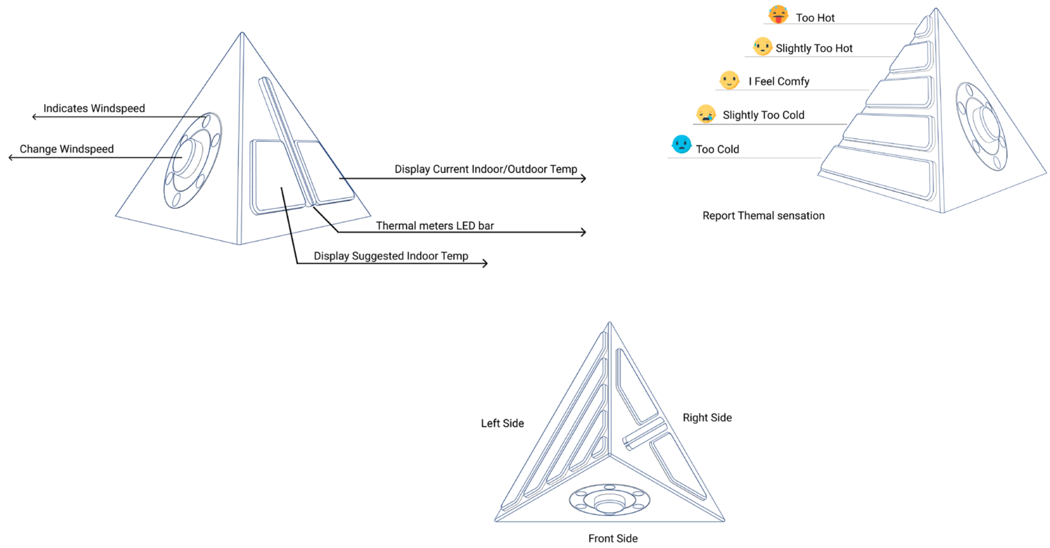
Participant 1 - Office Worker

Quotes:

"Each side should have a clear functionality"

"You should have only five degrees on thermal sensation, sometimes slightly warm or slightly cold is also comfortable for me, you need to rephrase to slightly too hot or war, "

"if you put buttons that low on the base it either needs to be quite heavy, or the thing will need anti-slip foam on the bottom"



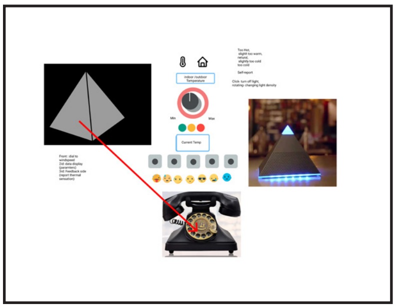


Figure 27-28: (one the left) Refined concept (on the right corner) Sketch from the participant

CONCEPT 2

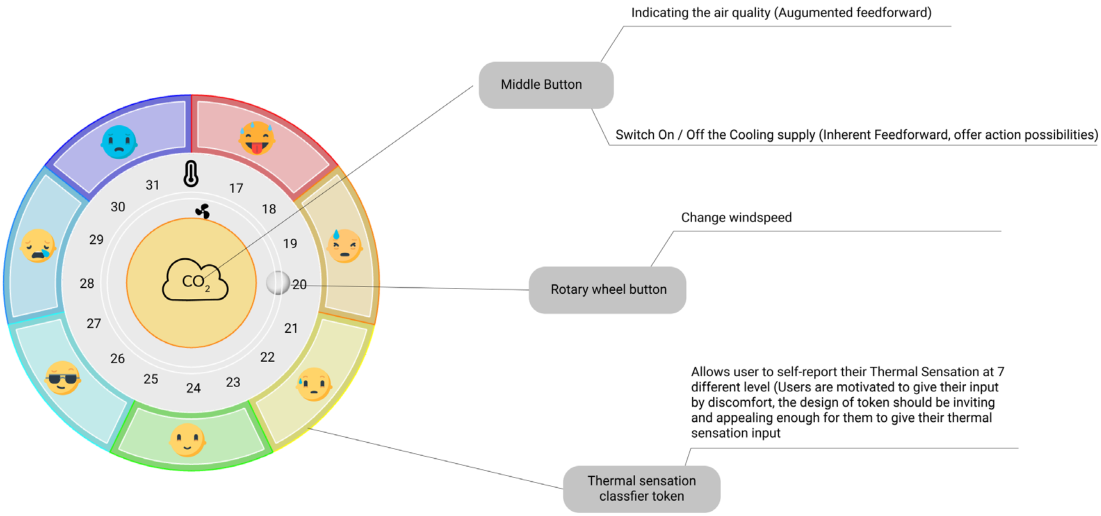
Participant 1 - Industrial design master student

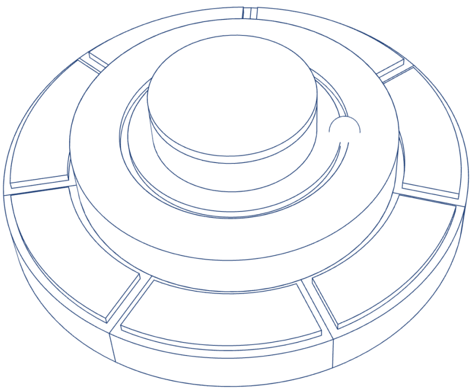
Quotes:

" I can't tell the difference between warm and slightly warm, but I think if I can tell the system how happy I am with the current indoor temperature, that will be really fun to do "

" If I can receive a message from the system that asks me if I feel comfortable or not, but I prefer to receive such a message like a quick notification on my laptop. "

" I think icons are self-explanatory, but I also want to know the current indoor temperature"





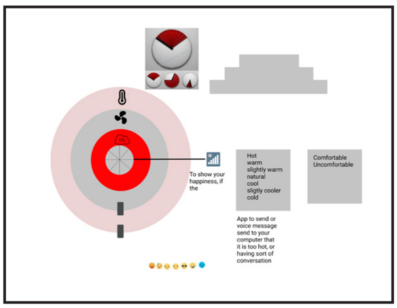


Figure 29-30: (one the left) Refined concept (on the right corner) Sketch from the participant

CONCEPT 3

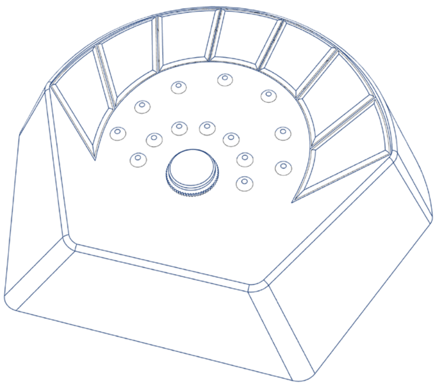
Participant 3 - Industrial design master student

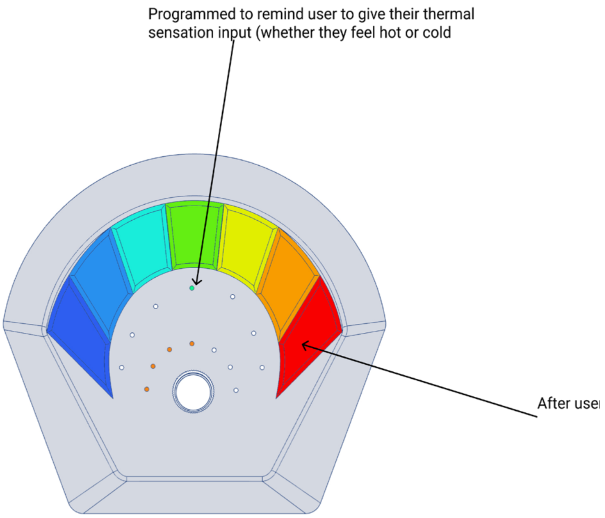
Quotes:

"(change airspeed) You should not think too much, just do it in a quick way."

"Set a timer on the LEDs, they start flashing every one hour, this is a reminder for users to give their thermal sensation input."

"The "hand fan' shape gives me an impression that is a UI for adjusting cooling, not heating."





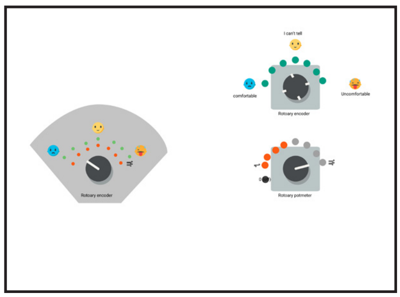


Figure31-32: (one the left) Refined concept (on the right corner) Sketch from the participant

CONCEPT 4

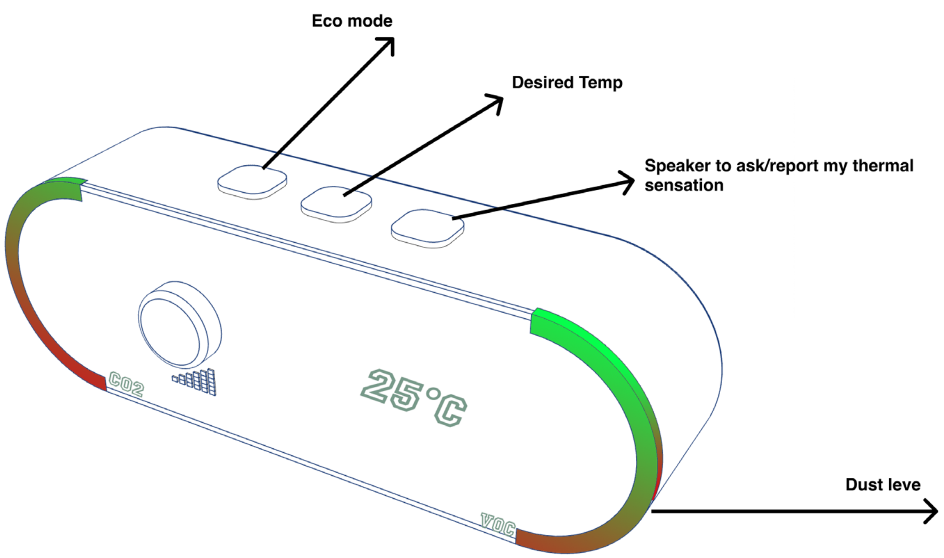
Participant 4 - Office Worker

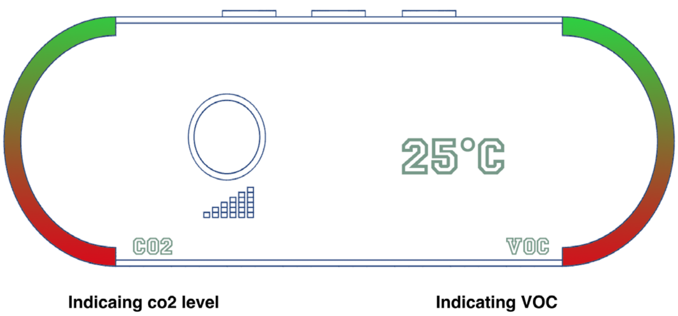
Quotes:

" I want to see CO_2 level to be displayed as well, so I know that the air quality"

"I sometimes forgot to switch off, so the system should switch off if I am not in the office

"I want to see all the possible data on this device"





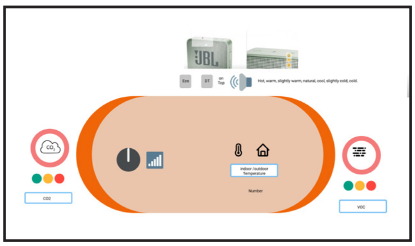


Figure 33-34: (one the left) Refined concept (on the right corner) Sketch from the participant

CONCEPT 5

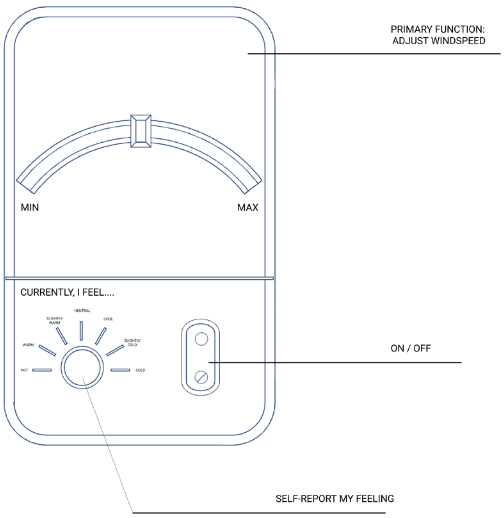
Participant 4 - Office Worker

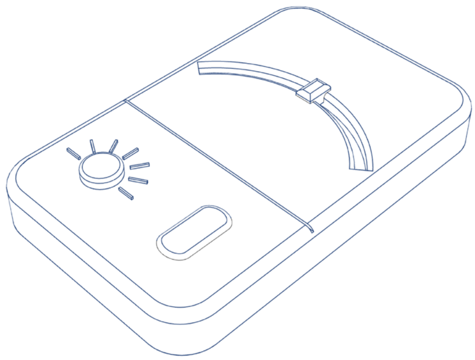
Quotes:

"There should be a clear separation of primary function and sub-function."

"On the aesthetics part, I suggest you follow the golden ratio."

"It should be very easy to use, for me adjusting airspeed, turning it on and off are enough."





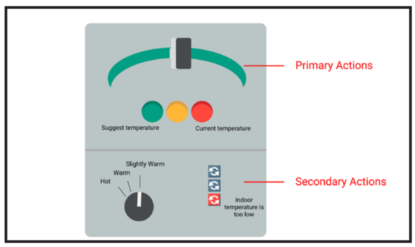


Figure 35-36: (one the left) Refined concept (on the right corner) Sketch from the participant

The conclusions were shaped by the findings through the questionnaire and online co-design sessions and interviews.

Here is an overview of the design criteria for designing an interface for PSC.

Simplicity:

First of all, the interaction steps need to be performed to change airspeed should be limited to a minimum. And the current state of the setting should to be visible. This can be achieved by creating a natural coupling between actions and functions in direction and time.

The self-report thermal sensation is important to facilitate machine learning. We learned from co-design sessions that it is difficult to motivate them to report or log their thermal sensation unless there is a strict demand. Based on the interviews and co-design sessions we found three potential solutions: 1) Reduce interaction steps that are needed, ensure the self-report function is easy and fast to achieve; 2) Report emojis that associated with different emotions instead of thermal sensations; 3)Add a reminder (notification or sound alarm)

Visibility of data information

The augmented information is needed to facilitate users to interpret the environmental factors. From the pilot study, as well as the co-design session, we learned that users are only motivated to interact with the interface by the moment of discomfort. For example, the change of the temperature is a cause of discomfort perceived by users. In order to motivate users to interact with the interface, the temperature information needs to be visible to the user.

On the other hand, we also learned from the questionnaire that displaying CO_2 level is the least desired function. However, from the interviews we know that some users have limited experience with interpreting or understanding the numerical information. They like to apply their cognitive skills in order to interpret air quality. Three concepts from the interviews mentioned:

[...]High-level CO_2 is bad for my health, so I want to have some fresh ventilation...

[...]I can't interpret numbers, but I know green light means good air quality, red means bad air quality...

[...]I like to see this information because I am always aware of the air quality in my office room...

Displaying light intensity was not required at all during all the co-design & interview sessions, it is likely that this parameter has a higher acceptance to be shared with the system, but plays a limited role in terms of communicating with users.

Trustworthy

The interface should take responsibilities to inform to the user the indoor air temperature and air quality. As well as reduce the energy consumption of the local cooling system. Therefore, in order for the interface to take these responsibilities. A presence detection should also be included. However, we learned from the questionnaire that there is a hesitation on this function in terms of data collection because it is clear that users have the lowest acceptance on it.

Ergonomic

The results of the co-design sessions revealed the fact that most users prefer one-hand interactions over than two in order to change airspeed on a PCS. This requires that the design of the interface needs to be ergonomic. The coupling of actions and functions in both direction and location needs to be natural and user friendly. For example, when pushing a button, the location should stay stable and won't slide away, and the direction of the product's reaction should be the same as the user's action.

Low-profile

Less distractive, the user interfaces should be nicely blend into an office environment. Although we learned that to do self-report a person's thermal sensation by using different emotions could be a promising solution by collecting the thermal sensation data. However, due to the fact that most of the participants prefer to have a low-profile looking interface on their working table, using emojis to represent 7 different thermal sensations might not be a good design direction.

CHAPTER 8

FINAL DESIGN AND DEPLOYMENT

The final design is equipped with ESP 32, also including three sensors that respectively measure CO_2 *(GSP30)*, temperature & humidity *(DHT 11)* and motion *(MH-SR602)* . The motion sensor is placed in the front of the interface which only detects a nearby range. There is also an internal fan built in, which serves two purpose: 1) supply cooling to the applied electronics; 2) supply air to the built in sensor. Two air-inlets are designed in the front of the measuring sensors in order to ensure that the measured air represents the correct room temperature and CO_2 level to create accurate measurement.

Two LED *(WS2812B)* bars are used as the indicators of the current room temperature and CO_2 level. 7 LED buttons *(LS12x12)*with different colours represent different thermal sensations. There is a built-in LED light inside of the button, when the system detects different temperatures, one of the buttons will start flashing to inform users the predicted thermal sensation. Users are also allowed to report their personal thermal sensations by pushing the buttons without being "required" by the systems.

Figure 37. Final Concept

Inherent Feedforward & Feedback

The inherent feedforward on this UI is given by the rotary encoder and 7 separated buttons. The central knob offers two types of action possibilities: pushing and rotating. When pushing or rotating the unit, the user can feel the state of the knob is changing, it is giving the user inherent feedback. 7 buttons offer one action possibility.

Augmented Feedforward &Feedback

The interface is mainly in black colour, only the sections where LED bars/ring are placed are in white colour, this serves to provide users augmented feedforward information where to look at. The texts on the left LED bar indicates the current indoor temperature, the texts on the right LED bar displays the current CO_2 level. The led ring in the centre indicates the current state of the knob. 7 TS buttons have a built-in LED with 5 different colours (Ideally 7 colours, only 5 colours are available). They are used to indicate the user's 7 thermal sensations. When rotating the knob, the LED lights which are located under the knob will follow the rotation, which provides augmented feedback to the user about the current position of the knob.

The LED bars, which are used to display temperature and CO_2 level, are programmed in showing different colours. The colour will be in blue when the temperature is low and red when the temperature is high. The colour stays in green, yellow and red if the measure CO_2 is low, medium and high respectively. The TS buttons start blinking in every 10 minutes. They offer the information on predicted thermal sensation for the user.

Functional Feedforward & Feedback

The HVAC cooling fan is providing functional feedforward. After the action (knob) is performed, the user can switch on the fan and adjust the airspeed by rotating the knob.

The TS buttons, on one side allow the user to self-report their current thermal sensations. However, users may forget to report their thermal sensation. In order to motivate them to give their input, the system will also anticipate in making a prediction of the current climate in every 10 minutes, one of the buttons starts blinking to display how the system defined a user's personal thermal comfort. The user could confirm the system's decision by pushing the flashing button or pushing other buttons to correct the system's decision. These choices will be collected and labelled by following the ASHRAR Standard (ASHRAR,2017). This serves to facilitate machine learning and therefore obtain the personal optimum thermal comfort.

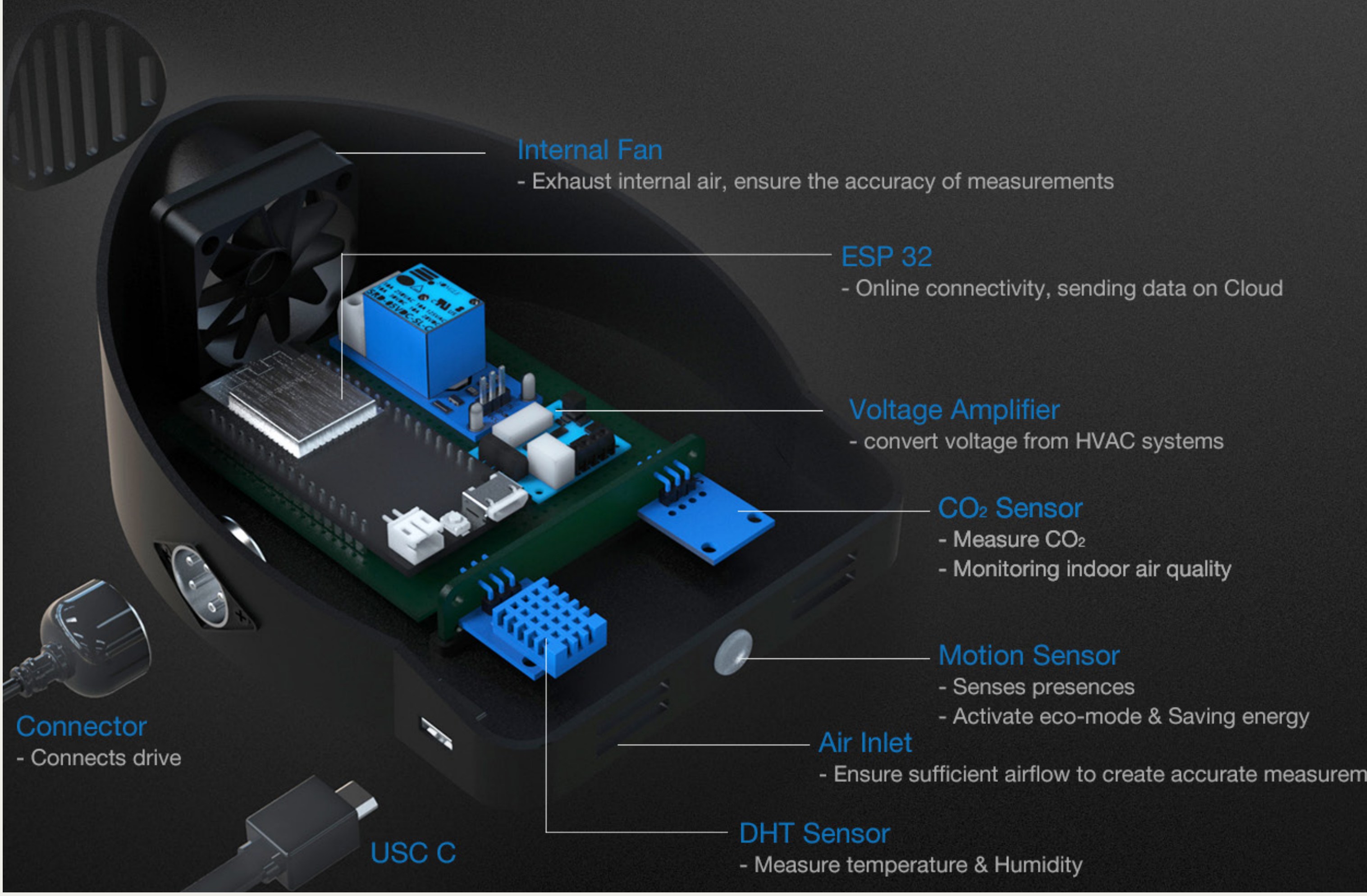
The PIR motion sensor in the front of the interface serves to activate eco-mode in order to save energy. If the system detects no movements in 10 minutes, the system will stop working. The central knob also allows the user to switch on / off the system. Therefore both the user and the system have control over the system. But the system is the main actor that acts the role of saving energy.

Subject	Inherent Feedforward	Functional Feedforward	Augmented Feedforward	Inherent Feedback	Functional Feedback	Augmented Feedback	Total Score (30)
User Interface	-Rotary Encoder -Push Button	UI for PSC	- Text - Symbal - LED lights - Color	- Sliding - Pushing - Range direction	- Change airspeed - Report air quality - Report TS.	- Light - Sound	-
Score	3	2	4	3	3	3	18

Table 6. Analysis of the user interface

PRODUCT SPECIFICATION

COOLINGSTAT



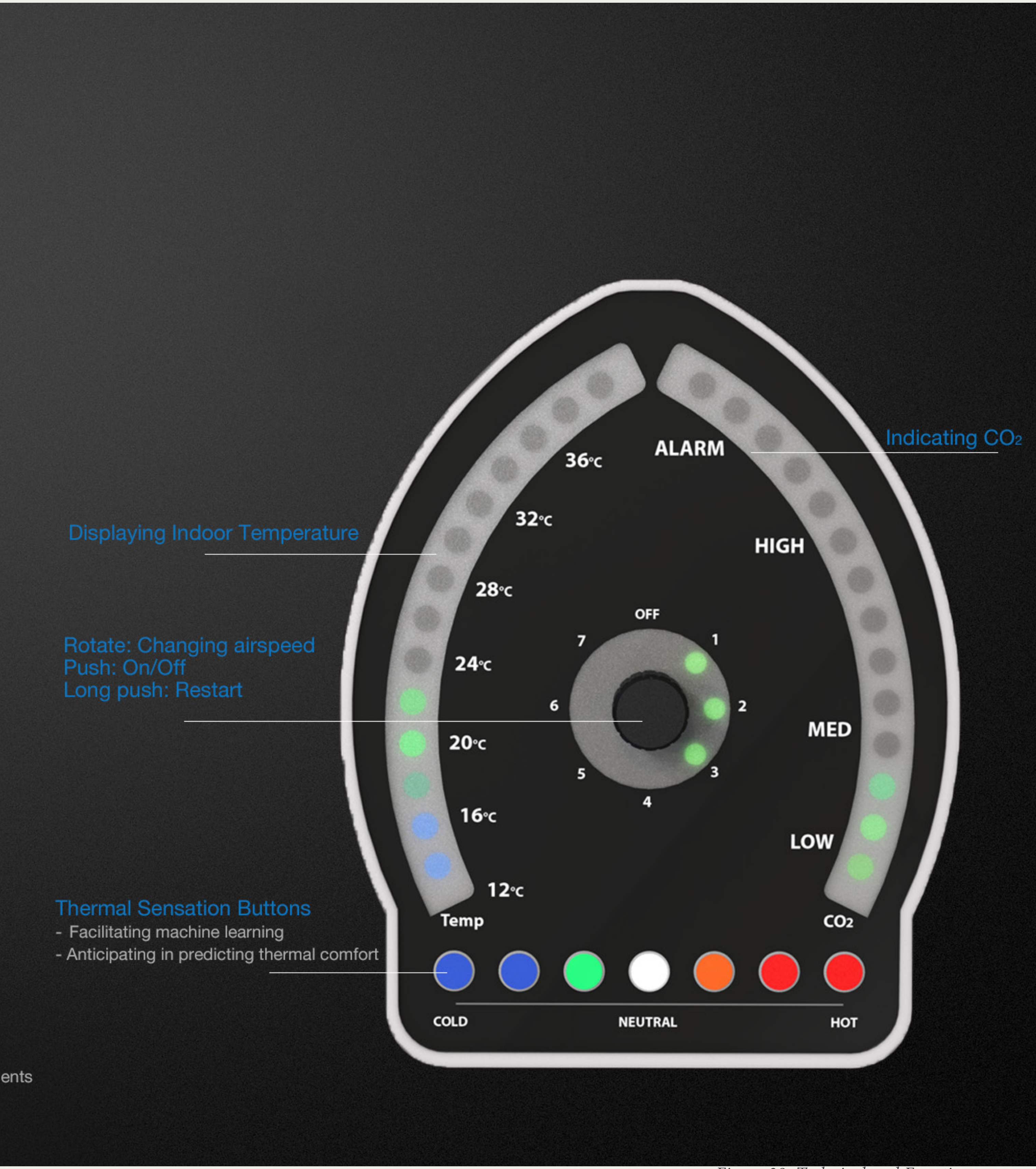


Figure 38: Technical and Functions

FINAL DEPLOYMENT

The prototype was deployed in the same place where the pilot test was conducted for over one week with the same participant. The setup followed the same setting as the pilot test. The participant was asked to interact with the new interface during the working hours. A semi interview was conducted after the final deployment to obtain his experience of the new interface.

Compared with the first pilot prototype, the new interface received more positive feedback in terms of form, function.

Form:

The aesthetic quality of the new interface was improved a lot according to the participant. The participant mentioned:

[...] First of all, I like its symmetric shape and balanced looking. Because I only need to know where I can change the airspeed. And I know I can do that by using the knob in the center…

[...] The use of the material of the interface for me is very appealing to interact with. I also like its black and white colour, nice contrast and makes the device professional

The visibility of measured information was perceived as useful and practical. The participant mentioned:

[...] Because I can see the current temperature and CO_2 *directly on the interface, when I see the colour of the light is changing, I know that the temperature is getting higher, same as the* CO_2*, so I am more aware of the air quality and temperature in my surroundings. I gain more and more insights about my indoor climate just by watching the interface. ..*

Function:

The final prototype was perceived as a multifunctional device by the participant, he stated:

[...] Besides changing the airspeed, I can also view more information on one interface. The best part of this device is that I can switch off everything, the sensor also detects my movement, the energy saving part is good.

Interaction:

The interaction (blinking light) of the TS buttons generates stress for the participants after a long term deployment. This could be that the interval (every 10 minutes) for asking the participant to report his thermal comfort input is perceived a bit short. He said:

[...] for me every 10 minutes I see the blinking lights, this makes me nervous, perhaps every half hour is enough..

[...] The first day I was curious and motivated to do it, but the rest of week I was annoyed by the flashing light. Sometimes I put my keyboard in front of the sensor to disable the blinking lights...

The new interface aimed to create rich interaction on this interface, for instance, the knob has three functions: the user can change airspeed by rotating the knob, it is also possible to switch off the entire system by pushing the knob. If the system is encountering an unknown problem, the user can restart the system by holding the knob for more than 2 second. However, during the deployment, On the interaction aspect, the participant did not experience the 'richness' on the knob, which means the participant did not discover the other two functions. He stated:

[...] I only know that I can change airspeed settings, but I did not know that I could turn it off, it should be mentioned somewhere...

Limitation:

There are some improvements that can be made in the future work, for instance, the internal fan creates more noise than it was tested in the pilot test. This could be caused by the design of the interface. The noise could also affect the user's productivity and emotions. More augmented information can be given on the knob to inform the 'hidden' functions.

The final deployment only involved one participant due to the Corona lock-down. We could not study the social interactions between more than two people with personal cooling in a shared working environment.

CHAPTER 9

DISCUSSION

Intrinsic & extrinsic motivation

We learned that the participants are most likely motivated to interact with the interface at a discomfort moment. This is driven by their intrinsic motivation. Because they are willing to invest time and efforts to create a comfortable indoor climate that satisfies their needs and desires.

The intrinsic motivation is also driven by the personal interest. Some participants from the co-design sessions have shown their interest in interpreting their thermal comfort through data visualization. In some designs smart thermostat, for example, the "ViCare App" from Viessmann (Viessmann, 2019) usually converted to graphs which can be easily interpreted by the users, so they can learn the energy performance of their home or workspace. If they chose to be energy efficient by compromising some personal factors (for example wearing less clothes if it is hot), at the same time, constantly giving their input on a fixed schedule, the system could learn their personal preference over a period of time. Thus, the system could also make more accurate predictions based on the behaviours of the users.

However, for people who don't have a technical background or less interest in energy performance of an office building it is difficult to motivate them to report their personal thermal comfort. Due to a lack of understanding and interest in machine learning, some users are not motivated to give their personal input to the system in an appropriate manner, which led to disappointment of the system in terms of energy saving (Yang & Newman, 2012).

We aimed to solve this problem by designing intuitive and easy interactions through an interface for users. Through two iterations, we have explored possible ways to motivate them to interact with the system. One of which is to make the data visible by proving strong augmented information on the interface. In this case, the augmented information is generally driven by extrinsic motivation. If the users are aware of the indoor temperature and perceived air quality by knowing the current CO_2 level in their surroundings, they are more motivated to interact with the system. However, we also discovered that by 'forcing' users to self-report their thermal sensation in a short interval was perceived stressful and not enjoyable unless there is stronger extrinsic motivation, for instance a reward. If the system could directly translate their effects into a reward, for example, reducing electricity bills by the amount of the personal inputs they gave.

Limitations of as a daily-use product

The final product is more useful as a research instrument rather than an interface that can be used on a daily basis. One reason is the unrealistic cost in order to have a personalised HVAC system in a shared workspace (Kim, 2018). Furthermore, the interface needs to be more technically developed to collect skin temperature data of the user by using some advanced sensing device (infrared camera). In combination with the environmental data, the prediction can be made more accurate, therefore, users are more likely to gain more trust on the system than disappointment. However, more advanced devices may result in a higher cost and even violate the privacy regulation.

On the other hand, in order to use data as a medium to learn about a context or user's daily behaviours, in both pilot test and final deployment, the prototype faced a privacy dilemma: the user's personal data. The duration of pilot test and final deployment was less than one week, the participant had a critical attitude and trust issue to share his personal data to the system, although both deployments were short-term. We also learned from the questionnaire that users are expected that the system can detect their presence for the sake of energy saving, but they were not willing to be reported to the system of their movements and activities.

Ease of user and control

One significant feature we learned from our users that the expectation from a smart agent (smart thermostat or interface) is that the applications and interactions are easy to use and control. Some smart products or devices aim to provide an automatic system by following the rule-based methods, in which products or systems are programmed to obtain a trade-off between good energy performance and optimum of thermal comfort. However, the programmed or automatic agent may cause the user to feel that (s)he is not in control. We argued that a smart agent is context-adaptive and capable of learning from users, therefore, we tried to implement a function that users also have controls to feed his subjective experience regarding their personal thermal sensation to the system, in order to co-perform tasks to define an appropriate indoor climate.

However, we also learned that if the user doesn't understand the logic which the smart agent performs, the result will be a disappointment of user trust and satisfaction. For instance, in the final design, 7 buttons are designed for users to self-report their thermal sensation in order for the system to learn the participant's cooling behaviours. These buttons with built-in light also aimed to motivate users to give their personal input. They were also programmed to give suggestions on predicted thermal comfort. The participant expected the system to be helpful for energy saving by learning their interaction patterns, but the participant was uncertain about whether the system actually learned his behaviours and whether the interface actually saved energy.

Lastly, we learned that users are willing to give up control for their own benefits. The mission of the final interface aims to learn from the users by self-reporting their thermal sensation. This function requires a high level of commitment and motivation, however, the interaction of the blinking lights results in user frustration and might result in switching off services.

CONCLUSION

In this report we presented a complete design process of a tangible interface for a PCS. Through two iterations of design, we have formulated a set of design criteria and qualities that were important for the design of the interface. We also argued the importance for a smart agent to take human input and contextual information into its decision making. Therefore besides the most required functions (e.g. change airspeed), we also explored the feasible ways to motivate users to give their input in an easy and intuitive manner. However, we learned that motivations from users heavily depend on their personal interest, level of commitment and convenient interaction offered by the interface.

In the future work, we plan to conduct more field studies in a shared workspace with more participants. The pilot test and final deployment only involved one participant with a technical background, although we tried to overcome this problem by involving more participants in the co-design session and exploration phase. Still, the findings from both field studies are limited and biased due to several factors: less participant, location and short duration of the deployment

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DIARY Booklet

A Study of Thermal Climate in an Office Room

Type
M2.2 | Final Master Project
Name
Yiwen Shen
Participant
____
Contact
y.shen1@student.tue.nl
Department
Industrial Design

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Informed Consent Form

This diary study is used to collect your data for this project. The project is hosted by Yiwen Shen, a student from the Department of Industrial Design for his Final Master project.

In this project, Yiwen Shen is developing and deploying a new interface for temperature control (cooling system), which collects data both environmental data and personal data. This happens at PAI Electric Installation, a client company located in Zeeland.

Furthermore, you data will be used to test machine learning algorithms to see whether your subjective thermal sensation and comfort can be understood and predicted. An interview will be conducted after the data collection, the whole interview will be recorded with a smartphone.

Your participation is completely voluntary, you can refuse to participate or answer certain questions without giving any reasons and you can, of course, end your participation at any time during the experiment. The information that we collected from this study will be only used for the development of the User Interface prototype.

If you have any questions, please contact the Yiwen Shen (email: y.shen1@student.tue.nl)

Certificate of Consent

I have read and understood this consent form. I agree to voluntarily participate in this study carried out by Yiwen Shen for scientific purposes of the project.
By signing I agree with this form and diary study:

Name: *Participant's Signature:* *Date:*

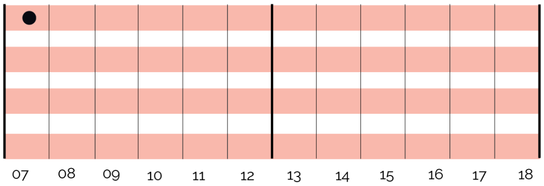
Instructions

Hi! Thank you so much for participating in this research. We would like to ask you to share your personal experience of the indoor climate in your office room. This study will take one week, and we would like to ask you to record some information for us that will be used for our study. Additionally, we have a sensor box that collects real-time data, the prototype will be deployed on your desk and you can adjust the fan speed to achieve a comfortable environment.
You are welcomed to fill in the following parameters on every page at least 8 times a day: date, outside temperature, weather condition, clothing and your activities. Please use the horizontal time chart to mark ho much you agree with the statement, at that point in time. You can also use the empty lines in the 'Activity Log' section to write down the activity you were doing at a point in time.

Your personal data will be only used for this study and will not be used for any commercial purpose. If you have any questions or concerns, please feel free to contact the researchers using the contact info on the first page.

Please Indicate how comfortable YOU find this Thermal environment Now:

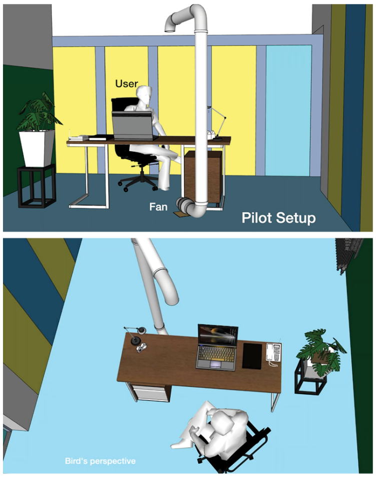
1. Comfortable
2. Slightly Uncomfortable
3. Uncomfortable
4. Very Uncomfortable

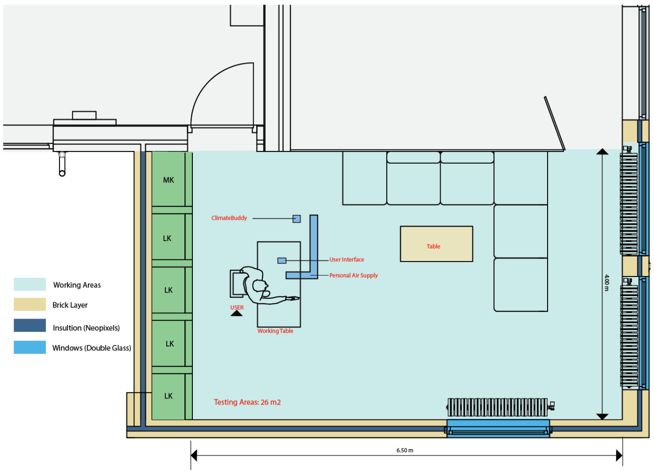


Setup

The pilot test will be conducted at an office room in Zeeland. The size of the testing office is around 26 square meters. Additionally, the room is well insulated by using a 12mm layer of Neopixels* in between two layers of brick walls. The windows in this office room are installed with a double-layered glass. The heatings are supplied with three radiators by using water as the medium from heat pump system.

In this office, A personal cooling air supply system is installed for the participant. The participant can use this cooling system for the duration of the cooling season. The pilot test will start in April. The cooling is supplied to the participant via cooled air, directed at the head from above.





Date: __/__/ 2020

Please rate on these scales how YOU feel NOW:

(The following chart represents a person's thermal sesation based on an internationally agreed thermal sensation scale)

- Logging period (sensor)
- Optional Logging Period (user)
- Required Logging Period (user)

Hour	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1. Hot																								
2. Warm																								
3. Slightly Warm																								
4. Neutral																								
5. Slightly Cool																								
6. Cool																								
7. Cold																								

		07	08	09	10	11	12	13	14	15	16	17	18
Please Indicate how comfortable YOU find this Thermal environment Now:	1. Comfortable												
	2. Slightly Uncomfortable												
	3. Uncomfortable												
	4. Very Uncomfortable												
Please Indicate how acceptable YOU find this Thermal environment Now:	1. Acceptable												
	2. Not Acceptable												
Please Indicate how acceptable YOU find this Thermal environment Now:	1. Satisfied												
	2. Not Satisfied												

		07	08	09	10	11	12	13	14	15	16	17	18
Please check in the weather condition at the moment	1. Sunny												
	2. Partly Cloudy												
	3. Cloudy												
	4. Light Rain												
	5. Light Showers												
	6. Storm												
Please mark your clothing at this moment	1. Socks												
	2. Shoes												
	3. Slipper												
	4. Short trouser												
	5. Short sleeves												
	6. Normal trousers												
	4. Vest												
	5. long sleeves												
	6. Thin sweater												

Activities Log:
(Prefered wind no. and activities at the moment)

NO.	Time	Activities	Notes

Questionnaire About Personal Cooling

Dear Participant,

Thank you so much for taking your time to complete this questionnaire. This questionnaire aims to collect your opinion and ideas to help us in developing a personal cooling system in an office room.

This questionnaire will take about 15 minutes to be completed.

* Required

Project Background

Creating a comfortable indoor climate is essential for buildings as it affects occupant's well-being, productivity and satisfaction. However, only 44%[Joyce et al, 2018] of the installed system is succeeding to accomplish the results that deliver a standard thermal condition which satisfies 80% of the occupants.
This questionnaire has 3 sections:

- In the first section, we would like to ask you to choose a cooling solution for your company or study place.

- In the second section, we would like to introduce to you our envisioned solution.

- In the last section, we would like to have a short interview with you and co-design session

Your Information

In this section we only collect your basic information, your data will be safe with us and won't be shared with a third party, they will be only used for the research purpose.

1. 1. What is your gender?

Mark only one oval.

- ( ) Male
- ( ) Female

2. 2. What is your age range?

Mark only one oval.

- 0-15
- 16-30
- 31-45
- 45-60
- 60-75
- Above 75

3. 3. What is your professional role?

Mark only one oval.

- Student
- self-emplyee
- Employer

4. If you are a student, what is the name of your study?

____

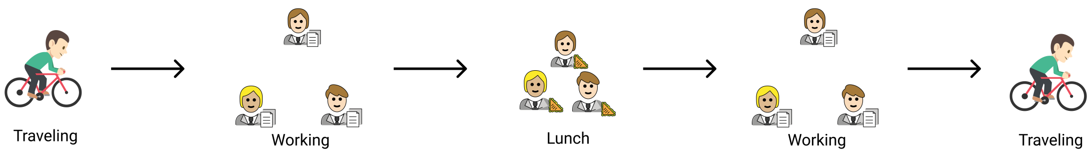
5. What is your title or role at the company?

____

First Section

Dear participant, thank you for completing the previous questions 👐 .
In the next section, we would like to ask you to imagine that you are on your (normal) daily routine to your company or school, just like the following picture shows 👇

Your daily routine to your company or school



6. 1: It is very hot today and you are on your way to school or the workplace, what would be your personal cooling solution after arriving at school or office? *

Mark only one oval.

A: Find a piece of paper and fold it like as in the picture

B: Find a supermarket or a vending machine to buy some cold drink

C: Go to bathroom and use cold water to wash your face

D: A mini fan which your ordered from the Internet

7. What is your reason for this solution?

8. 2: Luckily you know at your workspace there is a cooling supply, which is ---> *

Mark only one oval.

A: Air Conditioner

B: Central Cooling System

C: A Large Fan

D: None of them are in my office room, so I will use my own personal solution

Other:

9. 3: In the past two years, the temperature in summer was very high (40.7 °C was measured in Gilze-Rijen in North Brabant as the highest record since 1944 [Wiki]). Your company or faculty manager considers it is important to invest in the cooling system for the office. Which type you personally think will be the best choice? *

Mark only one oval.

◯ A: Air Conditioner

◯ B: Central Cooling System

◯ C: A Large Fan

◯ D: A personal fan on every table

◯ Other: ____________

10. 4: Investing a cooling system will probably increase the electricity bills. Your company or school needs to find a sustainable and affordable way to use energy for the cooling system. Which solution do you think is the most efficient? *

Mark only one oval.

A: Air conditioner

B: Central cooling unit

C: A Large fan

D: A personal fan on my table

Other: ____________

11. 5: Your company or school decided to install an air-conditioner in every office room, what is your opinion about this? *

Mark only one oval per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: It is not a sustainable solution	◯	◯	◯	◯	◯
B: It is bad for my physical health, I don't want to sit in a such room all day long	◯	◯	◯	◯	◯
C: I always need more cooling (or heating), but I am not sure if my colleagues all agree with this	◯	◯	◯	◯	◯
D: It cannot deliver air equally in the whole room and it makes some noise	◯	◯	◯	◯	◯
E: I think it is a good solution	◯	◯	◯	◯	◯

12. Why do you think it is a good solution? (only applicable if you agree)

13. 6: Imagine you have a deadline from your project, however, it is very hot in your working area because the air conditioner cannot deliver enough cold wind to your direction. What would you do to create a comfortable environment to ensure your productivity? *

Mark only one oval.

◯ A: Find a cooler working place if it is possible

◯ B: The working area from you colleague is cooler, you will ask to exchange working place.

◯ C: Using your one of the cooling options from question1.

◯ D: Just try to cope with the temperature

◯ Other: ____________

◯ E: Wear less clothes

14. 7: One of your colleagues is working close to the air-conditioner and he switches it off because he felt cold. However, for you it is still very hot, what will you do? *

Mark only one oval.

- A: Agree with him and switch off the air-conditioner
- B: Kindly ask him to wait for a while and then switch off air-conditioner
- C: Ask how other people in the room feel about this and then vote by the majority
- D: Don't do anything, cope by the temperature

15. 8: It seems that the air-conditioner is not a good solution to get an "agreeable" temperature for everyone. Your company or school considers to install a central cooling system, what is your opinion? *

Mark only one oval per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: It is not a sustainable solution					
B: It is bad for my physical health, I don't want to sit in a such room all day long					
C: I always need more cooling (or heating), but I am not sure if my					

colleague all agree with this					
D: It cannot deliver air equally in whole room and it makes some noise	⬭	⬭	⬭	⬭	⬭
E: I think it is a good solution	⬭	⬭	⬭	⬭	⬭

16. Why do you think it is a good solution? (only applicable if you agree)

17. 9: The central cooling system is integrated into the ceiling, everybody is happy now. But soon you realise that this programmed system does not satisfy every occupant in the room. Who should be able to change settings?

Mark only one oval.

- A: Everyone can do that because it is a shared equipment
- B: The system can decided time and airflow based outside temperature, I don't want to control it myself
- C: The system and all the workers can both decide what time and wind speed
- D: I just follow the majority, if it is getting too cold, I will wear more clothes
- E: "I thought only building manager can do that"

18. 10: A central cooling system is now available in your office, but it is not switched on because you are the only person working today. Luckily your company or school sponsors you a moveable cooling fan. What is your opinion? *

Mark only one oval per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: It is a good solution	◯	◯	◯	◯	◯
B: It is acceptable	◯	◯	◯	◯	◯
C: This is uncomfortable, the cold air comes from only one direction I want to switch on central cooling.	◯	◯	◯	◯	◯
D: I thought they want to be sustainable, but this also consumes electricity	◯	◯	◯	◯	◯

E: I got headache from the fan, then I prefer to switch it off and stay hot

19. Why do you think it is a good solution? (only applicable if you agree)

20. 11. In the afternoon, two more colleagues from different departments come to the same working place and they also want to borrow the moveable cooling fan, what will you do?

Mark only one oval.

- A: Find a best place for the moveable fan so the airflow can be shared.
- B: Give to them because you have already used it for the whole morning
- C: Kindly refuse them because you were first
- D: Give to them but ask them to return it in one hour

21. 12: okay, the above is clear, sharing is pain. Luckily you have a mini personal cooling fan. It is very quiet and sufficient. What is your opinion? *

Mark only one oval per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: It is not a sustainable solution					
B: It is bad for my physical health, I feel a bit headache from the direct wind					
C: This fan can provide air volume and direction which complies my needs					
D: I think it is a good solution					

22. Why do you think it is a good solution (only applicable if you agree)?

Personal cooling system

In this section, we will introduce you our solution. It aims to deliver cooling and use less energy

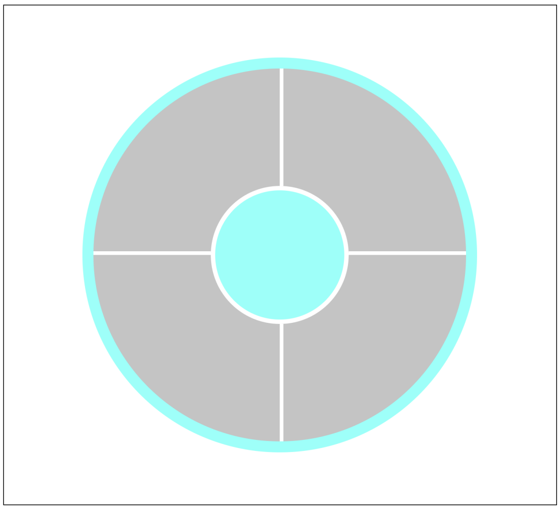
Personal cooling system concept (pilot prototype)

This cooling system is controlled with machine learning algorithms, it aims to predict your cooling demands and deliver a comfortable cooling air supply to you.

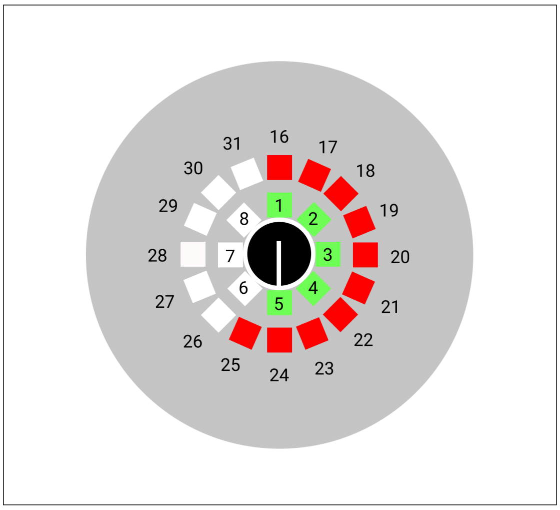
Interface design

The user interface exists out of two modules. PIR module detects your presence. The control module switches on/off the fan and controls the airspeed.

If the sensor does not sense presence for x minutes, then the fan will be stopped automatically.



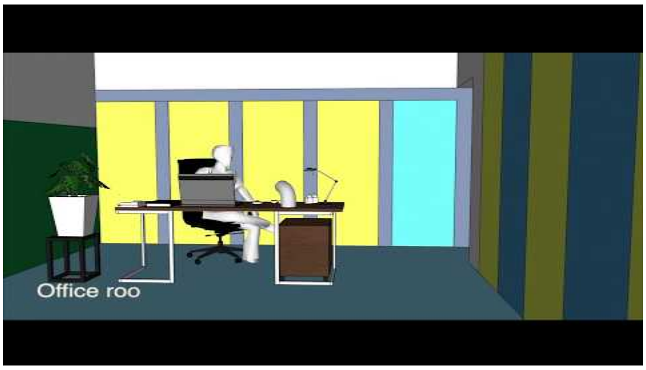
PIR module



Control module

If the sensor does not sense presence for x minutes, then the fan will be stopped automatically.

The Interface interface in an office room



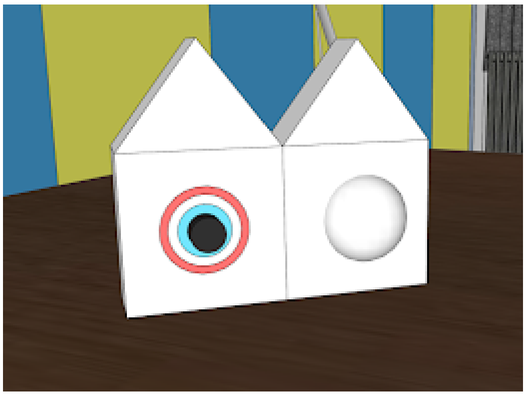
http://youtube.com/watch?v=fqEnFAT2920

Here is a mockup of the User interface (please try this).
https://www.figma.com/proto/HEw2qoHXpQGYMNg9YeYw47/FMP_prototype-1_Cooling-UI_version2?node-id=20%3A113&viewport=232%2C-349%2C0.5077722668647766&scaling=min-zoom

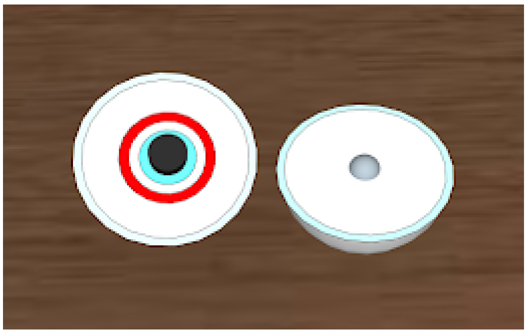
Here is a mockup of another User interface.
https://www.figma.com/proto/ypexqbqKZIf9UKTVdhKfJI/Co-design-session?node-id=6%3A171&viewport=-110%2C916%2C0.4765811860561371&scaling=min-zoom

23. In the video, we presented three different versions in terms of shape and size. which one you think will be the most convenient suitable one to use in the office room?

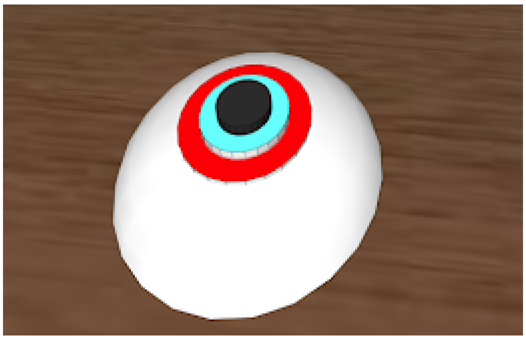
Mark only one oval.



A: Version 1: Control module + PIR module in a house shape



B: Version 2: Control module + PIR module in half sphere shape



C: Version 3: Control module (PIR sensor integrated inside)

Here we would like to present a short demo video of how each interface can be used.

Version 1: This version has two modules, one detects your personal working area and the other one controls airspeed.


http://youtube.com/watch?v=L8iPZZ1cbnU

Version 2: Similar to the version 1, but his version detects a wider range, and it is somewhat playful.


http://youtube.com/watch?v=8sDe4dZwvXA

Version 3: This version combines all the functions and like version1, it detects your personal working area.


http://youtube.com/watch?v=NJ4Q4bBZbJY

24. Which version in your opinion is attractive to use?

Mark only one oval.

- A: version 1
- B: Version 2
- C: Version 3

25. Why do you think version1 works the best?

26. Why do you think version2 works the best?

27. Why do you think version3 works the best?

28. What were the reasons you did not you consider the version1?

29. What were the reasons you did not you consider the version2?

30. What were the reasons you did not you consider the version3?

31. Which functions you consider are useful on this user interface *

Mark only one oval per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: Presence detection					
B: Change windspeed (airflow/air volume)					
C: Display indoor temperature					
D: Display outdoor temperature					
E: Display indoor co2 Level					

32. The user interface collects environmental data for the development of a machine learning model. Which environmental data you are comfortable to share with this system? *

Mark only one oval per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: Temperature & Humidity at office					
B: Light density at office					
C: CO2 Level at office					
D: TVOC (total volatile organic compounds)					
E: Your presence					

33. The user interface has a certain performance, which activities you think should be performed by you. (The system cannot perform) *

Mark only one oval per row.

	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: Change windspeed	◯	◯	◯	◯	◯
B: Make a cooling schedule based on your office hour	◯	◯	◯	◯	◯
C: Activate eco-mode and saving energy	◯	◯	◯	◯	◯
D: Sense presences and switching on or off automatically	◯	◯	◯	◯	◯
E: Switch on or off	◯	◯	◯	◯	◯
F: Display outdoor temperature	◯	◯	◯	◯	◯
G: Display current inside temperature	◯	◯	◯	◯	◯
H: Control windspeed when it is needed	◯	◯	◯	◯	◯

34. The user interface has a certain performance which has learned from the collected data, which activities you think should be performed by the System. (which you cannot perform) *

Mark only one oval per row.

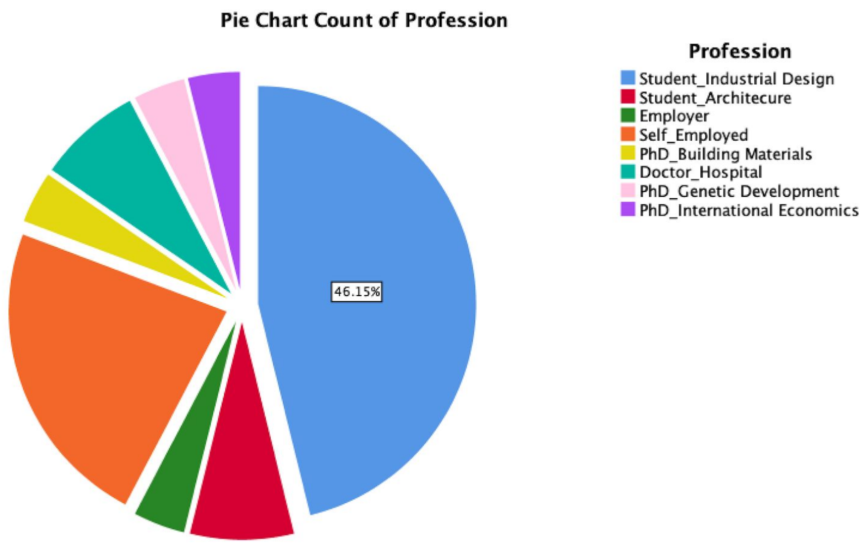
	Strongly agree	Somewhat agree	Neither agree nor disagree	Somewhat disagree	Strongly disagree
A: Change windspeed	⬭	⬭	⬭	⬭	⬭
B: Make a cooling schedule based on your office hour	⬭	⬭	⬭	⬭	⬭
C: Activate eco-mode and saving energy	⬭	⬭	⬭	⬭	⬭
D: Sense presences and switching on or off automatically	⬭	⬭	⬭	⬭	⬭
E: Switch on or off	⬭	⬭	⬭	⬭	⬭
F: Display outdoor temperature	⬭	⬭	⬭	⬭	⬭
F: Display current inside temperature	⬭	⬭	⬭	⬭	⬭
H: Control windspeed when it is needed	⬭	⬭	⬭	⬭	⬭

Thank you! The questionnaire is completed

Week 3 08-04-2020
Results from the Questionnaire
FMP Yiwen Shen

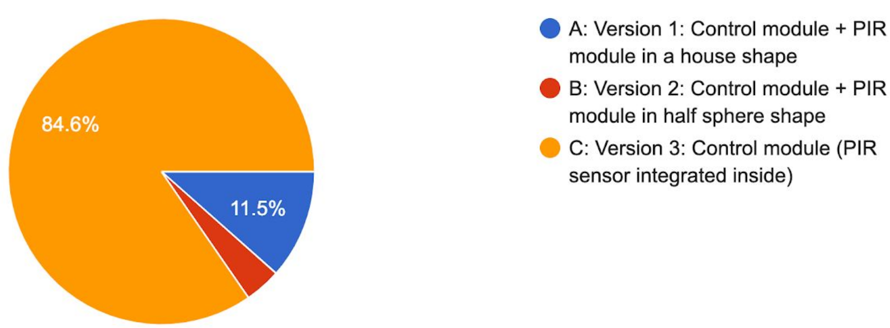
General Information

The questionnaire was filled in by 26 participants(14 female, 12 male), 46% of them are master students from industrial design, the rest of the participants have a diverse background. The average age of the participants is between 20 to 30.



Questions on the prototype design

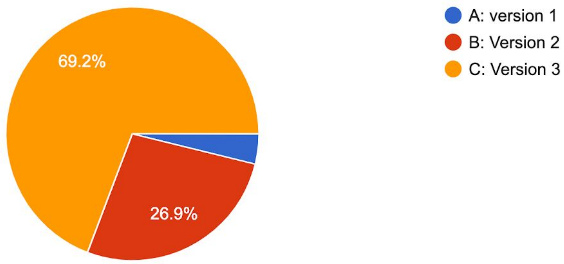
In the video, we presented three different versions in terms of shape and size. which one you think will be the most convenient suitable one to use in the office room?
26 responses



Conclusion: Version 3

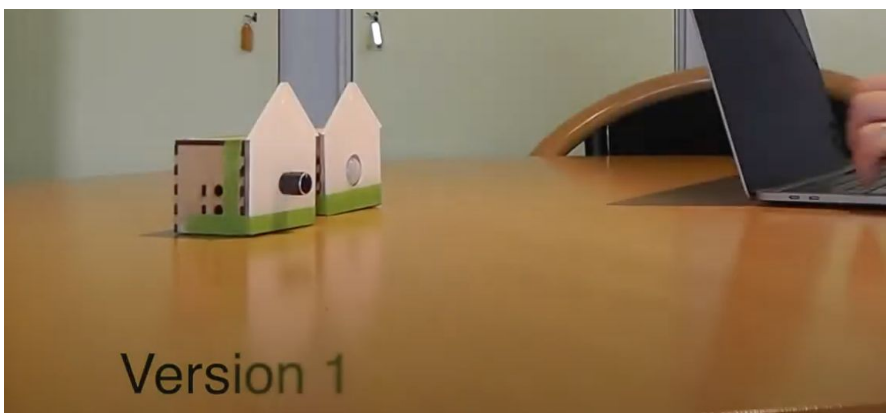
Which version in your opinion is attractive to use?

26 responses



Conclusion: Version 3

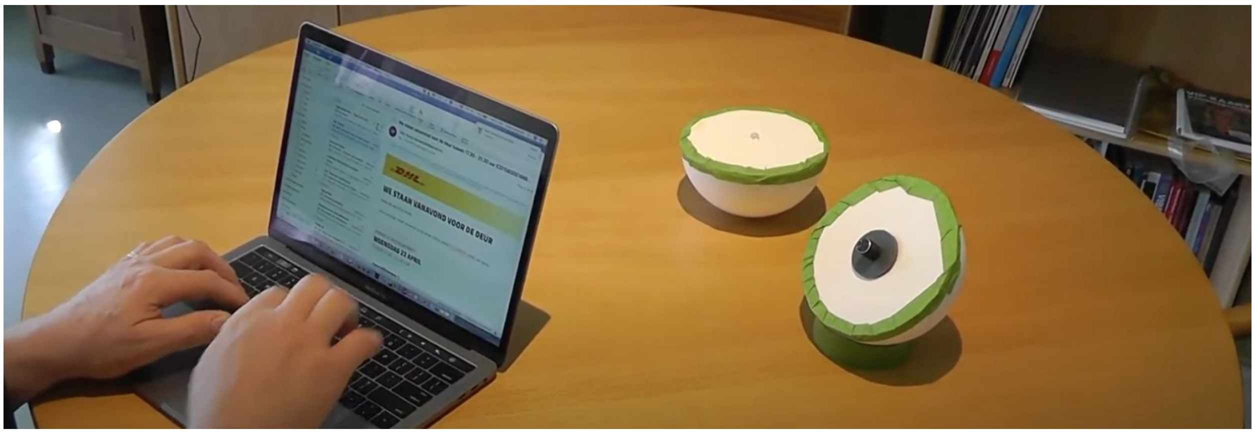
Remarks on Each version1



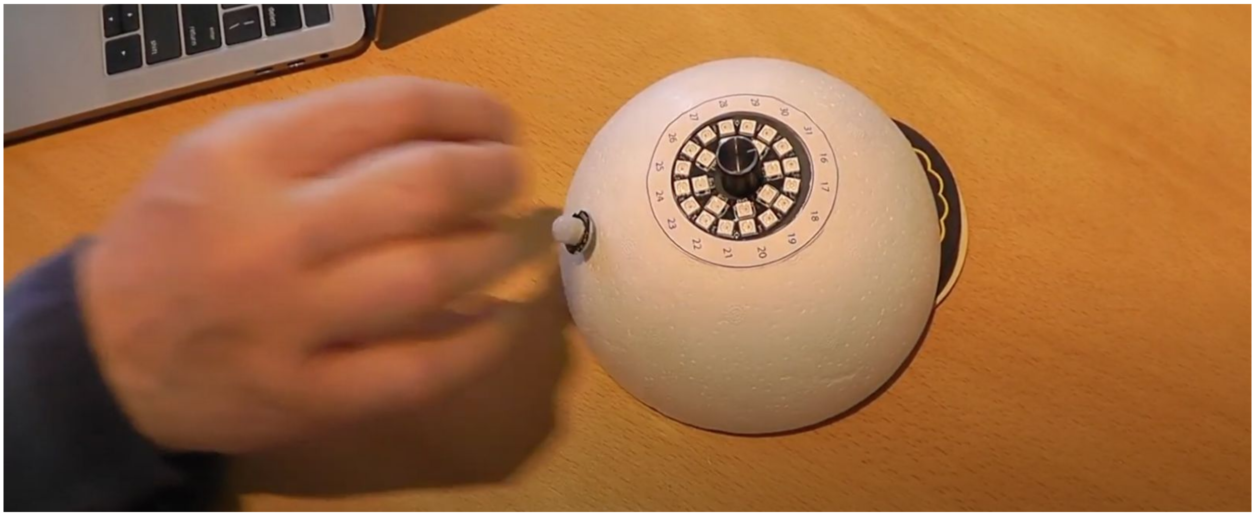
Positive (3)	Negative(21)
Aesthetic Aspect: 1. A best suitable range for tracking, best aesthetic and easiest to interact with 2. It looks more like an office decoration **Like two modules:** 1. I like that they are separate entities. I could place one house on another table or on a closet.	**Aesthetic Aspect:** 1. I don't like the look, decreased outlook, take space 2. I do not like this "house" shaping design. 3. The shape of the houses is for me not appealing enough to have on my desk. 4. Too bulky and too difficult of a design. 5. I did not consider version 1 because it seemed the most plain out of all versions. **Don't like two modules** 1. The other versions consist of two separate pieces, I think I will lose one of the two very quickly. 2. 2 modules and a sharp angle may hurt if I interact with my periphery attention 3. Don't like the design and prefer one item over two. 4. Two parts (module), capture motion range is wired 5. Two pieces are inconvenient 6. Two pieces. I think a two in one would be better. **Interaction (direction):** 1. 视觉方向不对，并且总怕把它推走 (The direct of the button, I am afraid I will push it away) 2. The button is horizontal and hard for the interaction, so I'm afraid that any rude interaction will push the interface back and affect detection negatively. 3. I like that it's a bit more decorative, but the interaction seemed a little uncomfortable

	because he needed to reach out to touch it. It also feels like if it needs to be moved a bit to make space on the desk, you would easily be out of detection range. 4. Version 1 is in 2 parts. It's a good version but I think that version 3 is more effective for adjusting the speed. 5. There are 2 models, harder to learn and easier to confuse **Usability:** 1. Complex 2. The area covers directly to the user's face 3. Too tiny controls 4. The small button looks unstable, 5. Small detection area's

Remarks on Each version2



Positive (8)	Negative(16)
Playful: 1. I think Version 2 would be most attractive to use as the interaction seems playful and the most interesting of all. **Interaction:** 1. For me, the interaction with the interface seems very fun and unique. It would look very cool on my desk. Also, the detection range is quite big which could lead to a better result. 2. The direction the cooling air is expressed is not to user's face 3. I think 2 and 3 are quite similar, but 2 just seems more comfortable when you grab it and hold it in your hand **Aesthetic aspect:** 1. cute **Detection Range** 1. Most form-giving field of detection I like that it invites being taken in the hands, which makes its use comfortable. 2. Larger detection area than 1 and 3 3. Bigger detection area and easy setup	**Stability:** 1. not stable on a flat surface without support, take space 2. 不稳定 (not stable) **Spacy**: 1. The second one takes a lot of space. Iit is two parts and playful, I worry it is gonna lose one someday 2. Large occupied area **Don't like two modules:** 1. The interaction with two hands causes too much interruption to users' work. 2. Two handworks 3. but it has 2 modules. 4. I don't like the fact there are two, less is more in my opinion. 5. 2 units instead of 1 **Usability:** 1. Complex 2. The presence detection area isn't good and the user is not appropriate. **Too Playful (distraction)** 1. More playful function will distract me from work 2. Normally, I like playful elements but for this purpose, I would you for easy, simple, and still. 3. It can be distractive 4. Too easy to play around with, distractive.



Remarks on Each version3

Version	Positive (22)	Negative (5)
3	**Stability:** 1. It is stable, I could adjust the temperature with one hand. and I will not lose it quickly because it is one piece. 2. Simply static (no playing around) **Interaction:** 1. However, I think Version 3 is the most technologically developed. The interaction seems precise, and I was able to get the most insights as to how the prototype worked out of all three versions. 2. 交互的时候，比1要方便，比2要稳定 (interaction is better, more convenient than version1, and more stable than version2) 3. Intuitive understanding of the function **Ergonomic:** 1. much ergonomic, this prototype could have a 360° outlook for round desk/office, seems easier for tuning (other skins, update,...), more futuristic look also :) 2. The button stands vertical, seems easy to control. The interface looks friendly. **'Only one':** 1. because it is one-part equipment 2. Capture motion in a reasonable range, and one hand use, no distraction 3. I like 1 module instead of 2 since my desk sometimes is messy and I could lose the second module. 4. It's all-in-one and it wouldn't get lost as easily as the others. Also , if it breaks, you only need to order one. 5. Compact layout 6. More convenient,, nice-looking appearance than 1 and 2 7. One item to handle, simple. Design is most appealing. Doesn't move like version 2. 8. it is one single object. 9. More compact than version 1 **Less Spacy:** 1. Less space occupied 2. It only considers my personal space, without affecting - others 3. Does not occupy much space. 4. It takes a few spaces, easy to use and the presence detection area is very good compared to the second version.	**Distractive:** 1. It looks like a timer which could distract me from work. **Inappropriate look:** 2. Small detection frame (plus looks like a boob, queue inappropriate office jokes) 3. It looks like a breast (sorry^^') 4. The third one I don't like the position of the PIR sensor 5. the shape looks off to me. The area covers directly to the user's face

	5. Less occupied area 6. less occupied area **Less distractive:** 1. Less playful than version 2, therefore, less distractive.	

Criteria

1. **Simplicity**

How easy for you to understand what this user interface does, without further explanation (menubook) about functionalities.

2. **Ergonomic**

Imaging using this interface with one hand, how comfortable if you want to achieve certain functionalities, like change wind speed or check current temperature.

3. **Low-profile**

Less distractive, the user interface nicely blend into office environment

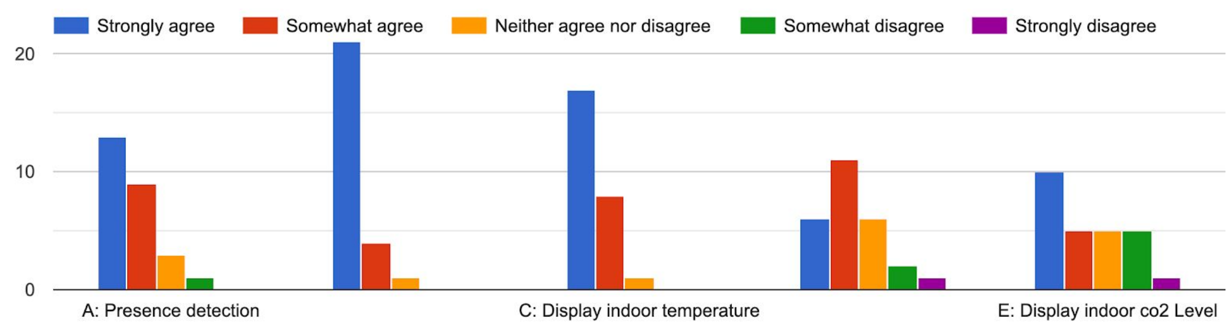
4. **Aesthetic**

The appropriate appearance in terms of form, color and size (e.g. symmetric shape or balanced looking)

5. **Usability**

Achieve certain functionalities quickly and naturally, UI collects data in a non-obstructive way.

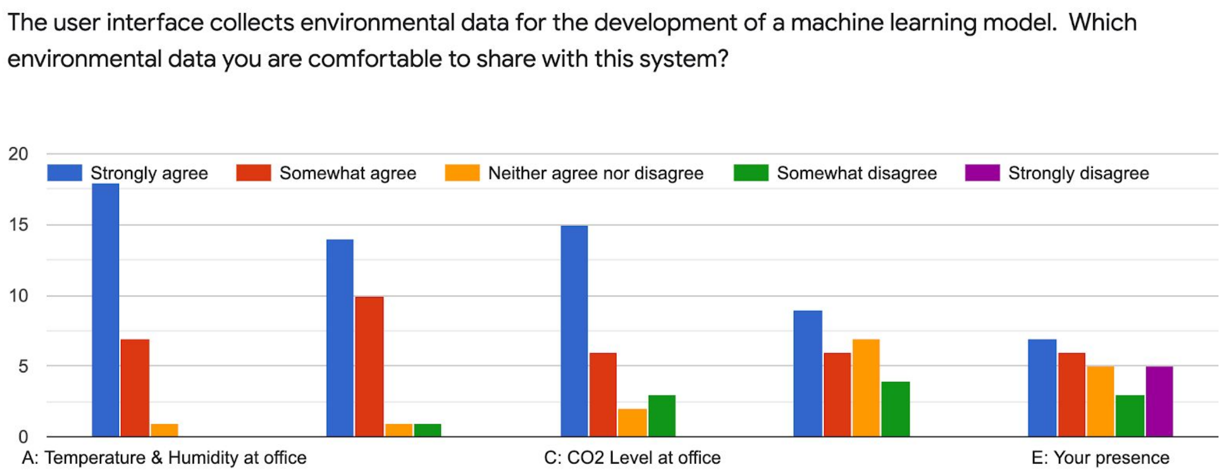
Which functions you consider are useful on this user interface



(Strongly Agree = 5, Somewhat Agree = 4, Neither agree nor disagree = 3, somewhat disagree = 2, Disagree = 1)

ID	Option	Total Score	Agreed Percentage	Rank
A	*Presence detection*	108	83%	3
B	*Change wind speed*	124	95%	1
C	*Display indoor temp*	118	90%	2
D	*Display outdoor temp:*	97	75%	4
E	*Display co2 level*	96	73%	5

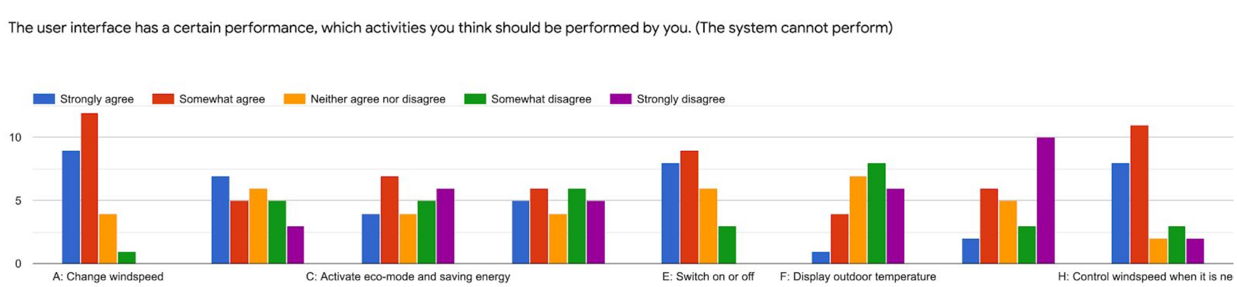
Conclusion: change windspeed and display indoor temperature are considered to be most wanted functions on the UI.



(Strongly Agree = 5, Somewhat Agree = 4, Neither agree nor disagree = 3, somewhat disagree = 2, Disagree = 1)

ID	Data Name	Total Score	Agreed Percentage	Rank
A	Temperature & Humidity	121	93%	1
B	Light Intensity	105	80%	3
C	CO2	111	85%	2
D	TOVC	98	75%	4
E	Presence	85	65%	5

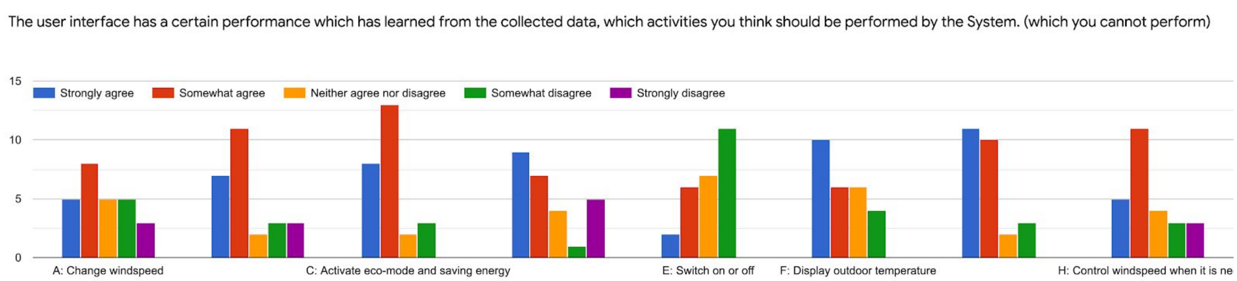
Conclusion: Temperature, humidity and co2 data has high acceptance for sharing, personal presence scores lowest acceptance.



(Strongly Agree = 5, Somewhat Agree = 4, Neither agree nor disagree = 3, somewhat disagree = 2, Disagree = 1)

ID	Performed Tasks	Total Score	Agreed Percentage	Rank
A	Change wind speed	107	82%	1
B	Make a cooling schedule based on your office hour	86	66%	4
C	Activate eco-mode and saving energy	76	58%	6
D	Sense presences and switching on or off automatically	78	60%	5
E	Switch on or off	90	69%	3
F	Display outdoor temperature	64	49%	8
G	Display current inside temperature	65	50%	7
H	Control wind speed when it is needed	98	75%	2

Conclusion: Control wind speed and switch on/off the cooling supply should be performed by users through UIs.



ID	Performed Tasks	Total Score	Agreed Percentage	Rank
A	Change wind speed	85	65%	7
B	Make a cooling schedule based on your office hour	94	72%	4
C	Activate eco-mode and saving energy	104	80%	2
D	Sense presences and switching on or off automatically	92	70%	5
E	Switch on or off	77	59%	8
F	Display outdoor temperature	100	76%	3
G	Display current inside temperature	107	82%	1
H	Control wind speed when it is needed	90	69%	6

Conclusion: Display indoor/outdoor temperature, active eco-mode to save energy should be performed by the system.

TOP 3 Desired functionalities:

1) **Change windspeed;**
2) **Display indoor temperature**
3) **Presence detection**
4) Display Outdoor temperature
5) Display CO2 level

Top 3 Acceptance of shared Data:

1) **Temperature & Humidity**
2) **Co2 Level**
3) **Light intensity**
4) TOVC
5) Presence detection

Conclusion: Three major functionalities should be display on the user interface,

Co-Design Session

A design exploration of Personal Cooling UI for a Shared Environment

Type

M2.2 | Final Master Project

Name

Yiwen Shen

Participant

____

Contact

y.shen1@student.tue.nl

Department

Industrial Design

EINDHOVEN UNIVERSITY OF TECHNOLOGY

Before the co-design session, a questionnaire was sent to participants.

The questionnaire has three sections.
1) The first section aims to collect their basic information, including age, gender and professions.

2) The second section serves to substitute role-playing in a shared working environment for participants who are currently working at home. This section aims to find out which personal cooling system that participants value most and how they deal with the social interactions in terms of using cooling systems in a shared working environment.

3) The last section, three concepts were presented and this section aims to:

1) Test the interaction flow and functions of the UI on Figma.

2) Provide three concept possibilities and define which concept is perceived as the most user friendly and useful. (define design criteria)

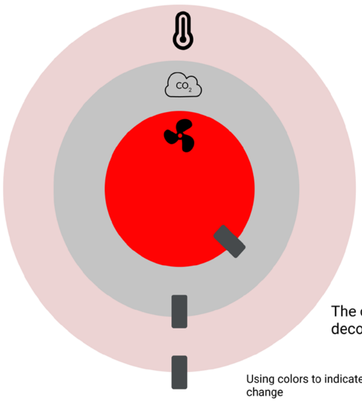
3) Define what information and parameters that participants feel 'easier' to share. What activities should be performed by the system or the user?

After the questionnaire, a co-design session was conducted with 10 participants, each of them was asked to design a UI for themselves on Figma. Their design activities, thoughts, inspirations and explorations were recorded. In the end, a sketch was created and will be converted to a 3D model by the designer.

All the design elements are presented on Figma and categorised into different themes. The co-design session followed a morphological method, which aims to find out what elements does a user value most and how they envision a UI for a personal cooling system can be designed.

So far there are 12 people participated in the questionnaire, 10 sketches were created and 6 of them were selected to be developed further.

participant 1 Concept Sketch

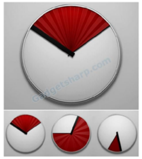


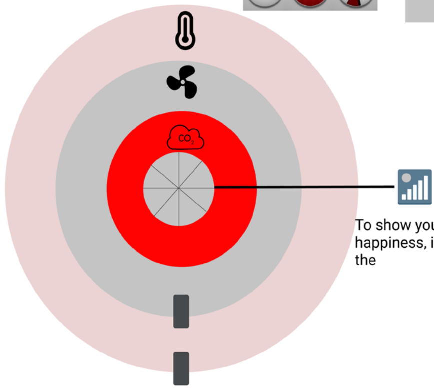
The circle looks clean and looks like a decoration

Using colors to indicate temperature change

Using height difference in a way 3D to indicate temperature change

The icons make it clear





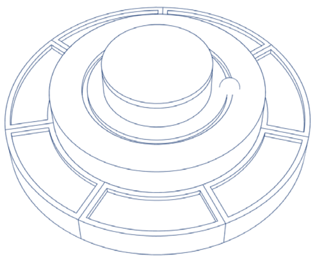
To show your happiness, if the

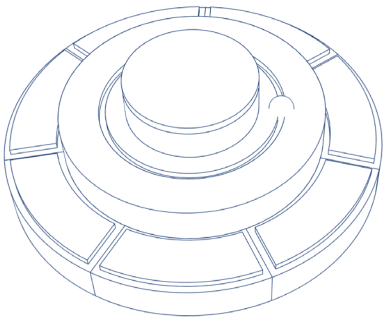
Hot
warm
slightly warm
natural
cool
sligtly cooler
cold

Comfortable
Uncomfortable

App to send or voice message send to your computer that it is too hot, or having sort of conversation

participant 1 3D Model

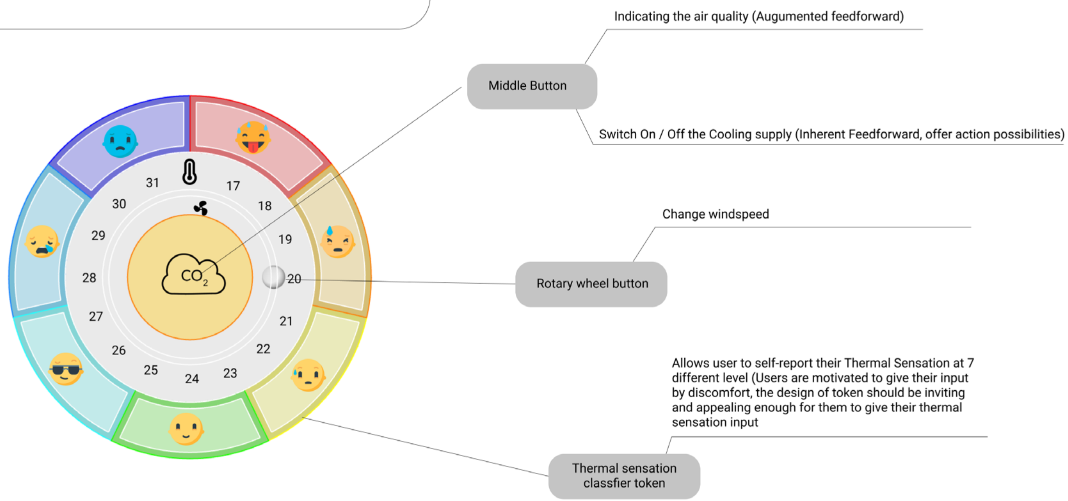




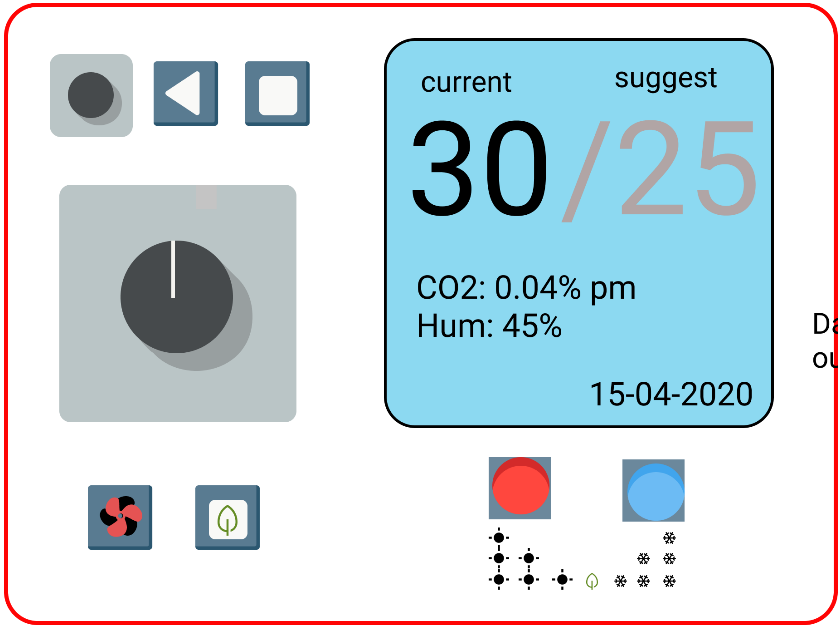
" I can't tell the difference between warm and slightly warm, but I think if I can tell the system how happy I am with the current inddor temperature, that will be really fun to do "

" If I can receive message from the system that ask me if I feel comfortable or not, but I prefer to receive such message like a quick notification on my labtop. "

" I think icons are self explanatory, but I also want to know the current indoor temperature"



participant 2 Concept Sketch



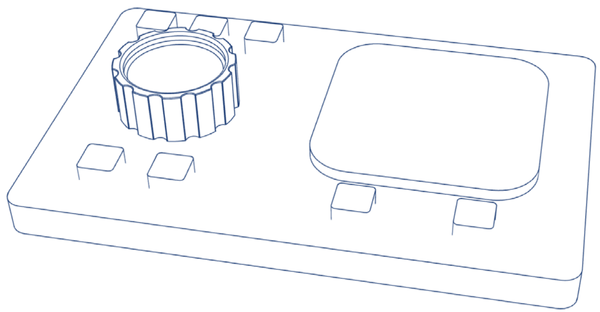
Date, time and indoor / outdoor temperature

A screen to display temperature / co2

Unconfortable

comfortable

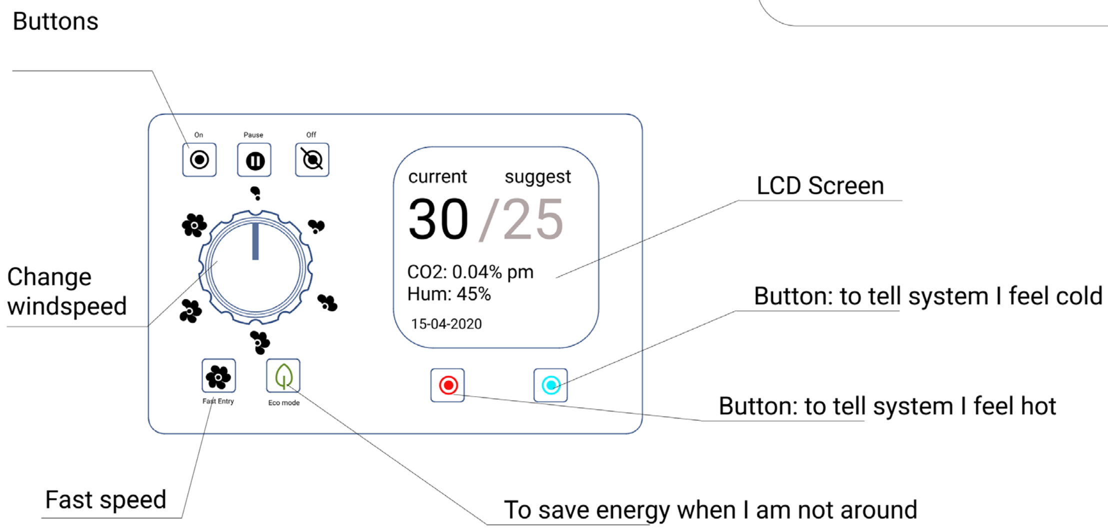
participant 2 3D Model



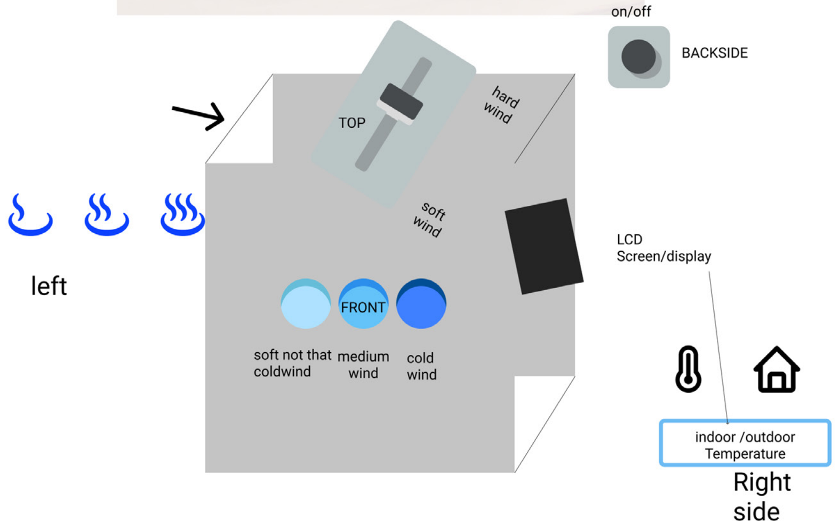
" I like to have function that can directly jump to a fast speed"

" I like every button has their own specific funtion, and I also would like to know more information like air quality, current temperature and suggest temperature"

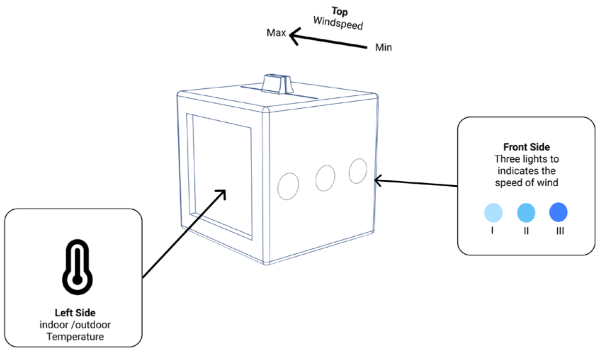
" The suggest temperature for me should be something like after some weeks learning of my inputs, system should be able to suggest a temperature that would be the most comfortable for me, and then I will change the windspeed to get that temperature for me"



participant 3 Concept Sketch



participant 3 3D Model

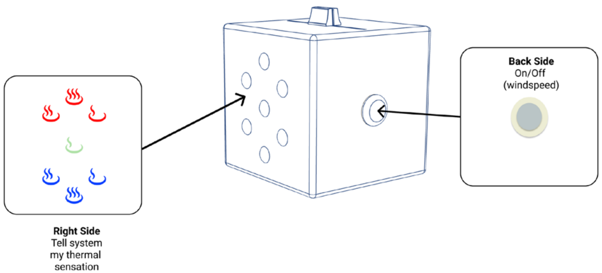


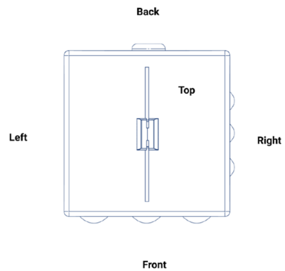
I think to change windspeed, I like to have a sliding action because for me it is easy to understand, up is to increase speed, down is to decrease speed.
The front part can show the change of windspeed,
I like to have three different levels, by using different blue light to indicate different level (windspeed)

For me I like the interface to be a playful object on my table.
I like the Version 2 (from the questionnaire) Because the interaction is playful and unique. I like it

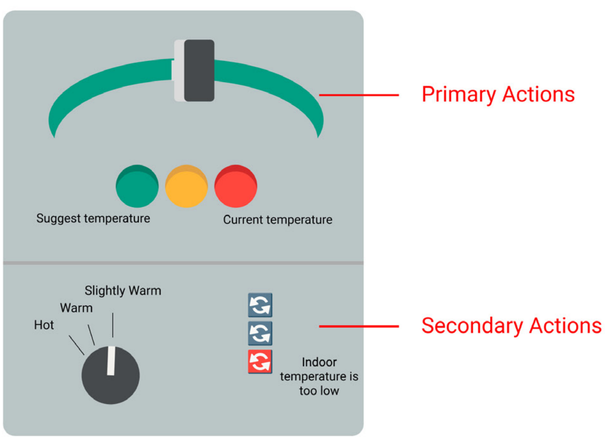
“Playful”

“Easy but not crazy”

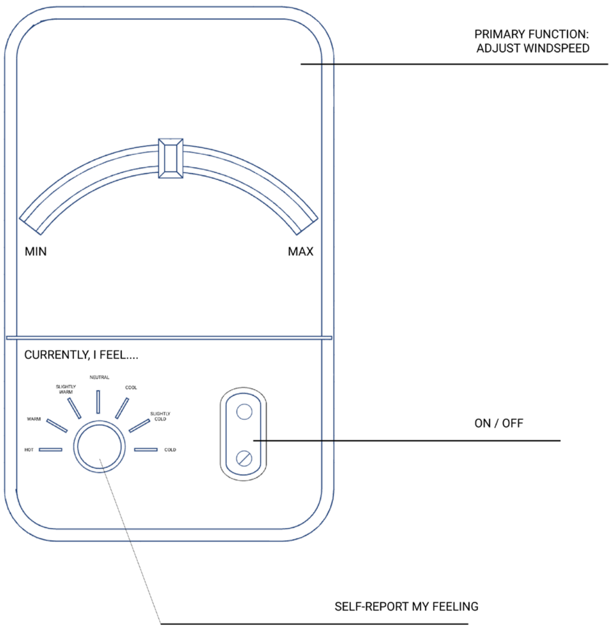


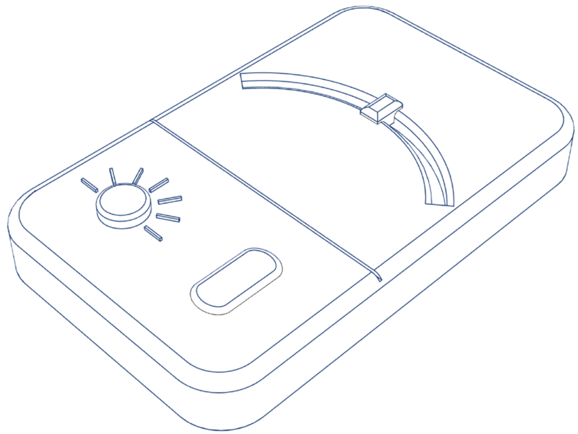


participant 4 Concept Sketch

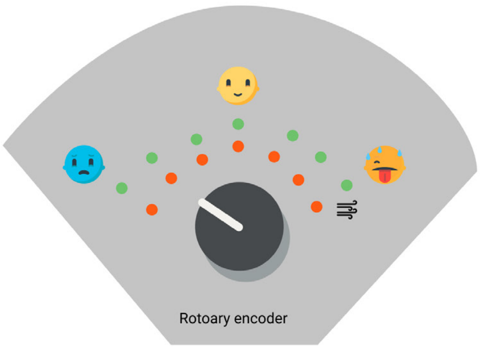


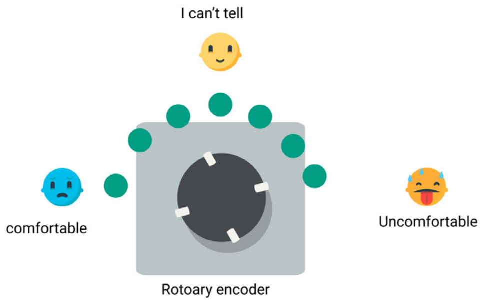
participant 4 3D Model

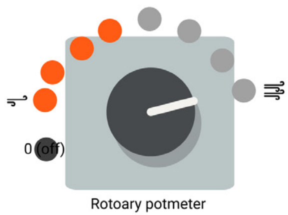




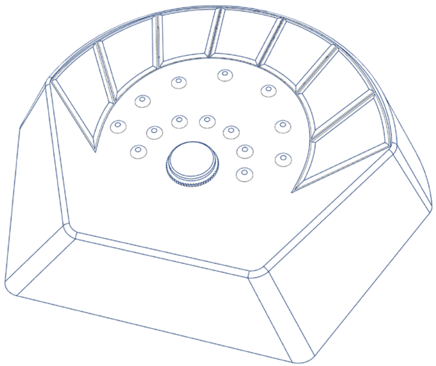
participant 5 Concept Sketch



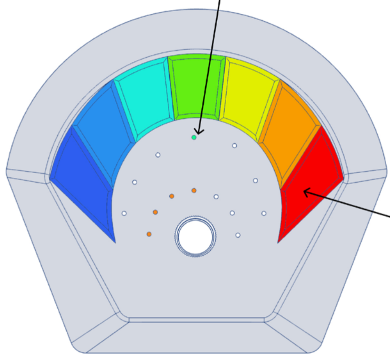




participant 5 3D Model



Programmed to remind user to give their thermal sensation input (whether they feel hot or cold



After user presses button, the flashing lights stop

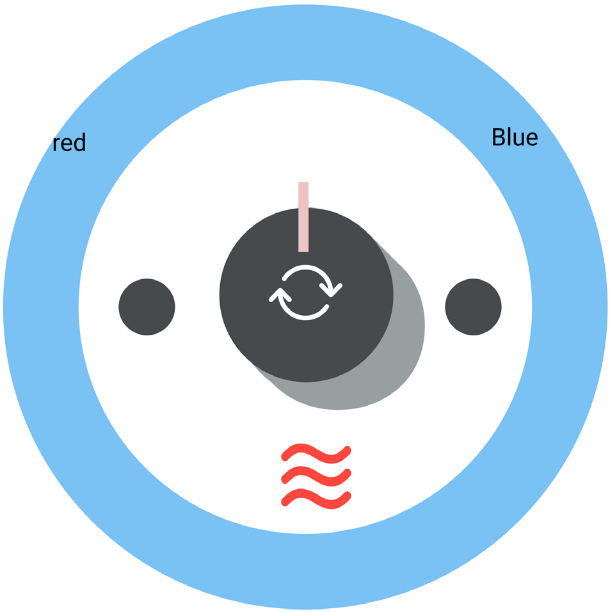
You should not think too much, you can just do it in a very quick way.

Set a timer on the LEDS, they start flashing every one hour, this is a reminder for users to give their thermal sensation input.
After user push one of the button (rainbow), all the lights stop flashing.

The rotary encorder can help users to adjust windspeed.

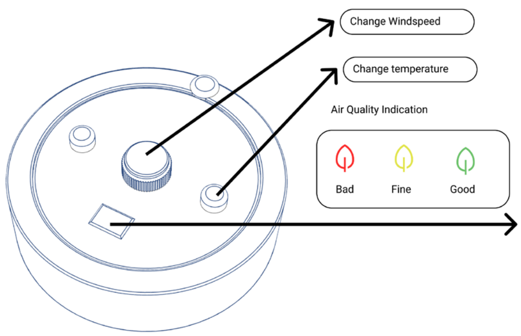
The “handfan’ shape gives me an impression that is a UI for adjusting cooling. not heating,

participant 6 Concept Sketch



In beginning there is no color, when I touch the light bar,the color and motion follows my finger, Color transforming with the finger motion (position + direction)

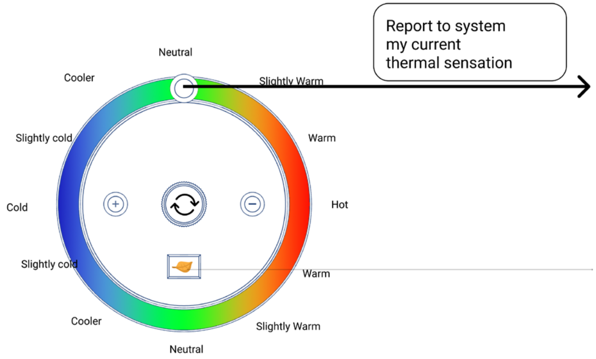
participant 6 3D Model



I don’t like using emoji, because it gives me kind of ‘social media’ feeling, I want to have a simple and ‘serious, neat and clean’ looking interface on my table.

In terms of machine learning, I think the system should also record how long I stay ‘hot or warm’

I like IPad circle ring, I like the sensation of the materials

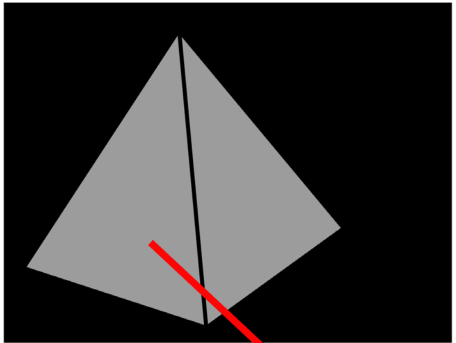


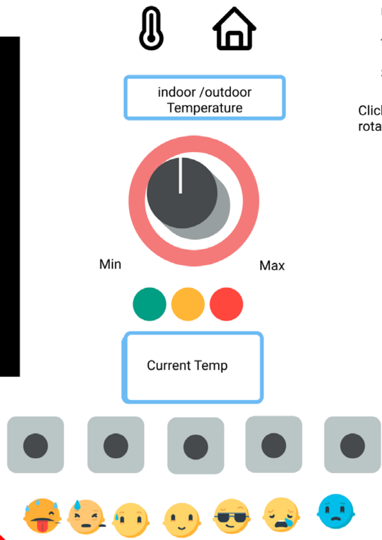
participant 7 Concept Sketch

Too Hot,
slighlt too warm,
netural,
slightly too cold
too cold

Self-report

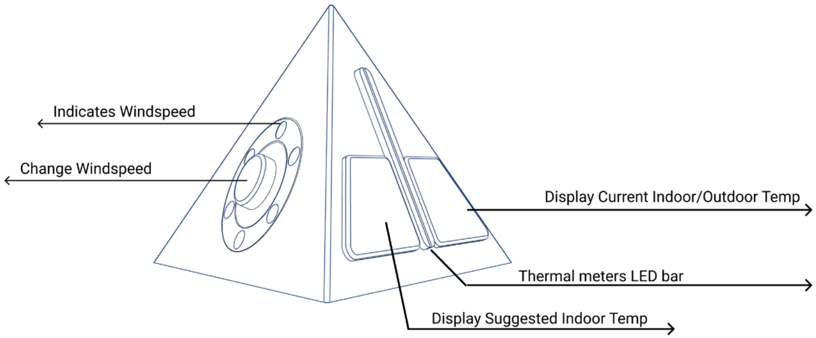
Click- turn off light,
rotating- changing light density

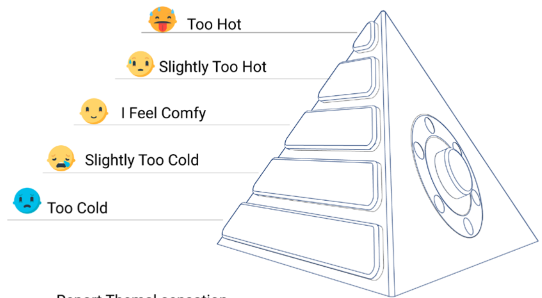




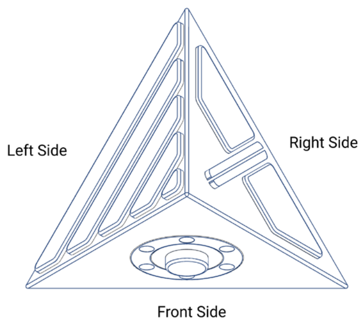
Front : dial to
windspeed
2id: data display
(paramters)
3rd: Feedback side
(report thermal
sensation)

participant 7 3D Model

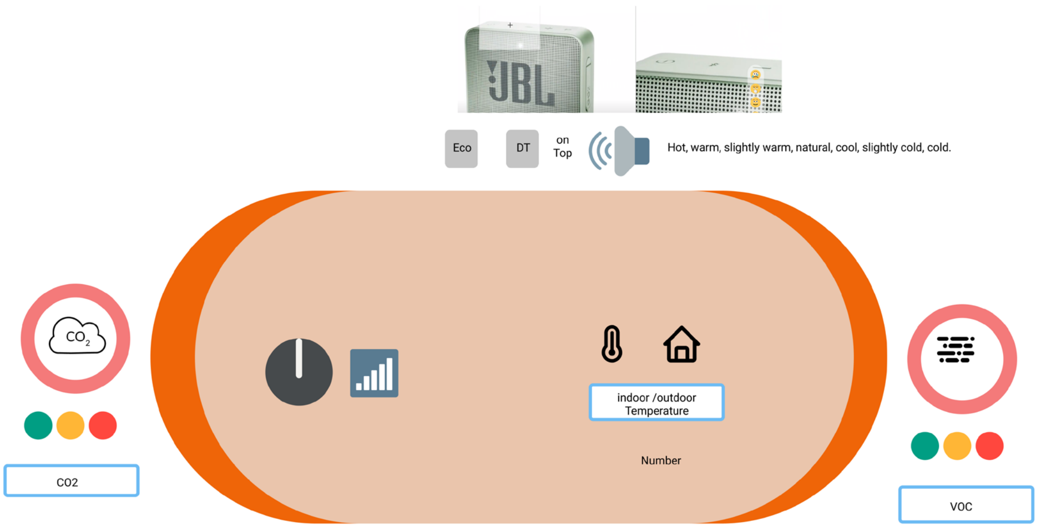




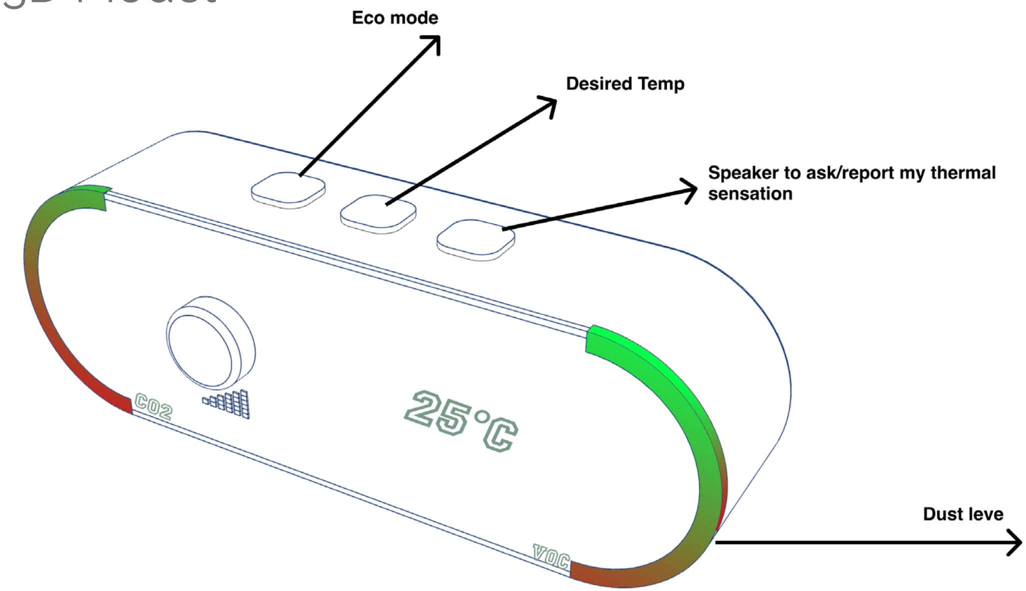
Report Themal sensation

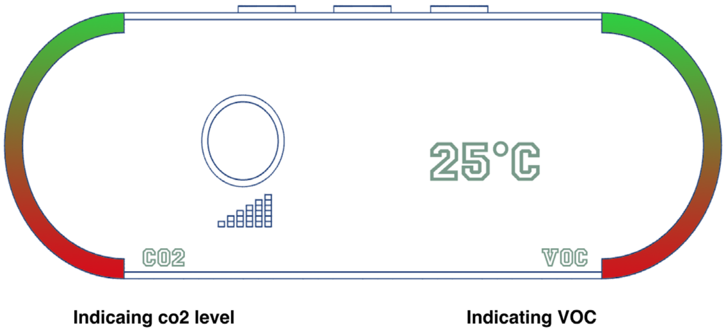


participant 8 Concept Sketch



participant 8 3D Model



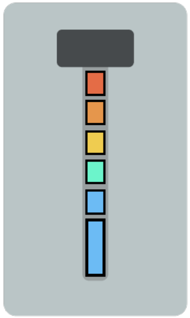


participant 9 Concept Sketch

trasnslate these numerical data to a piece of suggestion. and somehow by some means inform me. (pictogram) it is more zhi guan (intrusive)

Current Temp

I don’t want to see suggest temperature, I don’t feel like to receive such kind of information



25du

Knowing about windspeed is not importrant for me, I onlyt want to get the suggusted temperature by me (not system)

I don;t want to change windspeed, I only want to change the temeprature around me.

Predict Temp from system

If you change follow the suggested temperature, it willl be good for environment, (reward system, 如果　我只能有什么用，我会接受的)

工作上去解　的方法

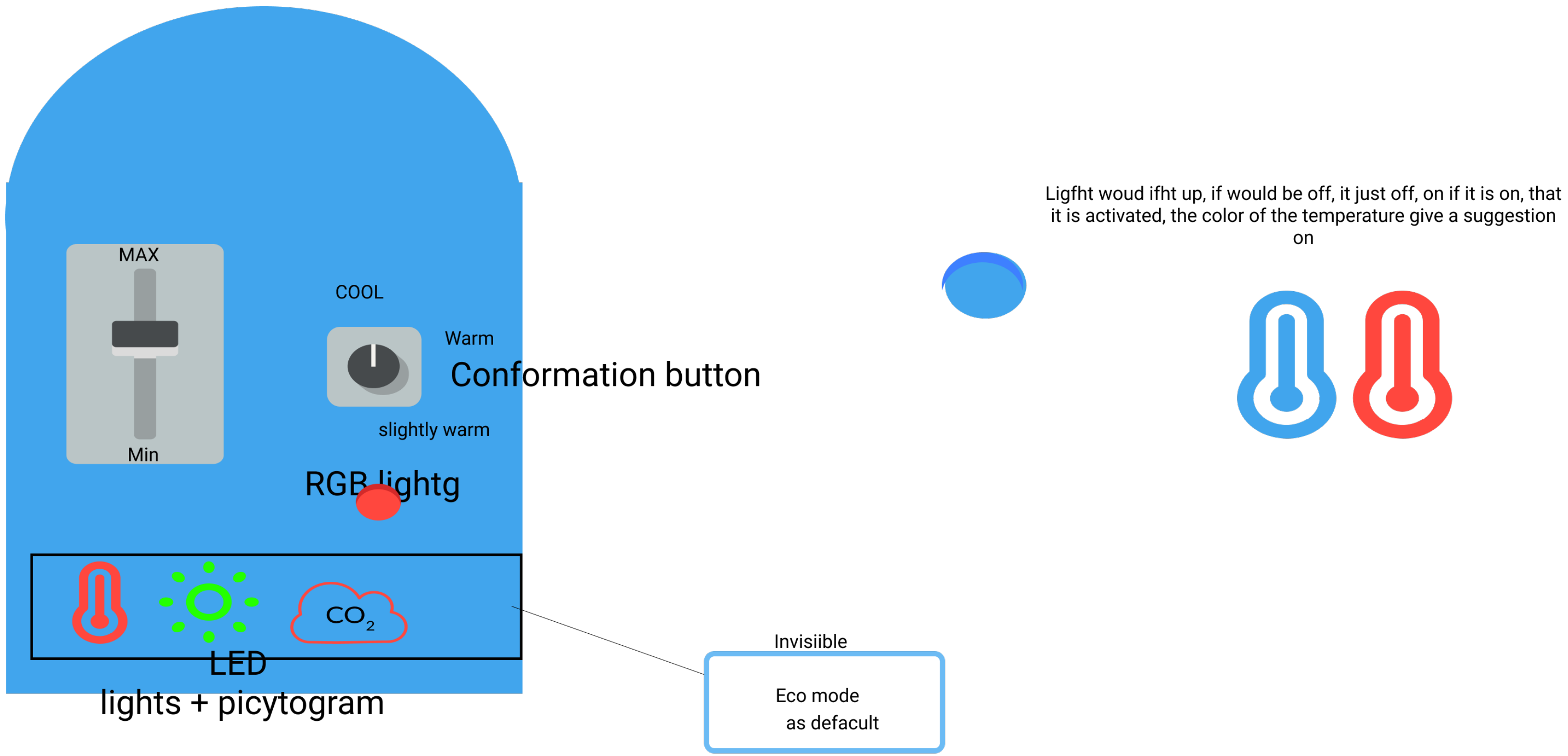
Air quality

Humidity

indoor /outdoor Temperature

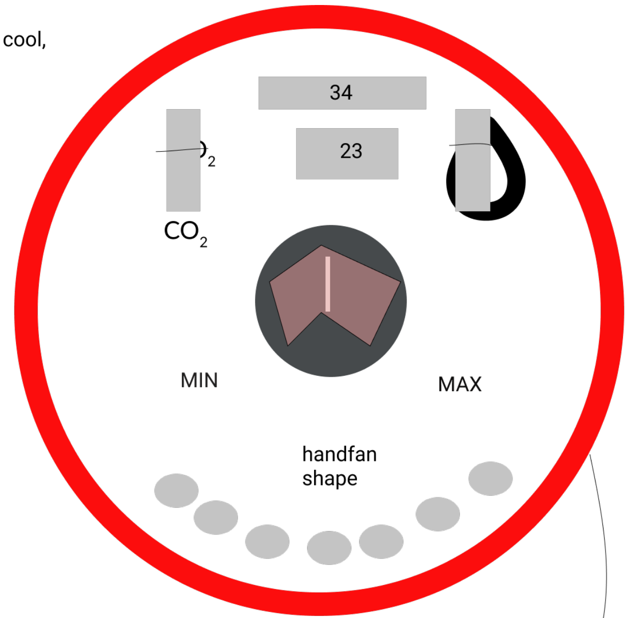
The reason why I pirchased your project is because I am buying ther sercices, not to give in extra effort to serive you.

participant 10 Concept Sketch



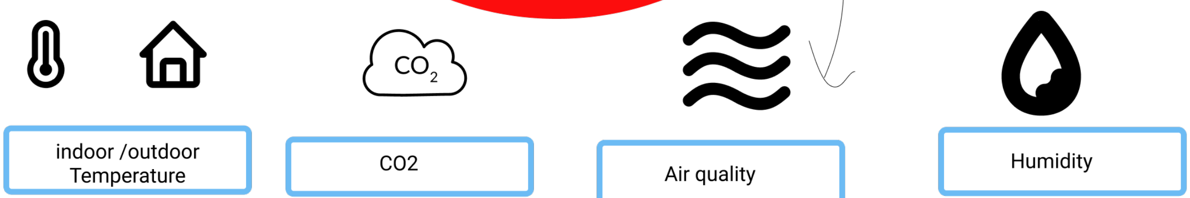
participant 11 Concept Sketch

Hot, warm, slightly warm, nautural, cool, slightly cold, cold



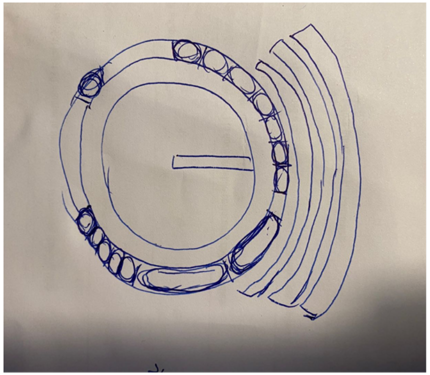
I like a round shape interface, not with a sharp edge

using sound to remind me that Every one hour give an input, if i forgot, remind me in 5 minutes, not more than that

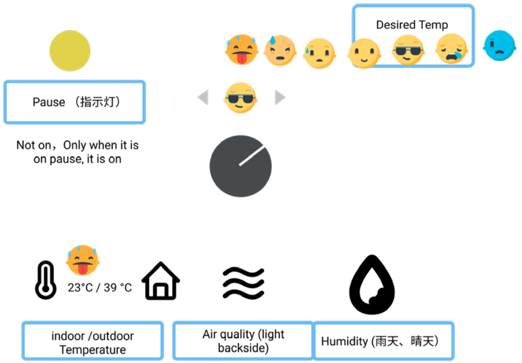


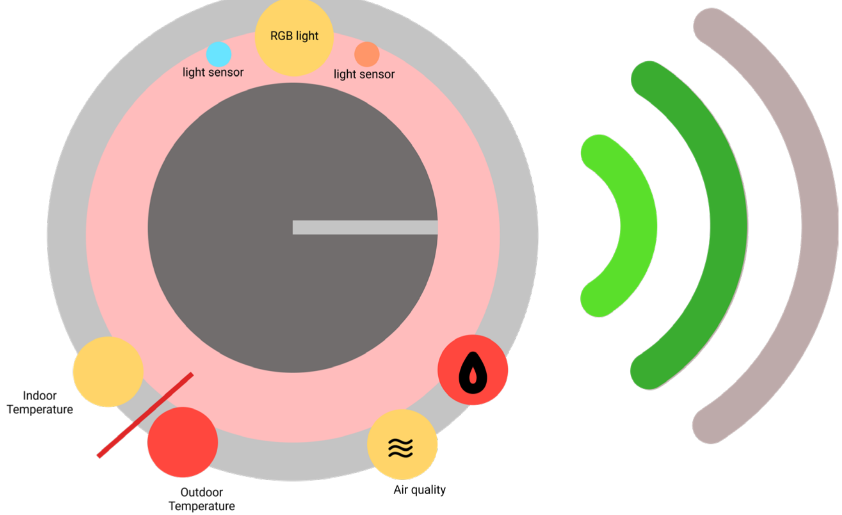
using three colors to distinguish the quality quality

participant 12 Concept Sketch



Hot, warm, slighly warm, natural, cool, slightly cold, cold





Evaluate 8 concepts by using the Interaction Frogger Framework.

This framework was informed by the theoretical notion of Gibson's ecological perception and embodied interaction, and inspired by phenomenology and pragmatism. The framework was developed based on philosophy notions, aims to offer a practical way for designers to explore and create intuitive and aesthetic interaction [Weesveen, 2012].

Feedback & Feedforward analysis

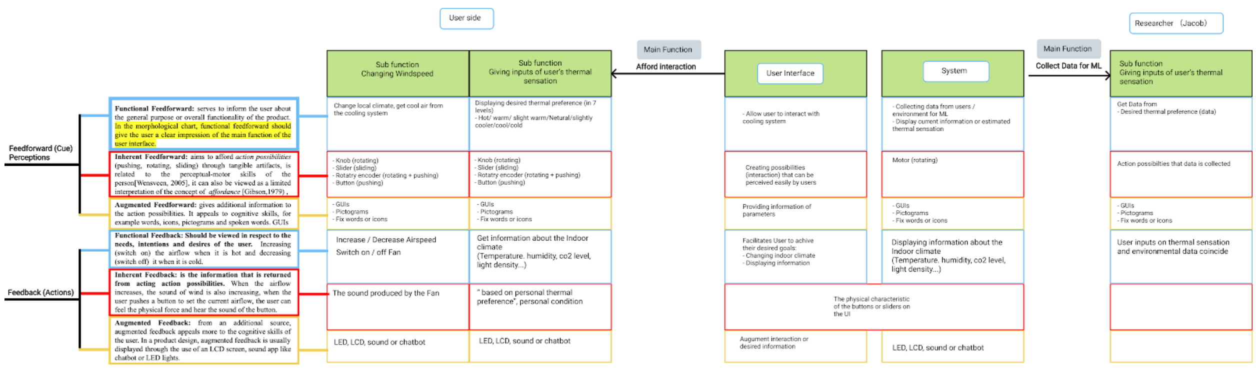


Figure 1: Feedforward & Feedback Analysis for designing UI for personal cooling system

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Mapping and Coupling Action and Perception

The **feedforward** determines the perception, it happens before the interaction, it usually serves to generate "the first impression" for users before they start to use it. And the **feedback** determines the action, it usually occurs during or after the interaction. To create natural mappings between action and perception (feedback and feedforward), 6 aspects should be applied:

Six aspects:

- Time (When does it happen, how long does it take?)
- Location (Where does it happen, micro or macro level)
- Direction (Translation or rotation? Max-min? Left-right? Up-Down? Towards-away? Back-forth, in-out?)
- Modality (Can it be seen? Heard? Touched? Smelled? Tasted?)
- Dynamics (What is the speed, acceleration, force?)
- Expression (What does it express? Warm-cold? Old-young? Open-closed? Does it have rhythm, tempo?)

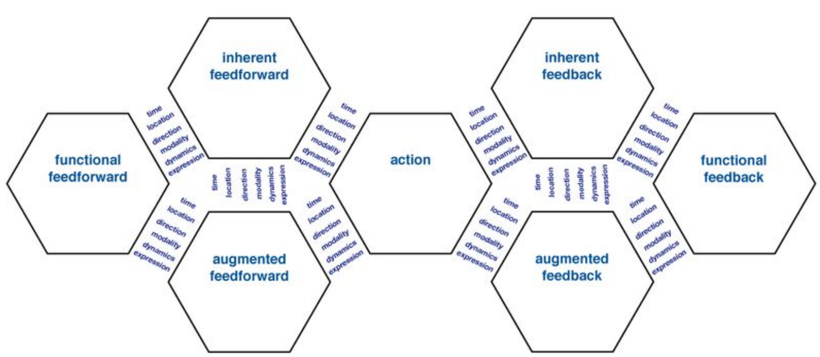

Figure 2:Interaction Frogger Framework, showing all theoretically potential mappings between the action and the elements of perception (feedforward and feedback)

Concept 1

Participant Quotes:

1. “ I think to change airspeed, I like to have a sliding action (possibilities), because for me it is easy to understand, up is to increase speed, down is to decrease speed.”
2. “ The front part can show the change of wind speed, I like to have three different levels (light colour), by using different blue light to indicate the different level (wind speed).”
3. “For me, I like the interface to be a playful object on my table, **easy but not crazy.**”

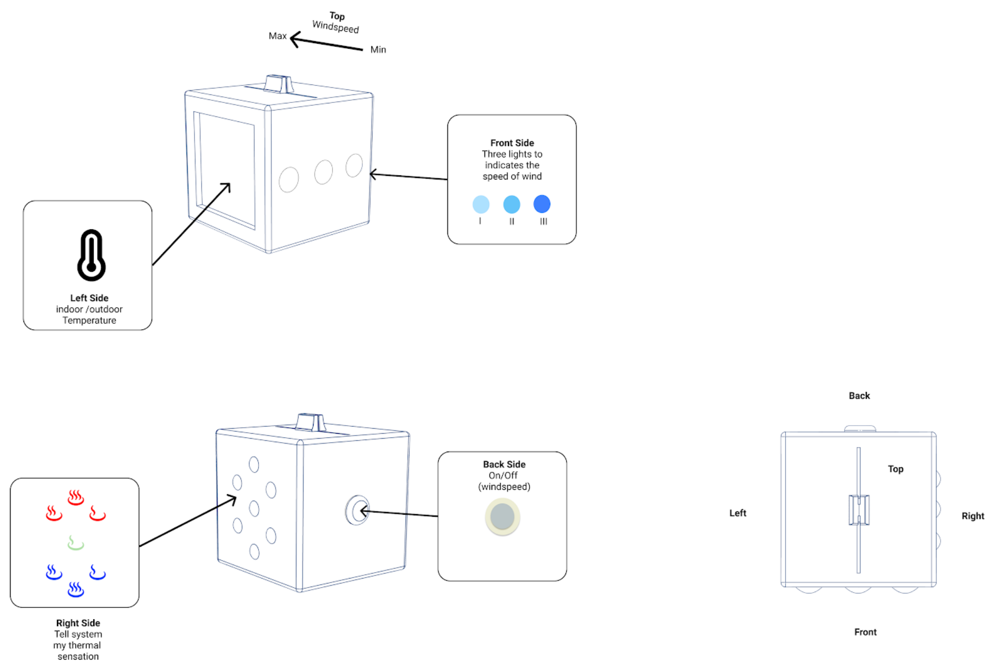

Figure 3: Concept 1

<table>
<tr><td colspan="2">Required Functionalities:
1) TOP: Change airspeed
2) LEFT: Report thermal Sensation
3) FRONT: Indicating airspeed by using lights
4) RIGHT: LCD screen to display Temperature
5) BACK: Switch On/Off</td></tr>
<tr><td>Positive Aspects:
- Coupling between Slider and three LEDs is natural. When sliding up, airspeed goes up, different LEDs react and inform the user which speed is currently being used.</td><td>Negative Aspects:
- Functional feedforward is weak. It cannot inform the user about the overall functionality of the product.
- The overall image of this UI doesn’t look like a UI for a personal cooling system.</td></tr>
</table>

Table1: Concept 1 analysis

Concept 2

Participant Quotes:

1. " I like to have a button that can directly jump at fast speed"
2. " I like every button has its own specific function, and I also would like to know more information like air quality, current temperature and suggest temperature"
3. "The suggested temperature for me should be something like after some weeks learning of my inputs, the system should be able to suggest a temperature that would be the most comfortable for me, and then I will change the wind speed to get that temperature for me"

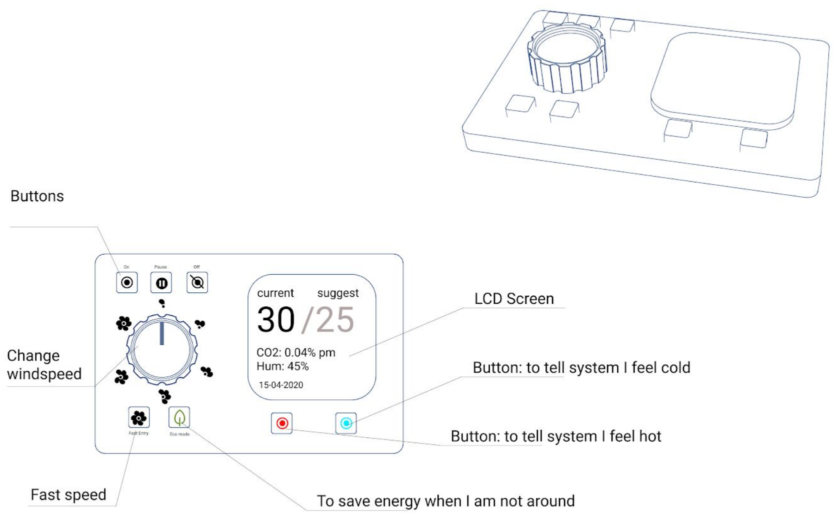

Figure 4: Concept 2

<table>
<tr><td colspan="2">Required Functionalities:
Front:
1. Change airspeed
2. Report thermal Sensation
3. LCD screen to display Temperature, suggested temperature, co2 and humidity
4. Acceleration
5. On/off
6. Eco-mode
7. Pause</td></tr>
<tr><td>Positive Aspects:
- Standardised 'thermostat' looking, which helps to create a clear image of what this UI does. (The participant has a medical background, without a design background, the assumption is that she is used to interact with a device with a flat screen.)
- Function feedforward is relatively strong.</td><td>Negative Aspects:
- Abuse the user's cognitive skills. ("There are too many buttons, too complicated")
- Too much information is displayed on the LCD screen (overkill on Inherent feedforward/feedback), users can't interact with the screen. It is only a display.
- Self-report on thermal sensation level is limited.</td></tr>
</table>

Table2: Concept 2 analysis

Concept 3

Participant Quotes:

1. " I can't tell the difference between warm and slightly warm, but I think if I can tell the system how happy I am with the current indoor temperature, that will be really fun to do "
2. " If I can receive a message from the system that asks me if I feel comfortable or not, but I prefer to receive such a message like a quick notification on my laptop. "
3. " I think icons are self-explanatory, but I also want to know the current indoor temperature"

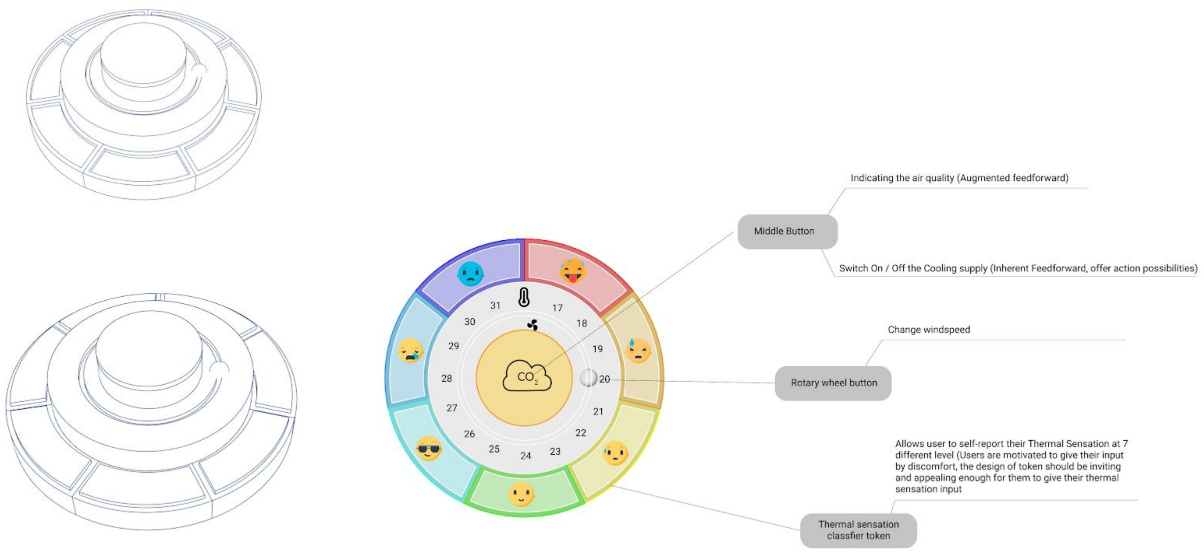

Figure 5: Concept 3

<table>
<tr><td colspan="2">

Required Functionalities:
Front:
1. Change airspeed
2. Report thermal Sensation
3. Display Temperature
4. Display airspeed (Glowing light inside of the middle button)
5. Switch on/off
</td></tr>
<tr><td>
Positive Aspects:
- Translate a user's thermal sensation to different emotions, which is considered to be an easy way to motivate them to give user input.
- A respectful way in terms of collecting user's data. They don't feel like it is a duty to feed their inputs to the system.
- Functional feedforward is strong.
</td><td>
Negative Aspects:
- The use of emoji (personally I think) is a bit childlike. I am not sure if office workers like to have such UI on their working table.
</td></tr>
</table>

Table3: Concept 3 analysis

Concept 4

Participant Quotes:

1. I don't like using emoji, because it gives me a kind of 'social media' feeling, I want to have a simple and 'serious, neat and clean' looking interface on my table.
2. In terms of machine learning, I think the system should also record how long I stay 'hot or warm'
3. I like IPad circle ring, I like the sensation of the materials
4. I can't interpret numbers, but I know green light means good air quality, red means bad air quality

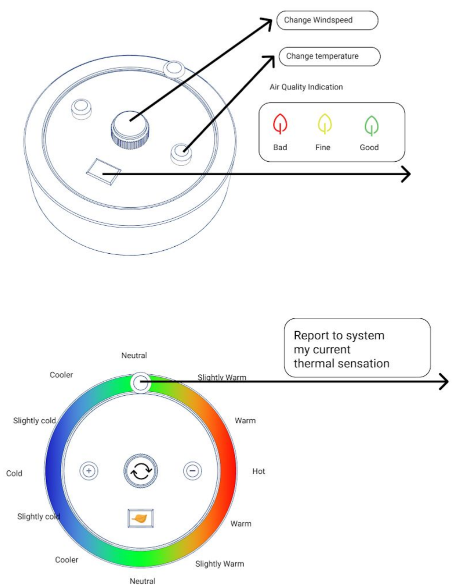

Figure 6: Concept 4

<table>
<tr><td colspan="2">Required Functionalities:
Front:
1. Change airspeed
2. Change temperature
3. Display airspeed
4. Switch on/off
5. Display air quality</td></tr>
<tr><td>Positive Aspects:
- The functional feedforward is strong,</td><td>Negative Aspects:
- There is no display for temperature
- The user wants to change the room temperature by using a personal cooling system. , this seems too hard to achieve.</td></tr>
</table>

Table4: Concept 4 analysis

Concept 5

Participant Quotes:

5. (change airspeed) You should not think too much, just do it in a quick way.
6. Set a timer on the LEDs, they start flashing every one hour, this is a reminder for users to give their thermal sensation input.
7. After the user push one of the buttons (rainbow), all the lights stop flashing.
8. The “hand fan’ shape gives me an impression that is a UI for adjusting cooling, not heating.

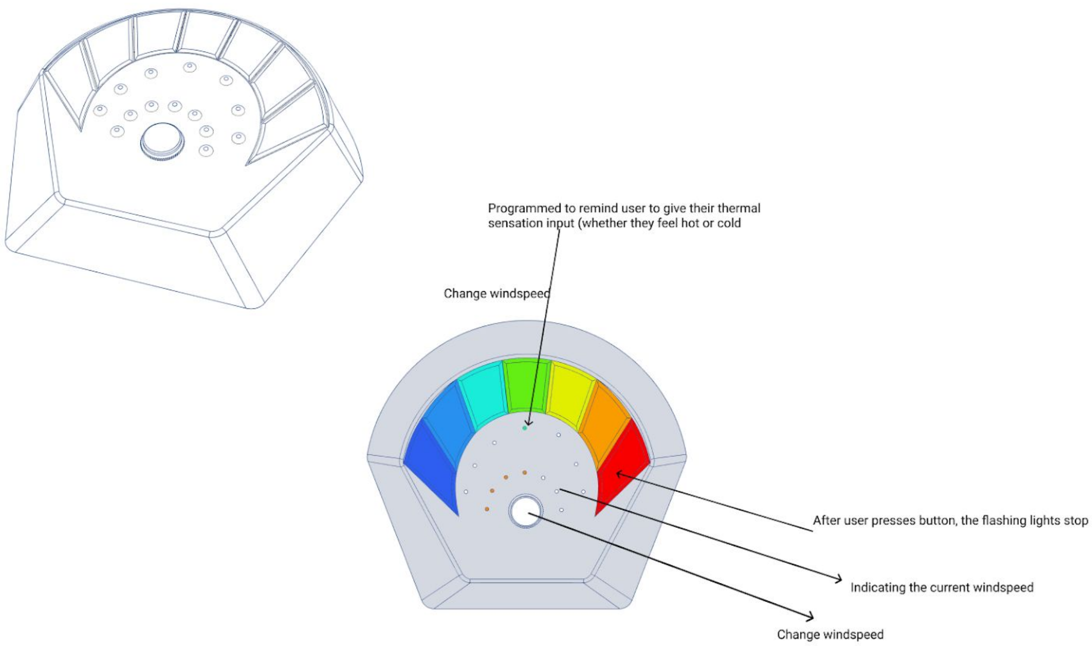

Figure 7: Concept 5

<table>
<tr><td colspan="2">Required Functionalities:
Front:
1. Change airspeed
2. Report thermal sensation
3. Display airspeed
4. Switch on/off</td></tr>
<tr><td>Positive Aspects:
- Functional feedforward is strong, the shape of this UI needs more adjustment to be a hand-fan looking.</td><td>Negative Aspects:
- There is no display for temperature</td></tr>
</table>

Table5: Concept 5 analysis

Concept 6

Participant Quotes:

1. “There should be a clear division of primary function and sub-function.”
2. “On the aesthetics part, I suggest you follow the golden ratio.”
3. “It should be very easy to use, for me adjusting airspeed, turning it on and off are enough. “

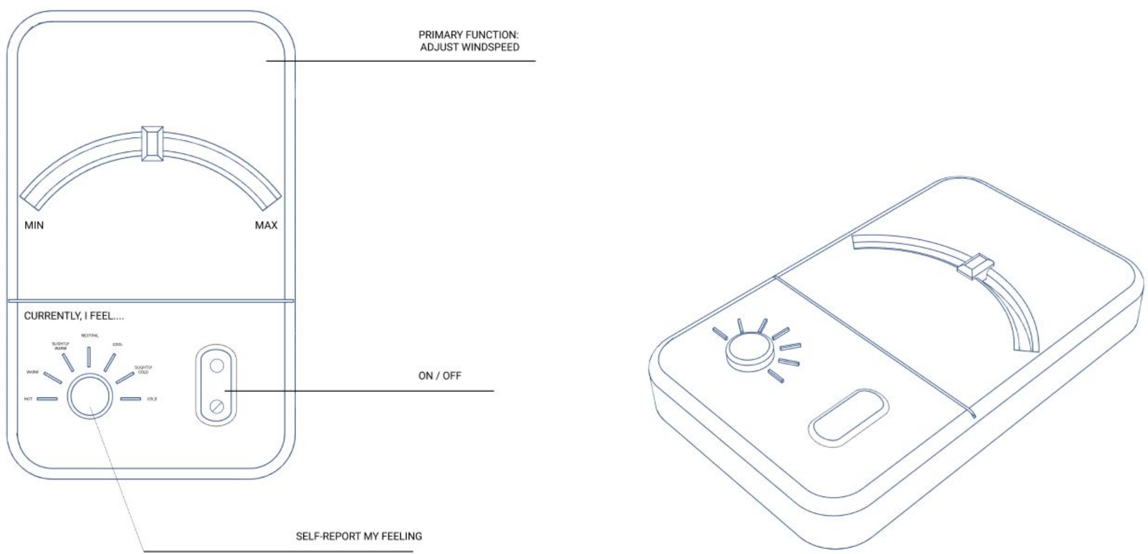

Figure 8: Concept 6

<table>
<tr><td colspan="2">Required Functionalities:
Front:
1. Change airspeed
2. Report thermal Sensation
3. Switch on/off</td></tr>
<tr><td>Positive Aspects:
- The “golden ratio” is a good design suggestion.
- Very easy to understand what this UI does, which means the functional feedforward is strong.</td><td>Negative Aspects:
- There is no display for temperature</td></tr>
</table>

Table6: Concept 6 analysis

Concept 7

Participant Quotes:

1. “Each side should have a clear functionality”
2. “You should have only five degrees on thermal sensation, sometimes slightly warm or slightly cold is also comfortable for me, you need to rephrase to slightly too hot or war, ”
3. “if you put buttons that low on the base it either needs to be quite heavy, or the thing will need anti-slip foam on the bottom”

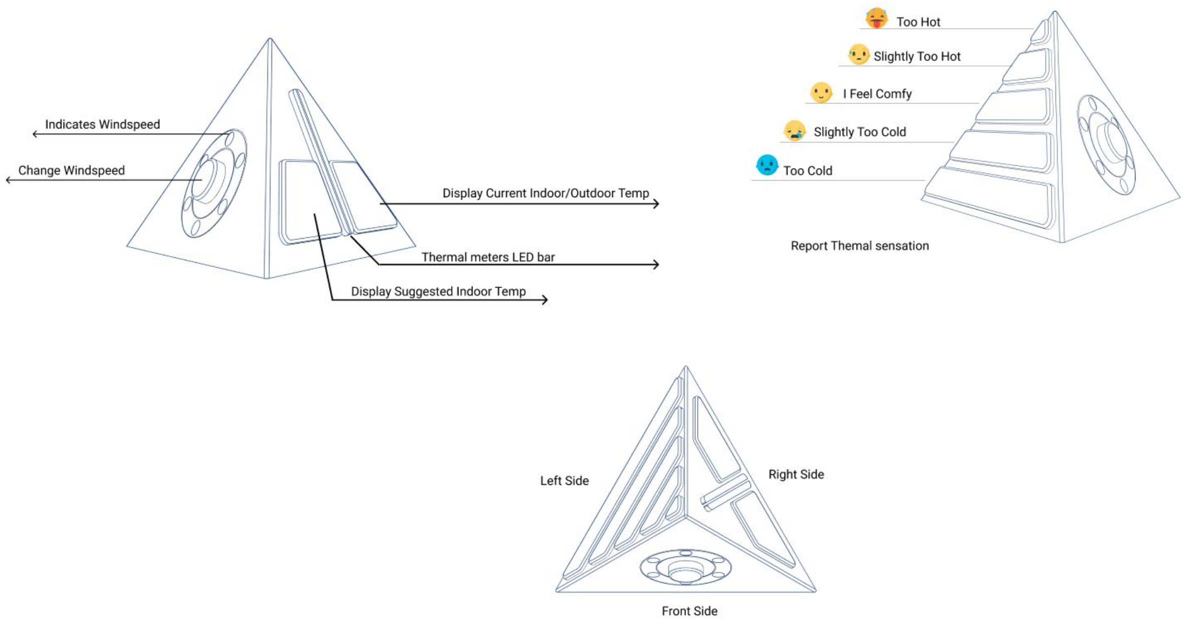

Figure 9: Concept 7

<table>
<tr><td colspan="2">Required Functionalities:
Front:
1. Change airspeed
2. Report thermal Sensation
3. Switch on/off
4. Display indoor temperature & suggested temperature on the LCD screen</td></tr>
<tr><td>Positive Aspects:
- Stable</td><td>Negative Aspects:
- Not comfortable to interact with, the design is not persuasive to use.</td></tr>
</table>

Table7: Concept 7 analysis

Concept 8

Participant Quotes:

1. “ There should be a speaker inside and asks me if I feel comfortable or not”

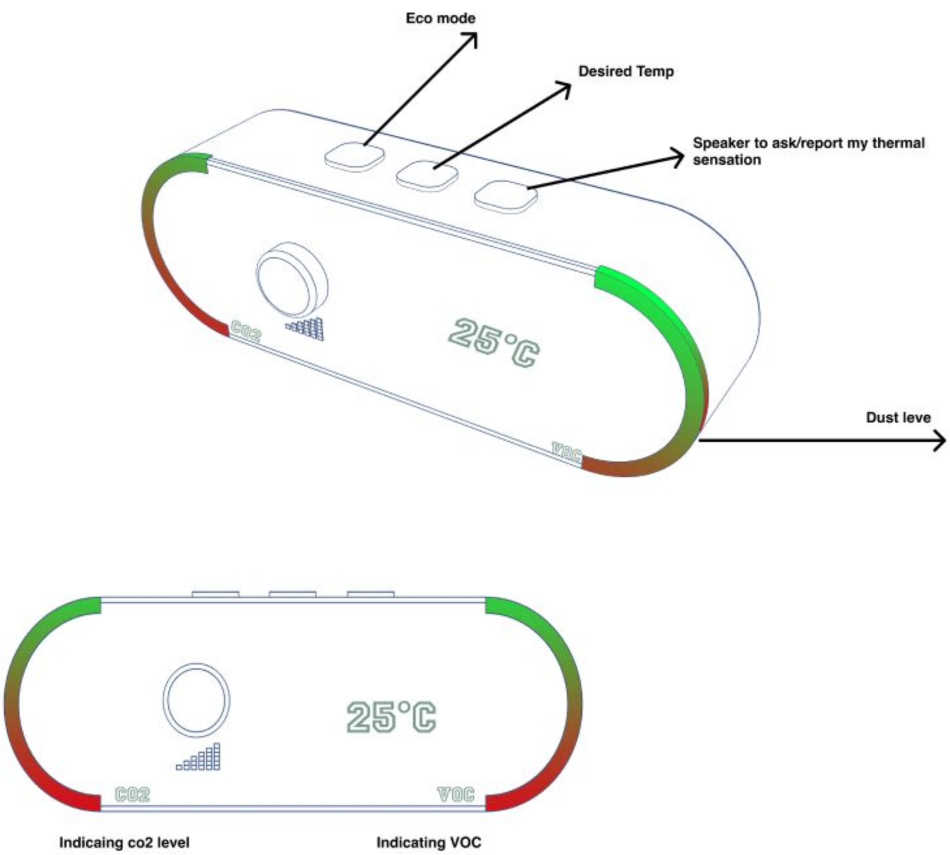

Figure 9: Concept 8

<table>
<tr><td colspan="2">Required Functionalities:
Front:
1. Change airspeed
2. Report thermal Sensation
3. Switch on/off</td></tr>
<tr><td>Positive Aspects:
- Balance looking, systemic and less distractive</td><td>Negative Aspects:
- Misleading impress (functional feedforward), it looks like a speaker/alarm to me.</td></tr>
</table>

Table8: Concept 8 analysis

Table 1: Tasks Division, inspired by co-performance

From the Questionnaire	
Top 3 tasks should be performed by Users: **1) Change airspeed** **2) Control airspeed when it is needed*** **3) Switch on / off the system** **We envision that users can still change airspeed in some strict situations (eco-mode) which means the user's cooling demand is above programmed rules.*	**Top 3 tasks should be performed by System:** **1) Display indoor temperature** **2) Activate eco or energy-saving mode** **3) Display outdoor temperature**

Table 9: Tasks Division

Functionalities

From the Questionnaire	
TOP 3 Desired functionalities: **1) Change airspeed (95% agreed)** **2) Display indoor temperature (90% agreed)** **3) Presence detection (83% agreed)** 4) Display Outdoor temperature 5) Display CO2 level	**Top 3 High acceptance of shared data:** **1) Temperature & Humidity (93% agreed)** **2) Co2 Level (85% agreed)** **3) Light intensity (80% agreed)** 4) TOVC 5) Presence detection
From the Interviews (co-design)	
Some functionalities mentioned during the interviews (not in the questionnaire) : **1) Display Air Quality (***I can't interpret numbers, but I know green light means good air quality, red means bad air quality'* | **Concept *3,4,8*)** **2) Quick Acceleration (** *If I just arrive at my workplace, I want to have a button allows to jump to most fast speed* |**Concept *2*)**	**Data to facilitate machine learning** Collect personal data to determine their thermal sensation: : **Self- Report Thermal sensation by** **a)** 7 tangible buttons **(concept 1,5)** **b)** 7 emotions **(7 buttons concept 3)** **c)** 5 emotions **(remove 'slightly cold/warm options, concept 7)** **d)** 2 buttons **(I feel cold/warm or comfortable or uncomfortable, concept 2)** **e)** 1 rotary encoder **(concept 4,6)**

Table 10: Functionalities combined from the questionnaire and Interviews

Conclusion:

From Table 9, we could see that the user likes to have more controls over the airspeed (also in some strict conditions like eco-mode). These are the parameters can be set by the user. These parameters aim to create thermal comfort for users.

The UI should take responsibilities to inform Indoor air temperature to users, as well as reduce the energy consumption of the local cooling system.

Conclusions can be drawn based on table 2 that the parameters communicated to users are indoor air temperature, CO_2 and light intensity. However,

1. Displaying CO2 level is the least desired function (result from the questionnaire), from the interviews we learned that some users have limited experience with interpreting or understanding the numerical information of environmental parameters, they like to apply their cognitive skills in order to interpret air quality. Three concepts from the interviews mentioned CO2 or Air quality on UI
   - Participant 3: "High-level co2 is bad for my health, so I want to have some fresh ventilation"
   - Participant 4: "I can't interpret numbers, but I know green light means good air quality, red means bad air quality"
   - Participant 8: " I like to see this information because I am always aware of the air quality in my office room"
2. Displaying light intensity was not required at all during all the co-design & interview sessions, it is likely that this parameter has a higher acceptance to be shared with the system, but plays a limited role in terms of communicating with users.

Presence detection should be also included, however, there is a disagreement on this function in terms of data collection because it is clear that users have the lowest acceptance on it.

The self-report thermal sensation is important to facilitate machine learning. Based on the earlier findings from the pilot test, users are only motivated to give their input by discomfort. Therefore it is difficult to motivate them to report or log their thermal sensation unless there is a strict demand. Based on the interviews and co-design sessions, we found three potential solutions:

1) Reduce interaction steps that are needed, ensure the self-report function is easy and fast to achieve;
2) Report emotions instead of thermal sensations
3) Add a reminder (notification or sound alarm)

Both presence detection and self-report thermal sensation should be designed in a non-obstructive way.

Conclusion in short:

Parameters can be set by the user	Parameters are communicated to users
1) Airspeed **2) On/Off** **3) Thermal sensation (emotions)** **4) Their presence**	**1) Indoor air Temperature** **2) Air Quality**

Design brief:

First of all, the overall image should give the user a good "first impression" (Strong functional feedforward) that this UI is designed for adjusting and changing indoor temperature, three main functions should be designed on this UI which allow users to give their inputs:

1) Changing airspeed
2) Switch on/off
3) Self-report thermal sensation

The UI should display two parameters as they impact the user's cooling demand and behaviours.

1) Temperature
2) Air quality

The following criteria should be considered:

1. Simplicity

How easy for you to understand what this user interface does, without further explanation (menubook) about functionalities. (Strong functional feedforward/ inherent feedforward and augmented forward)

2. Ergonomic

Imaging using this interface with one hand, how comfortable if you want to achieve certain functionalities, like change wind speed (Most of the users like to have one-hand, all-in-one UI, the tactile sensation of using the material, the effect that is needed)

3. Low-profile

Less distractive, the user interfaces nicely blend into an office environment.

4. Aesthetic

The appropriate appearance in terms of form, colour and size (e.g. symmetric shape or balanced looking)

5. Usability

Achieve certain functionalities quickly and naturally, UI collects data in a non-obstructive way. The coupling between action and function is perceived as natural and direct.

Decision Matrix

The highest is 5 and the lowest score is 1. Please give each concept a score in terms of the 5 following criteria.

Concept	Simplicity	Ergonomic	Low-profile	Aesthetic	Usability
1					
2					
3					
4					
5					
6					
7					
8					

```
//**************************************************************
// **********************LIBRARY************************
//**************************************************************
#include <RotaryEncoder.h>
//To support rotory encoder funtions, Set limitations on the rotation
//https://github.com/mathertel/RotaryEncoder

#include <SimpleRotary.h>
////https://github.com/mprograms/SimpleRotary
////To support click funtion, or longpush function

#include <FastLED.h>
//https://github.com/FastLED/FastLED
//To support LED Strip, changing color, or fading, transiting colors

#include <analogWrite.h>
#include <Arduino.h>
//https://www.arduinolibraries.info/libraries/esp32-analog-write
//ESP Wemos LILON doesn't have analog write function, this library provides an analogWrite polyfill for ESP32 using the LEDC functions

#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <DHT_U.h>
//https://github.com/adafruit/DHT-sensor-library
//To support DHT sensor (temperature & humidity)

#include <Wire.h>
#include "Adafruit_SGP30.h"
//https://github.com/adafruit/Adafruit_SGP30
//SCL connected to pin 22 on ESP32
//SDA connected to pin 21 on ESP32
//To support SGP 30 CO2 sensor

//**************************************************************
// **********************OOCSI SETUP************************
//OOCSI is used to collect data and send on DF for the development of ML.

#include "OOCSI.h"
// use this if you want the OOCSI-ESP library to manage the connection to the Wifi
// SSID of your Wifi network, the library currently does not support WPA2 Enterprise networks
const char* ssid = "Notsecurenetwork1";
// Password of your Wifi network.
const char* password = "Taiyuan1#";

// name for connecting with OOCSI (unique handle)
const char* OOCSIName = "CoolingstatTestVersion1";
// put the adress of your OOCSI server here, can be URL or IP address string
```

```
const char* hostserver = "oocsi.id.tue.nl";
// OOCSI reference for the entire sketch
const char* CHANNELName = "Coolingstat";
OOCSI oocsi = OOCSI();


//**************************************************************
// *********************OOCSI SETUP***********************
//The color arrangement of the two LED bars on the UI.

//from green to yellow to red
CRGB colorTransitionCO2[] =
{0x009444,0x319142,0x4A8E40,0x5C8B3E,0x6B873C,
0x79833A,0x847E38,0x907A35,0x9A7533,0xA56F31,
0xB9622D,0xCD4F29,0xD74327,0xE13426,0xED1C24};

//from red to blue
CRGB colorTransitionTemp[] =
{0xED1C27,0xD44C3E,0xD44C3E,0xC85A4B,0xBB6659,
 0xAD7065,0x9F7972,0x8F807F,0x7E888D,0x698F9B,
0x4C95AA,0x0B9CBA,0x00A1C9,0x00A7DA,0x00AEEF
};

//**************************************************************
// *********************Rotary Encoder************************
//Define the limitations of the rotary encoder, in this file, there are 7 steps, each steps could control certain airspeed.
// *PIN 34, 35 are used, these two pins don't have internal pull-ups or pull-down resistors. They can't be used as outputs
#define ROTARYSTEPS 1
#define ROTARYMIN 0
#define ROTARYMAX 7
RotaryEncoder encoder(34,35);
SimpleRotary rotary(34,35,39);



//**************************************************************
// ***************************LED RINGS ***********************
//Three LED strips are defined here, PIN_IN == airspeed indicator, PIN_Temp == temperature indicator, PIN_CO2 == co2 level indicator.
#define LED_PIN_IN 15  //灯环
#define NUM_LEDS_IN 8 //灯数
CRGB leds_IN[NUM_LEDS_IN];
#define BRIGHTNESS_IN        5
uint8_t gHue_IN = 0;

#define LED_PIN_Temp 14  //灯环
```

```
#define NUM_LEDS_Temp 15 //灯数
CRGB leds_Temp[NUM_LEDS_Temp];
#define BRIGHTNESS_Temp         5
uint8_t gHue_Temp = 0;

#define LED_PIN_CO2 27  //灯环
#define NUM_LEDS_CO2 15 //灯数
CRGB leds_CO2[NUM_LEDS_CO2];
#define BRIGHTNESS_CO2          5
uint8_t gHue_CO2 = 0;



//*****************************************************************
// *********************Cooling Fan****************************
//The big cooling fan and internal fan are defined here, the PIN 19 can switch on and off the cooling fan,
//The relay is to control the internal fan.
int fanValue = 0;
const int fanStop = 19;//on/off
const int fanSpeed = 25;//airspeed DAC input
const int RELAY_PIN = 26;
//switch on the internal fan, the internal fan is place in the back side of UI,
//two sensors are placed in the front, behind the air inlet.
//This ensure the fresh air is getting renewed around sensor area, which ensures the accuracure of the measurement.



//*****************************************************************
// *********************TS Buttons****************************
//Thermal sensation buttons, allows users to self-report their themal sensation, 7 buttons are assigned based on CBE ASHRAE 7 scale thermal sensation.
//https://comfort.cbe.berkeley.edu/compare ( cold, cool, slightly cool, neutral, slighly warm, warm, hot)

const int buttonPin1 = 2;//Blue light, cold
const int buttonPin2 = 36;//Ble light,cool
const int buttonPin3 = 4;//green light, slightly cool,
const int buttonPin4 = 16;//White light, Neutral
const int buttonPin5 = 17;//Yellow light,warm
const int buttonPin6 = 5;//red light, slight warm
const int buttonPin7 = 18;// red light, hot

int button1State = 0;
int button2State = 0;
int button3State = 0;
int button4State = 0;
```

```
int button5State = 0;
int button6State = 0;
int button7State = 0;



//LEDs on three buttons (neutral, slightly warm and warm, these three lights allows system to
anticipant the predictions of sugguested thermal sensation.
const int ledPinNeutral = 33; //White light -----> I feel neutral (temp range: 24-30)
const int ledPinSWarm = 23;//Yellow light ------> I feel slightly warm (temp range: 30-35)
const int ledPinWarm = 32;//red light -------> I feel warm (temp rang: 35-39)



//****************************************************************
// *********************rotary encoder ****************************
//
int newPos = 0;
long sendDataTime = 0;
int lastPos = 0;


//****************************************************************
// *********************PIR ****************************
//PIR sensor, to activate the system after it detects movement.
int inputPin = 12;             // choose the input pin (for PIR sensor)
int pirState = LOW;            // we start, assuming no motion detected
int val = 0;


//****************************************************************
// *********************DHT sensor****************************
//****************************************************************
#define DHTPIN 13     //Define PIN 13 as the input pin
#define DHTTYPE    DHT11     // DHT 11
DHT_Unified dht(DHTPIN, DHTTYPE);
//int temperature = event.temperature;
float Temperature = 0;
float Humidity = 0;



//****************************************************************
// *********************CO2****************************
//****************************************************************
Adafruit_SGP30 sgp;
unsigned int eCO2;
uint32_t getAbsoluteHumidity(float temperature, float humidity) {
```

```
  // approximation formula from Sensirion SGP30 Driver Integration chapter 3.15
   const float absoluteHumidity = 216.7f * ((humidity / 100.0f) * 6.112f * exp((17.62f * temperature) /
(243.12f + temperature)) / (273.15f + temperature)); // [g/m^3]
   const uint32_t absoluteHumidityScaled = static_cast<uint32_t>(1000.0f * absoluteHumidity); //
[mg/m^3]
  return absoluteHumidityScaled;
}




//**************************************************************
// ********************SetUP***************************
//**************************************************************
void setup() {

// 2 seconds delay, for some reason, having a short delay ensure the system works better, I don't
know why:(
 delay (2000);
 Serial.begin(9600);

//TS buttons (Thermal sensation buttons setups)
 pinMode(buttonPin1, INPUT);//user needs to give input on this
 pinMode(buttonPin2, INPUT);
 pinMode(buttonPin3, INPUT);
 pinMode(buttonPin4, INPUT);
 pinMode(buttonPin5, INPUT);
 pinMode(buttonPin6, INPUT);
 pinMode(buttonPin7, INPUT);

 pinMode(ledPinWarm, OUTPUT); // system gives output to the users
 pinMode(ledPinSWarm, OUTPUT);
 pinMode(ledPinNeutral, OUTPUT);

//to intialize OOSCI library
  OOSCIInit();
//The mini cooling fan inside of the UI. this aims to
 pinMode(RELAY_PIN, OUTPUT);// interal fan as output
 pinMode(fanStop, OUTPUT);
 pinMode(fanSpeed, OUTPUT);

//PIR motion sensor
 pinMode(inputPin, INPUT);

//DHT Sensor
 dht.begin();
 sensor_t sensor;
 dht.temperature().getSensor(&sensor);
```

```
  dht.humidity().getSensor(&sensor);

//CO2
 if (! sgp.begin()){
   Serial.println("Sensor not found :(");
   while (1);
 }
  Serial.print("Found SGP30 serial #111");

//LED rings
  FastLED.addLeds<WS2812, LED_PIN_IN,GRB>(leds_IN,NUM_LEDS_IN);
  FastLED.setBrightness(BRIGHTNESS_IN);

  FastLED.addLeds<WS2812, LED_PIN_Temp,GRB>(leds_Temp,NUM_LEDS_Temp);
  FastLED.setBrightness(BRIGHTNESS_Temp);

  FastLED.addLeds<WS2812, LED_PIN_CO2,GRB>(leds_CO2,NUM_LEDS_CO2);
  FastLED.setBrightness(BRIGHTNESS_CO2);

// encoder
  encoder.setPosition(0); // start with the value of 10.

}


//*************************************************************
// ********************Loop functions************************
// Loop functions. run code all the time

// for PIR sensor, where you can set a timer on how long you want to keep the system working. in this case, I set one minute
long millisTriggered = 0;
long TSbuttonsmillis = -10*60*1000;
boolean turnOff = false;
long turnOffTriggered = 0;


void loop(){
  byte i;

  // 0 = not pushed, 1 = pushed, 2 = long pushed
  i = rotary.pushType(1000);


  if(!turnOff){
  pirsensor();
    if(millis() - millisTriggered < 30*(60000)){// the cooling fan, internal fan, sensors and LED indicators start working after the PIR sensor detects movements.
```

```
  airspeed();
  ledRingRotation();
//  pushtype();
  temp();
  CO2();
  TSbuttons();
//  TCP();
  digitalWrite(RELAY_PIN, HIGH);
//  digitalWrite(fanStop, HIGH);
  }else{
      digitalWrite(fanStop, LOW);//The cooling fan, internal fan stops working if there is no
movements are detected.
    digitalWrite(RELAY_PIN, LOW);
    digitalWrite(ledPinNeutral, LOW);
    digitalWrite(ledPinSWarm, LOW);
    digitalWrite(ledPinWarm, LOW);
    setAllLeds(0,0,0);//all LED turn off.
    setAllLeds1(0,0,0);
    setAllLeds2(0,0,0);
    }

 }

if ( i == 1 ) {
  if(turnOff){
    turnOff = false;
  }else{
      digitalWrite(fanStop, LOW);//The cooling fan, internal fan stops working if there is no
movements are detected.
    digitalWrite(RELAY_PIN, LOW);
    digitalWrite(ledPinNeutral, LOW);
    digitalWrite(ledPinSWarm, LOW);
    digitalWrite(ledPinWarm, LOW);
    setAllLeds(0,0,0);//all LED turn off.
    setAllLeds1(0,0,0);
    setAllLeds2(0,0,0);
    turnOffTriggered = millis();
    turnOff= true;
  }
}


  if ( i == 2 ) {
    Serial.println("Long Pushed");
    checkNetwork();// check network if it is connected, if it is not, the ESP board will restart.
  }

  if(millis() - sendDataTime > 8000){ //sent data on DF every 8 seconds.
```

```
 updateSensor();
 sendDataTime = millis();
   }


 if(millis()- turnOffTriggered > 60*1000) turnOff = false;
 FastLED.show();// to show the LED lights
 }



//***************************************************************
// *********************PIR Motion sensor *********************
// PIR sensor function | to detect motion of occupants.

void pirsensor(){
 val = digitalRead(inputPin);  // read input value
 if (val == HIGH) {           // check if the input is HIGH
  // if (pirState == LOW) {
    // we have just turned on
    //Serial.println("Motion detected!");
    // We only want to print on the output change, not state
    millisTriggered = millis();
    pirState = HIGH;
   }
}



//***************************************************************
// *********************Airspeed function *********************
// Airspeed function | allows users to change airspeed. 7 degrees of airspeed are programmed.

void airspeed(){
 encoder.tick();

 // get the current physical position
 int newPos = encoder.getPosition() * ROTARYSTEPS;
if(newPos >= 1){
  digitalWrite(fanStop, HIGH);// to switch on the cooling fan
 }else if (newPos < 1){
  digitalWrite(fanStop, LOW);
 }

 if (newPos < ROTARYMIN) {
  encoder.setPosition(ROTARYMIN / ROTARYSTEPS);
  newPos = ROTARYMIN;
```

```
  } else if (newPos > ROTARYMAX) {
    encoder.setPosition(ROTARYMAX / ROTARYSTEPS);
    newPos = ROTARYMAX;
  } // if

  if (lastPos != newPos) {
    Serial.print(newPos);
    Serial.println();
    fanValue = map(newPos,0,7,0,180);//remap air speed
//  Serial.println(fanValue);
    analogWrite(fanSpeed, fanValue);//remap fan value
    lastPos = newPos;
  }
}


//*************************************************************
// ********************Display indoor temp ********************
// Sensor senses the indoor temperature, send data to the LEDs to display the temperature on the UI



void temp() {
  // Get temperature event and print its value.
  sensors_event_t event;
  dht.temperature().getEvent(&event);
  if (isnan(event.temperature)) {
    Serial.println(F("Error reading temperature!"));
  }
  else {
    Temperature = event.temperature;
    //Print temp
  //Serial.print(F("Temperature: "));
  //Serial.print(event.temperature-1);
  //Serial.println(F("°C"));
  }
  setAllLeds(0,0,0);


  //int currentTemperaturePosition = constrain(((event.temperature-14)/2),0,14);
  int currentTemperaturePosition = map(((event.temperature-12)/2),0,14,14,0);
//  Serial.println(currentTemperaturePosition);
  for(int i = 14; i >=currentTemperaturePosition; i--){
    leds_Temp[i] = colorTransitionTemp[i];
  }
```

```
  if(millis() - TSbuttonsmillis > 10*60*1000){ //sent data on DF every 10 seconds.



//warm temp range
//warm temp range
if (event.temperature>=22 && event.temperature <=24){
     if(millis()%200 <= 100){
         digitalWrite(ledPinNeutral, HIGH);
     }else{
          digitalWrite(ledPinNeutral, LOW);
     }
}else{
  digitalWrite(ledPinNeutral, LOW);
  }

if (event.temperature>=24 && event.temperature <=26){
   if(millis()%200 <= 100){
    digitalWrite(ledPinSWarm, HIGH);
   }else{
        digitalWrite(ledPinSWarm, LOW);
   }
}else{
  digitalWrite(ledPinSWarm, LOW);
}

// slightly warm range
if (event.temperature>=26 && event.temperature <=28){
  if(millis()%200 <= 100){
    digitalWrite(ledPinWarm, HIGH);
  }else{
        digitalWrite(ledPinWarm, LOW);
   }
}else{
  digitalWrite(ledPinWarm, LOW);
  }


//////Get temperature event and print its value.
  dht.humidity().getEvent(&event);
  if (isnan(event.relative_humidity)) {
    Serial.println(F("Error reading humidity!"));
  }
  else {
    Humidity = event.relative_humidity;
//    Serial.print(F("Humidity: "));
//    Serial.print(event.relative_humidity);
```

```
//    Serial.println(F("%"));
  }

  }// END OF if(millis() - TSbuttonsmillis > 10000)

}



//***************************************************************
// *********************Display co2 / air quality *********************
// Sensor senses the indoor co2 level, send data to the LEDs to display the co2 level on the UI

void CO2(){
  if (! sgp.IAQmeasure()) {
   // Serial.println("Measurement failed");
    return;
  }
  eCO2 = sgp.eCO2;
  //Print CO2 Value
 //Serial.print("eCO2 "); Serial.print(sgp.eCO2); Serial.println(" ppm");
 setAllLeds1(0,0,0);

  int currentCO2Position = constrain(sgp.eCO2/200,0,14);
  for(int i = 0; i <=currentCO2Position; i++){
    leds_CO2[i] = colorTransitionCO2[i];
  }
 }


//***************************************************************
// *********************TS buttons, self-reportive *********************
// Allows users to report their thermal sensation following by ASHRAE 7 point thermal scale.
void TSbuttons() {
  button1State = digitalRead(buttonPin1);//'I feel cold'
  button2State = digitalRead(buttonPin2);//'I feel cool'
  button3State = digitalRead(buttonPin3);//'I feel slightly cool'
  button4State = digitalRead(buttonPin4);//'I feel neutral'
  button5State = digitalRead(buttonPin5);//'I feel slighly warm'
  button6State = digitalRead(buttonPin6);//'I feel warm'
  button7State = digitalRead(buttonPin7);//'I feel hot'

   if (button1State == HIGH) {
    Serial.println("Cold");
    delay(500);
    TSbuttonsmillis = millis();
    updateSensor(-3);
  }
```

```
  if (button2State == HIGH) {
  Serial.println("Cool");
  delay(500);
  TSbuttonsmillis = millis();
  updateSensor(-2);
}

  if (button3State == HIGH) {
  Serial.println("Slightly Cool");
  delay(500);
  TSbuttonsmillis = millis();
  updateSensor(-1);
}

  if (button4State == HIGH) {
  Serial.println("Neutral");
  digitalWrite(ledPinNeutral, LOW);
  digitalWrite(ledPinSWarm, LOW);
  digitalWrite(ledPinWarm, LOW);
  delay(500);
  TSbuttonsmillis = millis();
  updateSensor(0);
}

  if (button5State == HIGH) {
  Serial.println("Slightly Warm");
   digitalWrite(ledPinNeutral, LOW);
  digitalWrite(ledPinSWarm, LOW);
  digitalWrite(ledPinWarm, LOW);
  delay(500);
  TSbuttonsmillis = millis();
  updateSensor(1);
}

  if (button6State == HIGH) {
  Serial.println("Warm");
  digitalWrite(ledPinNeutral, LOW);
  digitalWrite(ledPinSWarm, LOW);
  digitalWrite(ledPinWarm, LOW);
  delay(500);
  TSbuttonsmillis = millis();
  updateSensor(2);
}

  if (button7State == HIGH) {
  Serial.println("Hot");
  delay(500);
```

```
    TSbuttonsmillis = millis();
    updateSensor(3);
  }
}


//*************************************************************
// ******************** OOCSI SETUP ***************************
//*************************************************************
void OOSCIInit(){
  delay (1000); // Wait some time to activate the serial monitor
  oocsi.connect(OOCSIName, hostserver, ssid, password, processOOCSI);
  }



//*************************************************************
// ******************** uodate sensors ***********************
//*************************************************************
void updateSensor(int btn) {
  oocsi.newMessage(CHANNELName);
  oocsi.addString("device_id" , "d6790a8ea98794d17");
  oocsi.addInt("TSbutton", btn);
  oocsi.addInt("user_fanspeed" , lastPos);
  oocsi.addInt("temperature" , Temperature);
  oocsi.addInt("humidity" , Humidity);
  oocsi.addInt("eCO2", eCO2);
  oocsi.sendMessage();
  oocsi.check();  // needs to be checked in order for OOCSI to process incoming data.
}

void updateSensor() {
  oocsi.newMessage(CHANNELName);
  oocsi.addString("device_id" , "d6790a8ea98794d17");
 // oocsi.addInt("fanspeed" , newPos);
  oocsi.addInt("fanspeed" , lastPos);
  oocsi.addInt("temperature" , Temperature);
  oocsi.addInt("humidity" , Humidity);
  oocsi.addInt("eCO2", eCO2);
  oocsi.sendMessage();
  oocsi.check();  // needs to be checked in order for OOCSI to process incoming data.
}

void checkNetwork() {

  if (WiFi.status() != WL_CONNECTED) {
    Serial.println("Connection failed...");
    Serial.println("Rebooting...");
```

```
    ESP.restart();
  }
}




//***************************************************************
// ******************** LED bar functions ***********************
//***************************************************************

void ledRingRotation(){
for(int i = 1; i <= 7; i++)
  {
    if(i <= lastPos) leds_IN[i] = CRGB::Green;
    else leds_IN[i] = CRGB::Black;
     }
 }

void setAllLeds(int r,int g, int b){
for(int i = 0; i <= 14; i++)
  {
   leds_Temp[i] = CRGB(r,g,b);
  }
 }

void setAllLeds1(int r,int g, int b){
for(int i = 0; i <= 14; i++)
  {
   leds_CO2[i] = CRGB(r,g,b);
  }
 }

void setAllLeds2(int r,int g, int b){
for(int i = 0; i <= 7; i++)
  {
   leds_IN[i] = CRGB(r,g,b);
  }
 }

void processOOCSI() {
  // don't do anything; we are sending only
}
```