IEI, Linköping University

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Next Generation Beekeeping

Redesigning the beehive for winter season

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Abstract

The purpose of this project was firstly to investigate common problems linked with beekeeping during the Swedish winter season. Through field studies and interviews with members of the Linköping Beekeepers Society, in parallel with internet-based questionaries', two major problems were identified. The first problem is connected to how fluctuating outside temperatures forces the bee colony to frequently adopt the cluster to maintain optimal in-hive temperatures, which in turn increases the energy consumption of each individual bee. Thus, the first task became a thermoregulation problem where the group intended to diminish the occurrence of rapid temperature changes inside the brood box. The second problem is connected to the beekeepers themselves and how they are forced to perform non-ergonomic lifting during honey harvest. Hence, the group chose to redesign the treasure box with the intention to abolish heavy lifting.

The development ended up in a proof-of-concept prototype in the form of a down scaled beehive where the thermoregulation system was placed within the walls of the beehive. The configuration of the system includes Peltier modules, fans, heatsinks and a microcontroller to operate the system. To eliminate the possibility of bees applying bee wax on top the components of the system, the group placed the system inside the walls instead of directly in connection to the bee area. The heating subsystem performed as intended and was able to increase the temperature and the cooling subsystem did not manage to decrease the temperature as intended but the report includes possible technical solutions regarding how to improve the performance. To meet the ergonomic specifications of the treasure box a new design was created in the form of a dividable box. The solution showed tremendous result and the requirement could be considered fulfilled. The heaviest possible lift that can occur with this developed prototype turned out to be significantly lighter than similar non-dividable treasure boxes on the market.

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Terminology

American foulbrood: Serious disease affecting the larvae of the bees and often causing death of the entire bee colony.

Barrier grid: A grid placed in the hive between the brood box and the first treasure box to prevent the queen from entering the treasure boxes.

Bees: In this report it is referred to honeybees.

Bee colony: A bee colony consists of three kinds of adult bees which are workers, drones, and a queen. A colony usually has between 20 000 to 80 000 bees.

Bee entrance: A small space in the bottom of the hive where the bees can enter/exit.

Beehive: A beehive is the container in which bees are kept in to collect their honey. In this report the beehives will be designed as Langstroth hives, where boxes are stacked on top of each other. The terminology of the parts in the beehive that are used in this report is illustrated in Figure 1.

Brood box: The brood box is the portion of the hive in which the queen is allowed to lay eggs and create a nest.

Clustering: To survive the winter the bees cluster up in a globe formation where they, by vibrating, can keep their warmth.

Drones: The only male bees appearing within a bee colony. Drones are only good for reproduction, which is their only purpose. The drones do not collect nectar or produce honey.

Extractor: A machine where the honey frames are spun, and the honey is extracted as centrifugal forces draws the honey out from the combs.

Frames: Rectangular frames, often made of wood with a wax sheet in the middle where the bees build honeycomb on.

Honeycomb: A mass of wax built by the bees in hexagonal cells where they contain the larvae and stores the honey.

Treasure box: The boxes in the beehive where the frames are placed, and the honey are produced and stored.

Metasurface: Thin films composed of individual elements which have initially been developed to overcome obstacles that metamaterials are confronted with.

META-HILIGHT: A project that is still in its laboratory phase which works towards stand-alone sensing and quantitative characterization of biological tissue using metasurface technique.

Overwintering: Is the process by which the bees wait out the winter season in their hive.

Utsot: Affected microbiota and dysbiosis for honeybees, caused by various reasons.

Varroa mites: A common arachnid, usually attacking honeybee larvae resulting in virus damages in the bee colony, such as disformed wings, shrunken bottoms and overall death.

Weak colonies: Weak colonies are colonies which consist of fewer bees than in a regular colony.

Winter season: The time where the bees are in its overwintering phase. Usually in Sweden the winter season starts in early September and ends when spring arrives in March.

Winter losses: The death of bees during winter season, defined as the difference between hibernated and overwintered bees in a colony.

Working bees: Sterile female bees in a colony, that has several tasks as collecting nectar, making honey, and does all the work inside the hive.

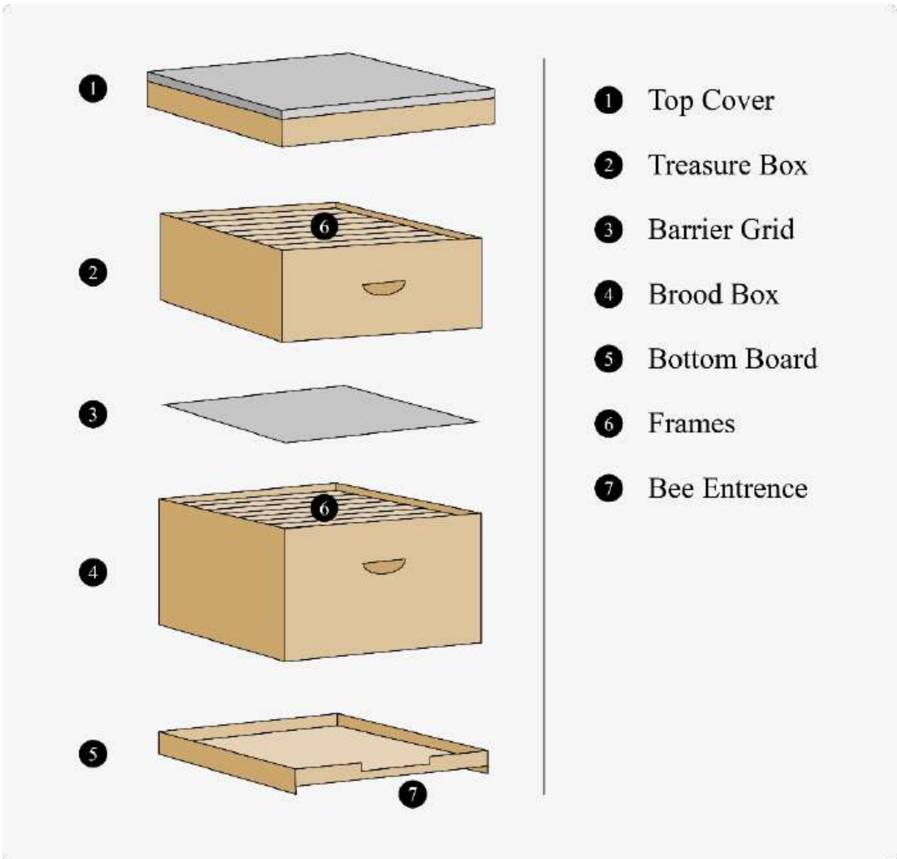


Figure 1: Terminology of the parts in the beehive used in this report.

1 Introduction

This chapter introduces the background to the project and describes the problem that will be investigated. The goal of the project is presented along with key questions that are intended to be covered. Thereafter, the scope is defined, followed by limitations and lastly the challenges with the project.

1.1 Project Background

Honeybees play a crucial role for worldwide food production and biodiversity as their way of continuously gather nectar to their colony also results in pollination of crops and trees. The pollinating does not only benefit the plants but provides humans with food, honey, and beeswax. The honey created by the bees are evolutionary produced as food for the bee colony to survive the winter in the beehive. The first, yet primitive beehives, were created already more than 9000 years ago to enable and control extraction of honey and beeswax. In the 1600's the movable hive was introduced and made it possible for human to harvest the honey without destroying the colony or honeycomb. This was made by using movable wooden frames where the honey is gathered, which typically are placed in wooden boxes which constitutes the hive. Since then, the beehive has not been developed much further. Still today, automatized beehives are rare occurrence, and thereby requires regular supervision by beekeepers to ensure an active and productive bee colony.

In this project, the group will cooperate with Linköping Beekeepers Society, a long-established association which mainly engages in hobby-based beekeeping (Linköping's Beekeeping Society, n.d.a). In addition to arranging courses and meetings for the members of the association, their goal is to make beekeeping known to a wider public with the hope of increasing interest in the area (Linköping's Beekeeping Society, n.d.b). The project is also introduced to META-HILIGHT, a technology consortium that has expertise in the research field of nanophotonics and Metasurfaces as well as optics and how light behaves with optical devices. The objective is to find new possible application areas for their technology, where beekeeping could be a possible adaptation.

1.2 Problem description

In the winter most insects hibernate or lay eggs to emerge in spring, something that bees do not do. Unlike insects, bees are active all winter long. In the winter when the temperature drops below 10 degrees Celsius the bees cluster in the beehive – to protect the queen. The bees can, to a certain point, control the temperature in the beehive to survive and protect the queen from the cold by shivering and flapping their wings. Since the honey is harvested by the beekeepers the bees are provided with feed as a substitution that should last during the winter season. Despite that, 10-20% of beehive colonies die during the winter season. The reasons why colonies die is numerous and varied.

The project concerns the winter season, and by this fact different problems could be identified in different time slots. The bees encounter certain problems on the spring side when the outside temperature differs a lot, and other problems when bees adjust their living habits to survive the cold. Other improvement points could be made to ease the beekeepers work in the aspect of keeping a clean and healthy hive, and after theoretical studies is it clear that the problem is divided into several subproblems that needs to be worked with hand in hand. The project will, by this reason identity the factors that contributes to winter losses, i.e., the death of bee colonies during winter season.

To detect and prevent some of these factor's sensors could be a game changer. There is an ongoing development of metasurface technology sensors that enables a new kind of optical devices that might have the qualities to automate the beehive. The META-HILIGHT project is still under construction but works towards stand-alone sensing and quantitative characterization of biological tissue using this technique. The project will explore the possibility to use this metasurface sensor and optical technology, as well as existing types of sensors, to improve the beehive.

1.2.1 Aim of the project

The overall aim of this projects is to figure out how to redesign the beehive and improving it with sensor technology to reduce the causes that results in winter losses of bees, whilst also looking into the aspect of improving the working conditions for beekeepers by redesigning the hives.

1.3 Key questions

Four key questions are formulated to concretize the problem description, which are listed below.

1. What are common dangers for a bee colony and reasons why they die during winter?
2. What are common 'pains' among beekeepers? What is difficult or boring to do?
3. How can the beehive be redesigned to better avoid those dangers for a bee colony and 'pains' among beekeepers?
4. What is META-HILIGHT, what does it do, and how could that technology be used to create a Beehive 2.0?

1.4 Scope

The main idea is to improve and suggest redesign solutions of the beehive related to problems during the winter season. From literature studies and interviews, two of the most common and severe problems for beekeeping and reasons for winter losses have been identified. The scope of this project is to build a prototype of a beehive adapted to those issues.

1. **Temperature changes in the hive**: In winter and early spring, the outside temperature sometimes dramatically changes during short intervals of time. When the temperature rises, the beehive becomes more active and consumes more food. Thus, unstable whether conditions make it more difficult for the beekeepers to ensure sufficient food supply which may result in starvation. Further, temperature variations may trick the

bees to leave the hive too early in the winter and thus die due to the unexpected cold or snow. To solve this issue the group will investigate temperature regulation and the isolation of the beehive.

2. **Redesign of the beehive**: A problem that has been addressed by the beekeepers is the heavy lifting of the treasure boxes. The boxes must be lifted every time the beekeepers check in on the queen as well as when the honey is extracted, with a weight of approximately 25 kg. Therefore, ergonomics for the beekeepers will be investigated to solve this problem.

The project aims to develop a beehive that will mainly be used by hobby beekeepers, rather than industrial beekeeping. This will affect choices concerning design, material, technology, and level of complexity for the concept solutions.

1.5 Limitations

The strict limitations the project is required to follow are:

- The issues with beekeeping will exclusively be investigated during the time-period from early autumn to early spring.
- Work within the project budget of 3000 Swedish crowns.
- The project is set to be done within the time-limit of the autumn semester.
- There is limited access to testing of the prototype, which means that the product won't be tested in a real case scenario. Thus, the behavior of the bees and the function of the sensors will be semi-hypothetical with some assumptions.
- Manufacturing/assembly of the product is limited to the extent of the university's workshop/machine park.

1.6 Project goal and impact goal

The main goal of this project is to improve and redesign the beehive by finding technical solutions, aiming to reduce the number of bee colonies dying during the winter season. This goal is achieved when prototypes with desired technical properties are built and tested to meet the thermal and ergonomically requirements. The ergonomic goal is to reduce the total weight of the treasure box, to limit the lifts to be maximum 10 kg. The thermal goal is to keep the temperature in the beehive within an interval of 2,5 °C related to the average outdoor temperature over a period of 4 days. By decreasing the abrupt temperature changes in the wall, the group aims to create more stable temperature conditions within the hive, illustrated in Figure 2.

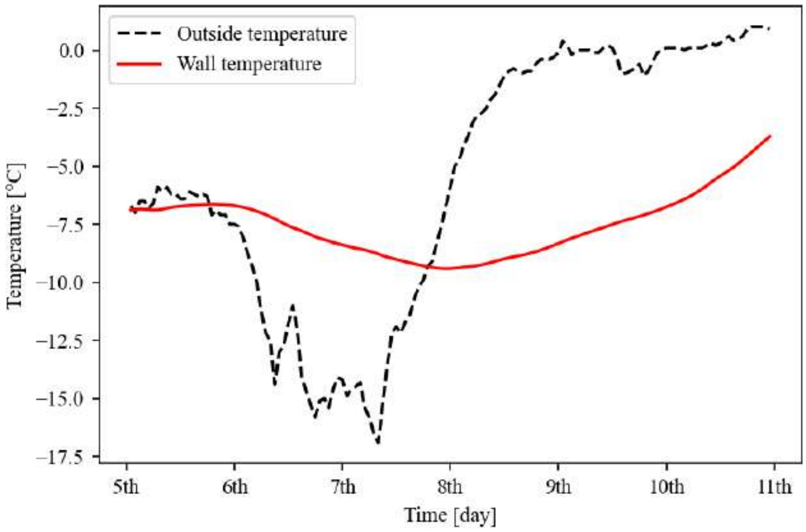


Figure 2: An illustration of real measured temperature, black dotted line, from the period of 5th to 11th of December 2021 and a simulation of desired wall temperatures, red line, in relation to monitored outside temperatures.

With data from SMHI, Swedish Meteorological and Hydrological Institute, a simulation was done to obtain information concerning the most severe temperature differences that would occur with the intended method. The temperature data used was collected between the 1st of October 2021 and the 8th of March 2022. Table 1 shows all days that the temperature difference between outside temperature and target wall temperature exceeded 10 °C, which only happened nine times during the current period. With this in consideration and our margin for error of 2,5 °C, the group consider the performance of the heat system to be a success if it manages to increase and decrease the wall temperature by at least 7,5 °C.

Table 1: Displays the dates when the temperature between the outside temperature and target wall temperature differed with at least 10 °C during a time frame from 1st od October 2021 to 8th of March 2022.

Date	Outside temperature	Target wall temperature	Desired temperature change
2021-11-21	-5,4	5,9	+11,3
2021-11-22	-6,3	5,3	+11,6
2021-12-21	-8,7	1,8	+10,5
2022-01-07	-11,6	-0,8	+10,8
2022-03-13	11,8	1,5	-10,3
2022-03-20	13,3	3,2	-10,1
2022-03-29	-4,1	6,6	+10,7
2022-03-30	-10,2	4,1	+14,5
2022-03-31	-8,5	2,4	+10,9

The margin for error of 2,5 °C also restricts how greatly the actual wall temperature is permitted to vary from the target wall temperature which is illustrated in Figure 3.

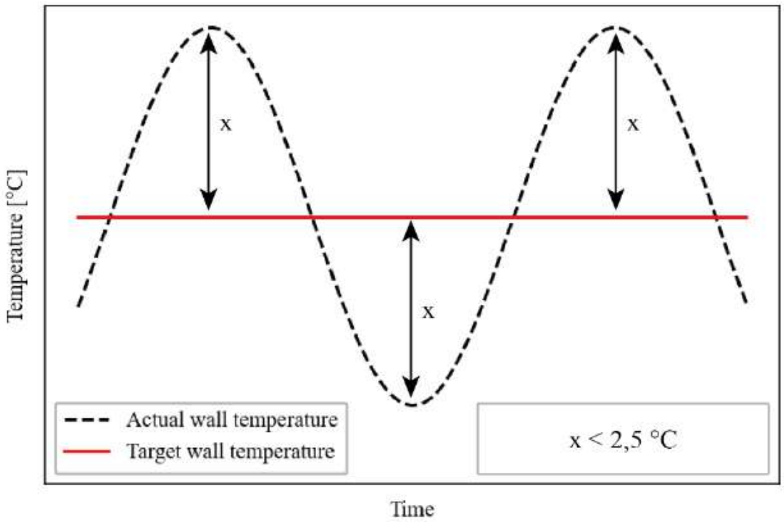


Figure 3: Illustrates how much the actual wall temperature is allowed to differ from the target wall temperature.

A subgoal for the project is to integrate sensor technology and find what common ground there is between what META-HILIGHT sensors can detect and how they could be used in an automatized beehive application. When sensor technology solutions are chosen it will be investigated how well the META-HILIGHT project and metasurface technology can be applied to the project.

The aim is to improve the hive so that more bees survive the winter, thus ensuring the future of the bee colonies. This is important from both an economic and affective perspective for beekeepers, but also from an ecological point of view as bees are valuable for agriculture and ecosystems in general. Furthermore, the aim is to facilitate beekeepers' interaction with the bees and the hives by improving ergonomics and reducing safety risks in their work.

1.7 Challenges of the Project

Bees are social animals with complex behavior patterns and their lives are affected by many factors, such as climate, environment, and pests. Thus, it can be difficult predicting their behavior and what actions are beneficial for their well-being and survival. As bees are overwintering, they will not be included in testing concepts or prototypes within the scope of this project. Their interaction with the final prototype will have to be investigated in future studies. Beekeeping is an activity that is obtained through experience. This includes different opinions on how bees should be maintained and reasons why colonies are doing well or poorly. The extended knowledge is a great asset for the project but also a challenge to navigate among different points of view.

Another challenge is how the META-HILIGHT technology will be adapted to the project. This includes both what the sensors are capable of measuring, but also how the data should be analyzed and acted upon. The question regarding whether the product aims at industrial or hobby use may pose different challenges, such as how much of the process should be automated. A challenge with implementing sensors and other technology in the beehive is that there are uncertainties about how the bees behave in relation to unknown objects.

2 Methodology

The methodology of this project is mainly based on the book *Product Design and Development* by Ulrich and Eppinger (2016), with some modifications due to earlier experience of product development projects. The flowchart of the project is presented in Figure 4 with each further described further below.

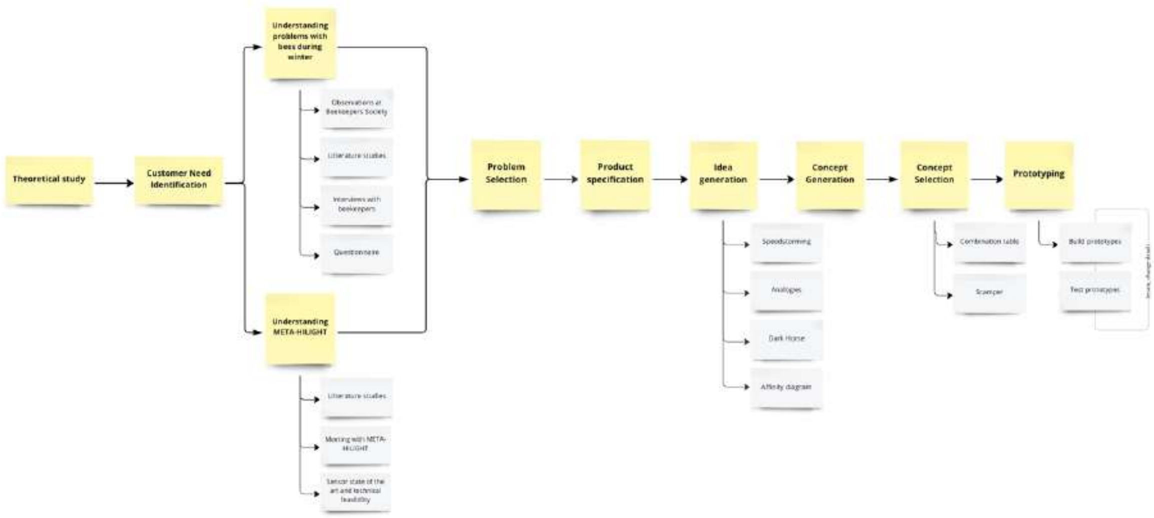


Figure 4: Flowchart of project.

2.1 Theoretical Study

A crucial initial step in product development is to obtain a thorough knowledge about the subject before dealing with anything else. Due to lack of prior knowledge in the subject, a theoretical study consisting of a wide range of topics linked to honeybees, beekeeping, sensor technology and components for heat transfer is conducted. This fundamental knowledge discloses potential problematics within the area of beekeeping in parallel with equipping the group with necessary terminology.

2.2 Customer Need Identification

According to Ulrich and Eppinger (2016), the identification of customer needs is usually done through interviews, focus groups or observing a customer use an already existing similar product. In this project, data is gathered on the most severe issues connected to beekeeping during the winter season, in addition to theoretical studies within the subject.

The group did in total visit Linköping Beekeeper’s Society three times. The first two visits are observational studies with unstructured interviews with the purpose of establishing a general awareness about the current routines, related to the preparations of the beehive before the winter season. The last visit consists of a semi-structured interview with prepared questions, combined with open discussions and follow-up questions.

In addition to interviews, a questionnaire is used. The main idea of creating a questionnaire is to support the qualitative data from the interviews with more quantitative data that can be analyzed in a more mathematical way. Another reason for conducting a questionnaire is to not only reach out to people who have beekeeping as a hobby but to the beekeeping industry and beekeepers that have beekeeping as profession as well. The overall aim of the interviews and the questionnaire is to support the so far gained overall understanding of the problem areas, to find out which areas to investigate further and as material that supports the choice of which problems to solve.

Lastly, a semi-structured interview with representatives from META-HILIGHT is conducted. The aim of the interview is to expand the understanding of earlier applications of their sensors and possibilities of monitoring inside the beehive, which could become a usable tool in future beekeeping.

2.3 Problem Selection

After customer need identification, identified problems related to beekeeping during the wintering season are summarized. These issues are thereafter evaluated based on how severe they are, as well as how they fit into the project's objectives and framework. Lastly, an analysis will be done to investigate if the problems are applicable, in terms of degree of difficulty, for the members of the group.

2.4 Product Specifications

The customer needs set the foundation of the target specification. Ulrich and Eppinger (2016) holds the view that some sort of product requirement list should be established in the form of short sentences describing the desired functionalities of the artefact, which the group intending to do. They claim that the sentences must include measurable details to establish concrete values for the engineer to consider. Determination of a hierarchy among the desired functionalities is essential, where some sort of rating usually is established, either through a grading scale or through definition if a functionality is required or desired (Ulrich and Eppinger, 2016).

2.5 Idea Generation

High quantitates of sketches, with low level of details, is a well-known strategy for efficient creation of early concepts (Ulrich and Eppinger, 2016). The authors point out the advantages of group sessions where each member individually generates numerous concepts during a predefined interval of time, primarily to avoid influence among group members, which could diminish the solution space. The methods *Speedstorming*, *Analogies* and *Dark Horse* are used to generate and develop ideas, which are explained further below.

The first method, *Speedstorming* is a variant of brainstorming which is influenced by speed dating (Wikberg Nilsson, Ericson and Törlind, 2021). The aim of the method is to create many ideas by forcing the participants to produce ideas rather than discuss or ponder them, meanwhile making all participants' voices get heard. Wikberg Nilsson, Ericson and Törlind (2021) describes the method to consist of five steps. In the first step, the problem questions are put on different tables with paper and pencils. Secondly, two of the participants stand at each table and brainstorm for about 3 minutes. Thirdly, when the time is up, the participants rotate to the next question. In the fourth step the process is repeated. The final step is that the session continues until all participants have brainstormed at all tables.

The second method used, *Analogies*, is explained by Wikberg Nilsson, Ericson and Törlind (2021) to be describing a problem based on different metaphors and analogies where the goal is to open the mind for new possibilities.

The third idea generation method *Dark Horse* origins from horse-racing and describes a horse that you don't know much about and therefore an unlikely winner. Wikberg Nilsson, Ericson and Törlind (2021) describes a "dark horse" as an idea that appears risky, radical, or crazy and is not in line with the goal of the project, but rather steer the work in a new direction. The idea further requires extensive development and testing to be successful but could be revolutionary if its full potential is achieved. The reasoning behind the method is to force the participants to develop ideas "outside the box" and see potential in solutions that initially do not seem to have it (Wikberg Nilsson, Ericson and Törlind, 2021).

The method *Affinity diagram* consists of organizing ideas based on their relationships to one another (Plain, 2007). It is used to get an overview of ideas after a brainstorming session.

2.6 Concept Generation

From the idea generation early concepts are created and concretized into more realizable concepts. According to Ulrich and Eppinger2016), each function of the most promising concepts should be broken down with a *Concept Classification Tree*, where potential ways of realizing the function are listed. A *Combination Table* assists the engineers to investigate if various function could be combined in unexpected ways.

2.7 Concept Selection

The pros and cons for each of the generated concepts are identified and listed in a table. Thereafter, a multi-criteria-method is used to select the top concepts for further investigation. Derelöv (2002) describes this as a simultaneous valuation of the solutions against several set criteria. Derelöv (2002) further describes that the workflow is similar for different multi-criteria-methods, including: identifying and formulating evaluation criteria, evaluate the solutions against the criteria, rank the solutions, combine, and improve the solutions and finally reflect on the result and the process.

In this project, cardinal methods will be used, which means that the solutions are judged absolutely against the criteria, i.e., independently of the other solutions. These methods require well-defined criteria and solutions.

The *Criteria Weighing Method* is used where relevant criterions are selected from the product specification and weighted towards each other. The relative importance of each criterion is summarized into a normed score which in total equals to 1 and placed along the two axes of a table, where their importance is weighted towards each other. The numbers *0*, *1* and *2* refer to *less important than*, *equally important than* and *more important than*. Lastly, a ranking of the criteria is achieved depending on their importance.

For the final concept selection, the Date Method is used, where each concept is compared to an existing solution, in this case the existing beehive, and the weighted criteria. This means that a concept that fulfils important criteria better than the existing hive gets high points and vice versa.

The last part of the concept selection includes supervision with knowledgeable in the field. This includes the group's supervisor Juan Felipe Ruiz Muñoz, associate professor Torbjörn Andersson and lecturer Fredric Malm. All are working at the Department of Management and Engineering (IEI) at Linköping University at the division of Product Realisation. Torbjörn is a lecturer in Product Ergonomics and Fredric is an assistant lecturer in Machine Design. Both are involved in hobby beekeeping and thus have knowledge in the area, which is valuable for providing input on promising concepts.

2.8 Prototyping

Ulrich and Eppinger (2012) define prototyping as the process of developing an approximation of the product along one or more dimensions of interests. There are different types of prototypes depending on the goal and in this project two physical prototypes are built to test desired functionality. For the ergonomic task, the dimension of interest is on how the design affects the beekeeper's interaction with the hive. For the temperature task the dimension of interest for prototype is focused on validation of the thermoregulation system.

The final step of the project is to test and refine the prototypes, which usually is done by customers in their own use environment (Ulrich and Eppinger, 2012). This includes testing of the ergonomic concept where the beekeepers of Linköping's Beekeeping Society will get the opportunity to try-out the product. The only ones that will take part of the testing of the thermoregulation prototype is the members of the group.

3 Theoretical study

In this chapter the information gathered from literature studies is presented, which includes theory related to bees such as history, structure of honeycomb and beehive, wintering season, environment in the beehive and common diseases and pests. Thereafter information about metasurface and the META-HILIGHT technology is presented and finally state of the art which consists of information about similar solutions to ergonomic and thermal problems.

3.1 Introduction

Bees has the scientific name Apis mellifera, which means a honey carrying bee. They live in colonies with approximately 60 000 other bees during the summer and about 20 000 through the winter. They visit flowers and plants to collect nectar as well as pollen to make honey of the nectar and use the pollen as a nourishment full of protein. The nectar is transported in a bladder design for the cause and is then carried to the hive in small "pockets" on the hind legs. They then build cakes of vax that is produced in vax glands where they then stock honey and pollen in hexagonal cells. The cells are also used as room for the queens to place her eggs, which then leads to room for larvae and pupae. The honeybees do mostly help the human by pollinating both cultivated and wild plants. Today most of the bees is held in beehives where beekeepers harvest honey, pollen, propolis and gel made by the queen. (Fabricius Kristiansen, 2020)

Within the bee colony all the working bees are sterile females and the male bees, or so-called drones, is only good for reproduction, which means to pair the queen. Every society has one queen, notable by its long back part of its body. One queen could lay up to 200 000 eggs each summer. From the eggs, bee larvae are hatched and then grown into pupas within the cells. Fertilized eggs produce females and males from the not fertilized ones. There are several tasks for the working bees, for example there is cleaning bees, building bees, guards and when grown into seniors they become dragging bees.

Honeybees communicate through different sorts of chemical fragrances and by dancing. During the summer new queens is made. The bee colony prepares special queen cells that are more nutritious. The queen is fed through its whole life by the honeybees, mainly with queen's jelly. There are always a few bees that sees after her and fulfills her needs. For honeybees to breed there is a phenomenon called swarming. This means that the old queen leaves the beehive together with approximately 50% of the bees.

To survive the winter the bees do cluster up in a globe like formation. Thanks to that can they, by vibrating, keep the warmth. This is the time where the food store is used to survive. (Fabricius Kristiansen, 2020)

3.2 History of bees

There is an approximation that the domestication of honeybees started for about 6000 – 7000 years ago in the middle east. But according to research the human did honey hunting way before the start of the man's refinement of the originally wild bees through breeding. Both in cause of collecting the sweet honey itself but also for the larvae full of protein. After lots of years trying to tame bees, the human has learned that the honeybees should not be tamed, beekeeping is about to keep the bees thrive and healthy. The difference between bees and other pets is that the wild bees doesn't act any different than the ones taken care of. The typical beehive has therefore evolved a lot through the years and have a different design today. (Fabricius Kristiansen, 2020)

3.3 The structure of the beehive

The most important factor is that honeybees need enough room and cavity to build their hive. The difference between honeybees and wasps is that the honeybees can't build their own protecting outer layer. Instead, they produce their own building material in form of bee wax, which they use to build the hexagonal cells in form of wax cakes. Those are placed in a distance within 10mm and works mainly as pantry where the honey and pollen is stored. It is also used as a room for the queen to lay her eggs. The optimal placement of a beehive would be in a large living tree with a small opening about 4,5 meters above the ground. (Fabricius Kristiansen, 2020)

3.3.1 The modern beehive

There is plenty of different types of beehives but to have some standardized measures the Swedish Beekeeping National Federation (Sveriges Biodlares Riksförbund) provided norms. This applies to both the hives and the frames. The design should be adjusted by the Swedish climate. (Fabricius Kristiansen, 2020)

One of the most common beehives is the stacking hives, also called Langstroth hives. It consists of a couple of loose boxes placed on each other with a bottom box that works a beehive entrance. On top of the boxes is a cover plate which is meant to impede the bees from firmly building in the roof. The roof itself is placed on top of the stack and makes the hive protected from weather and wind. The importance of the isolation by the roof can't be undermined as the warmth rises and would leave the hive if it isn't tight enough. To ease the maintenance of the hive frames are placed into the boxes to prevent the bees from building wherever they want. The frames are built with one partition wall made of beeswax. The bees then build as they desire from the partition wall. In that way wax cakes are built which is easy to lift out without destroying what the bees have built. One alternative to that method is to use the top list and fasten a strip made of wax. Then the bees can build freely from that. The stacking hive, top-list hive as well as a third common type on beehive called Warre hive are shown in Figure 5.

Figure 5: Three of the most common types of beehives.

To prevent that the queen lay eggs in the so-called treasure boxes, which is where the honey is stored, a barrier grid is used. The usage of the barrier grid differs and can both be used during the whole season or just before the end of the season. (Fabricius Kristiansen, 2020)

3.4 Overwintering of bees

The preparation for the cold is rather dependent on the outside temperature than the calendar. The bees adjust to survive according to the temperature and prepares themselves with the outer circumstances in mind. When the temperature drops the colony prepare itself, the queen lowers its egg production, and the bees begin to seal properly in the hive with propolis. The bees can seem to be more aggressive at this point of the year because of that they guard their honey storage. Therefore, it could be even more important to follow a routine and know the behavior of the bees (Fabricius Kristiansen, 2020).

The wintering process consists of a few stages, all to give the bees the conditions to survive the weather during the winter. The most critical stages are often during the spring when preventive acts must be done for the cause of pests (Fabricius Kristiansen, 2020).

The preparation starts when the bees can’t find nectar outside anymore. The beekeeper's role at this time is mainly to give the society new vax cakes for the bees to sit on, the brood box shall be shrunken to the appropriate size to survive the winter, do a final harvest, check as well as treat if there are any signs of varroa mites, fuel the community for the queen to continue laying eggs, attach a food box with sugar solution to keep the bees fed during the winter and lastly check the health and status of the queen, which means that you eventually need to replace her (Fabricius Kristiansen, 2020).

Before the process starts there is a brood box in the bottom of the stack, with a treasure box on top. Between the two boxes is there a grid with the purpose of preventing the queen to place new eggs inside the treasure box. It should be enough to attach this grid around three weeks before the wintering process. The first step is then to move all the bees from the upper boxes, down to the brood box. At this time, it could be adequate to check for varroa mites. On top of the full brood box is a plastic sheet placed to prevent the bees from vax build-up on the bottom side of the feed box. There are some gaps in the plastic sheet which allows the bees to get their food. The food box, that is placed on top of the brood box, is built in a way that one gap makes it possible for the bees to make its way from the brood box to the food box. The food box is filled with sugar solution, approximately 16-21 kg, and are removed when all food is gathered by the bees into the brood box. The food is meant to be enough for the entire winter and from this stage is it just the cover left to be placed upon the stack (Fabricius Kristiansen, 2020).

3.5 Winter losses of bees

During the year of 2006 there was a big attention about the observance of big colony losses of honeybees in USA, a phenomenon named as Colony Collapse Disorder (CCD). Soon same tendencies appeared in Europe. In the article from Jordbruksverket 2009 the name "mass death" is used as a common notion for both CCD and winter losses. It is explained that that CCD and winter losses are not the same thing, but that they can occur from interacting factors and mainly that CCD can be one of the reasons to winter losses. An often-mentioned cause to CCD is pests and diseases, leading to viruses that decreases the immune system of the bees which may result in winter losses. Winter losses are the difference between hibernated and overwintered bee colonies (Rahbek Pedersen *et al.*, 2009).

COLOSS (Prevention of honeybee COlony LOSSes) is a network studying and reporting honeybee colony losses through national surveys. In their article presenting the winter losses of year 2018/2019 there was 31 European countries participating and the overall winter loss in Sweden was 11.4% (Gray *et al.*, 2020). Jordbruksverket explains that losses between 5-10% of inhabited bees are considered as normal (Rahbek Pedersen *et al.*, 2009).

3.6 Environment in the beehive

Efficient methods for regulating temperature- and humidity levels have been developed during the evolution of the honeybee. This chapter will describe the inner mechanisms of the bee colony that enables these phenomena and certain external factors that causes unfavorable impact of these regulating methods.

3.6.1 Temperature

According to (Jarimi, Tapia-Brito and Riffat, 2020), the ideal temperature of the microclimate in conjunction to the brood box is known to be around 35 °C. To maintain this climate, during the winter season when temperature drop under 15 °C, the honeybees gather in a cluster around the brood, where the queen is located in the middle (Jarimi, Tapia-Brito and Riffat, 2020). To diminish heat loss, because of air leakage, the bees create a mixture of resin, collected from plants and trees, with bee wax and attach the solution to current holes and cracks inside the beehive. This substance is known as propolis, and beyond the good properties as construction material, it also has a beneficial antibacterial effect on the bee colony (Vreeland and Sammataro, 2017). The outmost determining factors of a successful heat regulation are the supply of food and health condition of the hive. Unfortunately, fluctuating temperature in the surrounding nature will enforce the cluster to either expand or shrink to sustain these optimal heat conditions, which in turn increase the energy consumption (Jehlička and Sander, 2018).

3.6.2 Humidity

Research have shown that the survival of the bee community is heavily dependent on sufficient hydro- and thermoregulation. The probability of egg hatching inside a hive with relative humidity below 55 % is significantly low and reaches its optimum in the range of 90 to 95 % (Eouzan *et al.*, 2019). Even though humidity levels inside this range is considered beneficial, fluctuations inside this interval could cause harm to the offspring (Eouzan *et al.*, 2019). Thus, fluctuations of weather conditions demand greater consumption off energy among the bees, not only because of thermoregulation, but also regulation of humidity level. Another consequence off inefficient hydroregulation is the emergence of condensation inside the hive, which can lead into growth of mold inside the brood box (Jarimi, Tapia-Brito and Riffat, 2020).

3.7 Diseases and pests

Honeybees can get sick or suffer from pests. Diseases can be caused by bacteria, fungi, viruses, single-celled animals, or mites, but can also be caused by disturbances in the bees' metabolism. Only varroa mites, American foulbrood and European foulbrood have been detected in Sweden, where the last-mentioned is uncommon. (Jordbruksverket, 2022)

The varroa mite is an arachnid found on all continents where honeybees are cultivated (Jordbruksverket, 2022). In an untreated hive, the varroa mites can increase into a huge population and result in a collapse of the bee colony after 3-4 years (Rosenkranz, Aumeier and Ziegelmann, 2010). The mite is difficult to detect on adult bees and can exist in bee colonies without the beekeepers being aware of it (Jordbruksverket, 2022). Varroa mites cause large losses of bees in central and southern parts of Sweden, mainly during the winter and effective treatment before hibernation is believed to have a large impact (Sahlin and Klatt, 2018).

American foulbrood is caused by a bacterium that kills honeybee larvae and turns them into a foul-smelling mass filled with spores. The spores spread easily and are extremely long-lived, which in many countries requires the destruction of bee colonies (Bikaun *et al.*, 2022). If symptoms of American foulbrood are found in bee colonies, both bees and hives must be destroyed (Jordbruksverket, 2022). Detecting American foulbrood is a problem as the diagnosis often is slow and relies on the beekeeper’s ability to detect symptoms in the colony and thereafter confirming it on a molecular level. Slow detection can result in large outbreaks during pollination events, thereby jeopardizing livelihoods and food security (Bikaun *et al.*, 2022).

Additionally, the disease Utsot affects microbiota and dysbiosis for honeybees. Utsot is the Swedish word used for diarrhea among honeybees referring to an affected microbiota and dysbiosis for the honeybees (Anderson and Ricigliano, 2017). An English word that can be used for Utsot is dysentery. Dysentery among honeybees' is a condition defined by the result of an abnormal amount of stool in the honeybee's gut (Burlew, 2021). Utsot or dysentery is mainly present during the winter or early spring and is leading to bees leaving feces inside of or around the beehive, which results in poor hygiene and indicates an unbalanced colony or atmosphere in the hive. Some of the reasons to Utsot are or abnormal consumption of feed, external disturbances or humidity (Allt om biodling, 2022). Other reasons can be improper consumption of carbohydrates or due to presence of pests (Galajda *et al.*, 2021).

3.8 Ergonomics

Alike many other agriculture areas, beekeeping involve multiple ergonomically risk factors, such as heavy lifting, high degree of manual materials handling, twisting, and awkward positioning (Fels *et al.*, 2019). This section covers the area of load ergonomics, manual lifting, handle design, anthropometry and ergonomics related to beekeeping.

3.8.1 Load Ergonomics

Load ergonomics is the field dealing with movement and the load ratio of the supporting organs in humans at work, where load primarily refers to physical load in the form of mechanical forces and moments acting on the human body. Load ergonomics has long focused on reducing load amplitude and introducing various aids to reduce the required effort. Over time, it has become obvious that the duration and frequency, and thus the variation of the load, are of great importance in how quickly fatigue and pain in movement and the supporting organs will appear. Fatigue and pain often result both in acute and chronic problems, therefore the work must be designed so that it provides load variation with alternating light and heavy load with enough and breaks in between. (Bohgard et al., 1994)

3.8.2 Manual lifting

Overloading when moving heavy objects poses a great risk of damage to the musculoskeletal system, where the lumbar spine is particularly vulnerable. The risks in lifting work can be divided into three classes: injuries due to accidents, overload due to heavy loads and cumulative injuries due to repeated. The load on the back largely depends on the weight of the load and the distance between the body and the load, where the lifting technique affect the compression force on the intervertebral disc in the lumbar spine. The relationship between the weight of the load and the compression force on the lumbar spine for different lifting technique is described in Figure 6. (Bohgard et al., 1994)

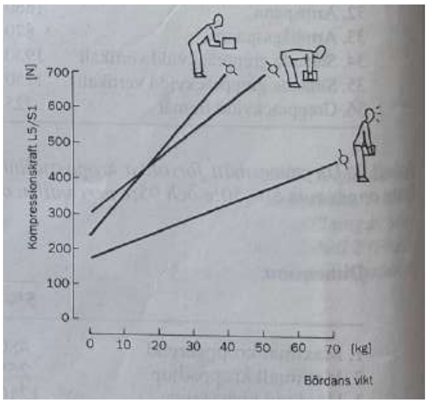


Figure 6. Correlation between weight of the load and compression force on the lumbar spine for different type of lifts (Pheasant, 1991: Ergonomics, work, and health)

The American National Institute of Occupational Safety and Health (NIOSH) created a guide for the recommended lift one can make without risk of injuries. The formula calculates the maximal allowed lifting weight, L [kg]. (Bohgard et al., 1994). The meaning of the variables is explained in Table 2 and some of them are illustrated in Figure 7.

$$L = 23 * H_m V_m D_m A_m F_m C_m$$

Table 2: Explanation of variables used in the formula used to calculate the maximal allowed lifting weight, L

Variable	Description
$H_m = \frac{25}{H}$	H is the horizontal distance from a point between the feet and the grip position of the load [cm]
$V_m = 1 - 0{,}003\ \lvert V - 75 \rvert$	V is the vertical distance between the floor and the grip position of the load [cm]
$D_m = 0{,}82 + \frac{4{,}5}{D}$	D is the lifting distance [cm]
A_m	The asymmetry line with twisted upper body [degrees], i.e., the angle between the lifting direction and the mid-sagittal plane of the body. This is the vertical plane that runs straight from front to back and divides it into a right and left part.
C_m	Can be obtained in Table 3.
F_m	Can be obtained in Table 4: Factor F_m for lifting frequencies between $0{,}2 - 1$ lifts/min. .

Table 3: Factor C_m for the contact between the hands and the burden.

Contact	$V < 75$	$V \geq 75$
Good	1,00	1,00
Acceptable	0,95	1,00
Bad	0,90	0,90

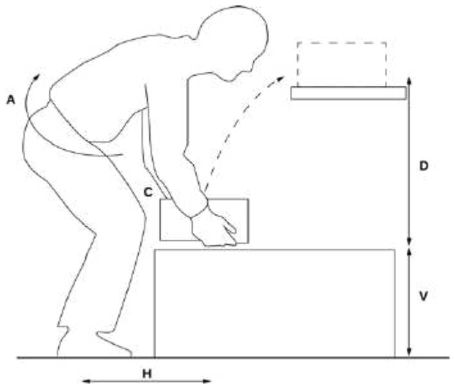


Figure 7. Visualization of variables H, V, D, A and C.

Table 4: Factor F_m for lifting frequencies between $0{,}2 - 1$ lifts/min.

Frequency [lift/min]	Duration of work $2 - 8$ [h]		$1 - 2$ [h]		< 1 [h]	
	$V < 75$	$V \geq 75$	$V < 75$	$V \geq 75$	$V < 75$	$V \geq 75$
0,2	0,85	0,85	0,95	0,95	1,00	1,00
0,5	0,81	0,81	0,92	0,92	0,97	0,97
1	0,75	0,75	0,88	0,88	0,94	0,94

The guide is primarily intended to be used when planning new works but can also be used to investigate the risks in existing works. The starting point is a lifted weight of 23 kg, which is reduced by six work-related multiplication factors. (Bohgard *et al.*, 1994). 23 kg is a load constant that was established by NIOSH to, under ideal conditions, be safe for 75% of females and 90% of males (Government of Canada, 2022).

3.9 Sensors

Sensors can be used to get information about what's happening inside the beehive and, from the collected data, take actions to increase the number of bees surviving the winter. As a subgoal of the project is to investigate possible techniques for META_HILIGHT to apply in a beehive, the research area of Metasurfaces and the META-HILIGHT project is described in this section.

3.9.1 Metasurfaces

Metasurfaces is a research area in optics that has grown rapidly in recent years. The definition of a metasurface is an "ultrathin arrays composed of subwavelength meta-atoms enable precise control of the various aspects of electromagnetic waves". It is used as a tool for describing, understanding, control and modify fundamental properties of light and optical beams (Scheuer, 2020). Meta- materials and surfaces have characteristics that are beyond what naturally can be seen in nature. Normally when wavelengths are emerging from a conventional curved lens, the light travels slower though some parts of it and the wavefront is converging. Metasurfaces are instead of a simpler, plane shape and can have different material properties in the middle of the lens, which is why the light waves can be controlled. This enables the possibility of having a completely arbitrary wavefront at the other side of the lens (Nanowerk, 2022).

The metasurfaces are flat and ultrathin, properties which are beneficial for adapting them into small components and for integration with functional materials and with nonplanar surfaces. Examples of usage areas are contact lenses, Meta-lenses for cameras, virtual reality projectors, PV solar-cells and thin detectors. Advances and improvements in nanofabrication processes and metasurfaces have matured the technology. This in turn has paved the way for more relevant and attractive commercial applications. However, the maturity and cost differ between specific applications. Adapting these new technologies might be more expensive for the manufacturer and customer compared to existing solutions until enough research and development has been done within this field. Metasurface technology aim to replace existing optics and solutions have been found for many of the difficulties with metasurfaces, such as dispersion and bandwidth, to the extent that some metasurface-based optical components is now comparable to conventional products (Scheuer, 2020).

3.9.2 Metalenses

Metalenses are one of the most researched areas of metasurfaces, especially flat lenses (Scheuer, 2020). Today, electronics requires smaller optical components are than earlier. Tinier lenses are difficult to manufacture with traditional technique as components in a lens of glass must be stacked to correctly focus the light.

Metalenses consist of a flat, thin surface covered by several objects in nano size, for example pillars or drilled holes. When the light hits the objects, its properties changes, such as the polarization, intensity, phase, and propagation direction. Scientists can place the nanoobjects in a position so the light from the lens has required properties. The lenses are so thin that multiple can be stacked without affecting the size significantly. Beyond reducing the size, metalenses should with time be able to lower the costs for optical components as they can be produced with already existing equipment within the semiconducting industry. This could contribute to a possibility to manufacture the electronical and optical components at the same time. Now, the costs are still too high as it is difficult to exactly place components in nano size on a chip in centimeter scale. Other limitations with the technology are that metalenses does not transfer light as effectively as traditional lenses, an important property for adaptations such as images in colors. The lenses are also too tiny to capture a large amount of light, which means they are currently not suitable for high-quality photographs.

The potential adaptations for metalenses appear attractive enough to gain support from government agencies and companies such as Samsung and Google. At least one start-up company, Metalens, expects to be able to launch metal lenses on the market within the next few years (DiChristina *et al.*, 2019).

3.9.3 META-HILIGHT

META-HILIGHT is a consortium of people specialized in metamaterials and how light behaves in a nanometer scale. META-HILIGHT is a project initiated to develop the technology of diagnosing and studying tissue diseases and tissue biopsy by using metasurface techniques and supervised machine/deep learning. The described aim with the project is to realize a radically new diagnostic modality for stand-alone sensing and quantitative characterization of biological tissues. The usage of this is detection of cancer, Alzheimer, other chronic diseases as well as healthcare applications (Dirdal, Bozhevolnyi and Meglinski, 2022).

3.10 Thermostatic maintenance

The adjective for thermostatic is having or maintaining a consistent temperature. This means that the heat, which can occur in different forms, must be regulated by adding energy and thereby lower or higher the heat. One common problem

3.10.1 Heat transfer

Conduction and convection are two of the three ways of heat transfer and heat transfer is the physical act of thermal energy being exchanged between two systems by dissipating heat. Conduction transfers heat via direct molecular collision. This means that an area of greater kinetic energy will transfer thermal energy to an area with lower kinetic energy. Conduction is the most common form of heat transfer and occurs via physical contact. Convection on the other hand is when a fluid, such as air or a liquid, is heated and then travels away from the source, it carries thermal energy along. At a molecular level, the molecules expand upon introduction of thermal energy. As temperature of the given fluid mass increases, the volume of the fluid must increase by the same factor. One other heat transfer is radiation, but in this report, it is not considered. A temperature sensor is a device, typically, a thermocouple or resistance temperature detector, that provides measurement in a readable form through an electrical signal (*konduktivitet - Uppslagsverk - NE.se*, no date).

3.10.2 Peltier effect

The Peltier effect is a thermodynamic consideration of thermoelectricity in metals. The coefficient was derived from the difference in the total energy of electrons in two metals in contact. The effect is the reverse phenomenon of the Seebeck effect which means that the electrical current flowing through the junction, connecting two materials will emit or absorb heat per unit time at the junction to balance the difference in the chemical potential of the two materials (Terasaki, 2016). The advantages of thermoelectricity solid state energy conversion are compactness, quietness and localized heating or cooling. It is foremost used in refrigerators because of its ability to quickly transport heat (Tritt, 2002). Figure 8 illustrates a thermoelectric module and the electronic refrigeration (Peltier effect) capabilities of it.

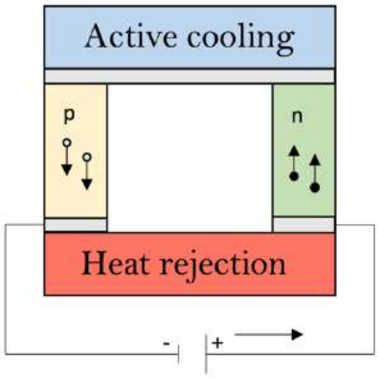


Figure 8: A thermoelectric couple made of an n-type material (electrons with black circles) and one material of p-type electrons (white circles). The diagram illustrates the electronic refrigeration (Peltier effect) capabilities of the thermoelectric module.

3.11 State of the art

Studies linked to automation of beehive have been conducted all around the world, and this chapter will summarize some of this studies that could be related to the subject of this report.

3.11.1 Label Abiele

A new "smart" beehive is in its testing phase in New Caledonia and has been developed by Axians startup company Label Abeille. The experiment involves an intelligent box (Figure 9) that can be placed under the beehive and with help from sensors register weight, temperature, direction, light and geolocation of the beehive. All this information is then sent to the customer via an app. The product has the dimensions 48 cm x 43 cm x 14 cm. The sensors and app measure the following data (*APICULTEURS*, no date):

- Mass: Evaluation of the health of your colony and the progress of honey production.
- Orientation and tilt: Indication of orientation (cardinal points) and inclination (stability of the hive).
- Brightness: Yield optimization - bee pollination period during the day.
- Temperature: Monitoring of the state of the hive (possible opening, addition of a drinker necessary...)
- Humidity: Monitoring of the state of the hive (possible opening, addition of a drinker necessary...).
- Atmospheric pressure. Prevention of weather changes influencing the behavior of bees.
- Geolocation and anti-theft alert: Saving time in organizing rounds and reporting in the event of theft via email and/or SMS alerts.

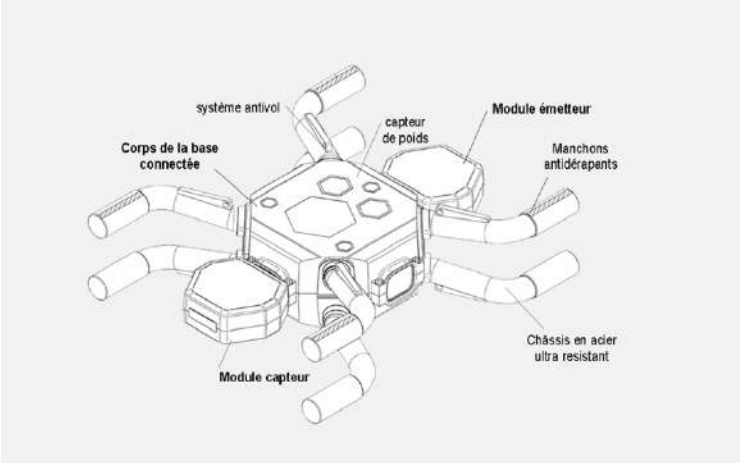


Figure 9: Sketch of the intelligent box.

3.11.2 Nomadi APP

An Italian EIP-AGRI Operational Group is installing sensors on beehives. The sensors are used to collect data and send via an app (NOMADI-APP) directly to beekeepers. The sensors that are placed in the hive collect data on temperature, weight, and humidity. Information from meteorological forecasts, pesticides and flowering times are completed to the sensor data (Ina Van Hoye, 2019).

3.11.3 Buzz-detecting beehives

Nottingham Trent University (Nottingham Trent University, 2018) started conducting research on a beehive that uses accelerometers to detect a beehives activity during winter. It is meant to give an indication of how the hive is doing, and to easier identify when something is wrong. If a hive is doing good its buzzing should be withing a certain range. If it’s either too high or too low, it may indicate there’s something wrong.

There is also hope that in the future humans can decode different kind of buzz, to determine exactly what the problem is just from the different frequencies (Underhill, 2013). However, this is still in its infant stage.

Since the hive can’t be opened during winter this is mainly to indicate that something is off. If the beekeeper is lucky, it might be an external problem that messes with the hive, and it can be resolved by them. For example, if there has been heavy snowfall that has blocked the ventilation to the hive, thus making the hive work harder to ventilate, the beekeeper can remove the snow. However, if the problem is internal, such as the queen being sick, there is nothing that can be done.

3.11.4 Department of Electrical Engineering, University, Bangka Belitung, Indonesia

In a study from Department of Electrical Engineering, University Bangka Belitung, Indonesia a design for a hive has been developed to control the temperature regulations inside the hive. The design of the hive is made in the shape of a box with an exit/entrance hole for the bees including a cover for the hive. In the hive there is an electronic circuit that starts from a DHT22 sensor, LDR sensor, TCRT5000 sensor and Infrared sensor. The temperature setting works between the intervals of when the temperature is below 28 ºC and when the temperature is between 28 ºC and 35 ºC. When the temperature is below 28 ºC the lights and fans are OFF and when the temperature is between the interval of 28-35 ºC the light is OFF, and the fans are ON. In the electronical circuit a Arduino is installed and acts as a microcontroller that get analog and digital data from the sensors, from this Arduino sends the data to Nodemcu (that is connected to Wi-Fi) which sends the data to a Blynk server and from this the sensor reading can be displayed on a smartphone (Fard Hanarkan, 2020). The system design diagram for this solution is presented in Figure 10.

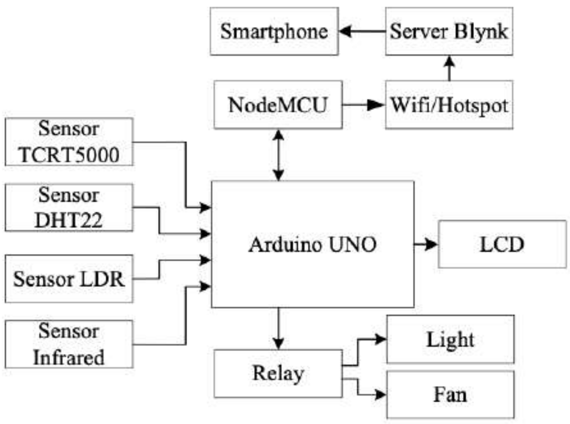


Figure 10: System Design Diagram (Fard Hanarkan, 2020)

3.11.5 Application of wireless sensor networks for beehive monitoring and in-hive thermal patterns detection

In Brazil it has been investigated on how the high temperatures affects the beehive during the year, the results have showed that many bee colonies are lost due to colony absconding. To alert the beekeepers about when its overheating inside the hive an automatic mechanism has been developed to determine based on thermal patterns when this happens. The clustering-base mechanism consisted of a regulated approach from the thermal patterns which identifies readings outside the expected range. To assess the integrity of the history of thermal patterns and the sensor data that was collected from the field consisting of temperature data from a hive a proactive and continuous monitoring via WSN was used (Kridi, de Carvalho and Gomes, 2016).

4 Customer Need Identification

This chapter present the steps within the process of identifying numerous issues linked to beekeeping followed by a selection of target subjects.

4.1 Field study

In the very start of this project, the project group visited Linköping Beekeepers Society at two separated occasions. At the fist occasion the project group met the beekeepers at the society for the first time, and the beehives was showed. In the meantime, there was an ongoing conversation about the general functions and roles in a bee colony, and questions about the hive and problems during the winter season was answered. At the second occasion the wintering procedure of the bees and the honey extraction was executed by the beekeepers, which was studied by the group and each step was explained by the beekeepers. These studies introduced some important knowledge to the project area, a step-by-step observation of the process of wintering the bees as well as a first understanding of all the parts in a hive.

4.2 Meeting with META-HILIGHT representative

In the second week of the project the project group had a meeting with a representative from META-HILIGHT consortium to update him about this project. A communication was held about so-far identified problem areas to regarding winter losses of bees and some general, more wide suggestions was given on how metasurface and sensors could be used. This gave a better understanding of the meta surface topic and how sensors and metasurfaces can be integrated into the project.

Some of the sensor types and possibly suitable areas of use for this project that was brought up by the META-HILIGHT representative was:

- IR-cameras: To identify the queen and detect the movement of the cluster. An idea to use IR to not disturb the bees with any light.
- Compact microscope: Identify pests
- Spectroscopic image: Make usage of the information from different wavelengths. Gases have different wavelengths. By adapting gas-sensors it can tell something about the health of the colony – predicted that some disease generates a special kind of smell and therefore gas.
- Temperature sensors and regulation
- Combined biological technology and small optic technology: disease for bees might be detected through the honey.

4.3 Interviews and Questionnaire

The general idea was to generate a relaxed atmosphere for the interviews and making them feel more like a conversation rather than an enquiry. By this reason, a mind map (Figure 11) based on identified problems areas was created and could be used as a guide for the interviewers during the interviews to cover all areas, rather than following prepared questions exactly. However, several questions were prepared for each problem area. The interviews were conducted at the premises of Linköping's Beekeeping Society, and 3 people were interviewed. The project group, consisting of six people, divided into pairs where one asked question, while the other took notes and asked any follow-up questions.

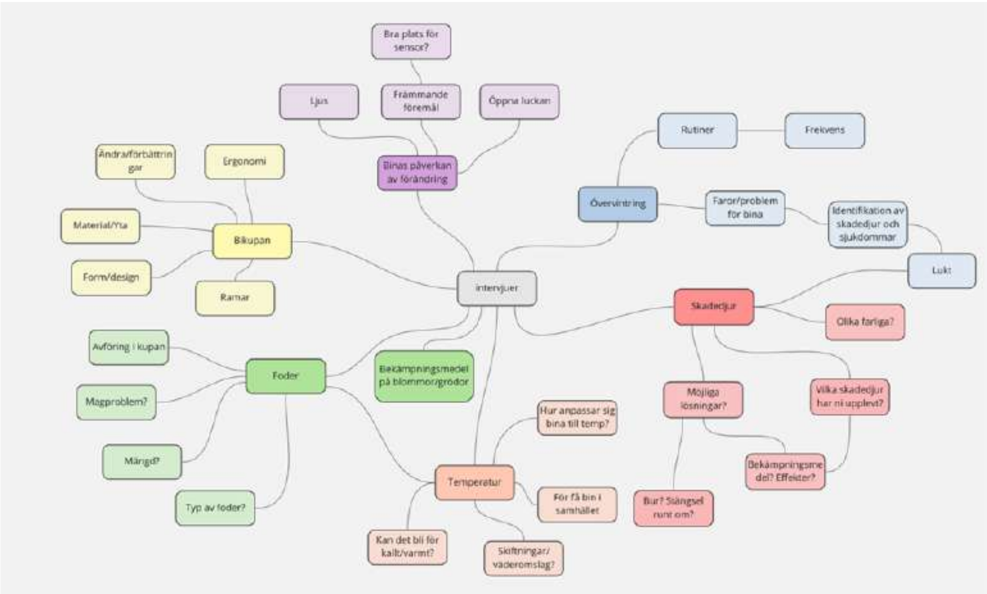


Figure 11: Illustrates the mind map that the project group aims to use as a guide to create and ask questions that covers all areas of interest on the interviews with the beekeepers.

The questionnaire was based on the same questions that was prepared from the interviews. The main differences are that the questionnaire contains less questions in total, basically by using less free-text answers. Instead, the questionnaire contained questions that could be ranked to facilitate an evaluation of the data in SPSS. The investigation of problems areas during the winter season was first asked as a free text question, and later the respondent could rank seven problems areas from 1-5. The questionnaire was posted at Facebook-groups for beekeepers to mainly reach out to hobby beekeepers and emailed out to beekeepers that has beekeeping as a profession.

4.3.1 Summary of interviews

Each of the three interviewed persons have been informed about the aim with this interview and how it is related to the project. They are told that the project group do have any intentions of destroying the beekeepers' interaction with the bees but will rather look at development potentials to ease their work and save more bees during the winter. All three of the interviewed persons have agreed anonymously be used as references in this report and will be referred to as P1, P2, and P3. The answers and information given during the interviews are summarized in Appendix 1 – Summarized answers from interviews. The most relevant takeaways are given below.

The three interviewed persons have been active beekeepers from 9-20 years and all of them are using variants of Langstroth hives. P1 is visiting and checking on the hive each ten days, whilst P2 and P3 is not doing it until spring. P3 informs that only reason he might visit the hive earlier is to remove snow from the bee entrance, or dead bees from the bottom grid, to facilitate ventilation and reduce the risk of mold. All of them informs that you should try to disturb the bees as little as possible and not open the top cover during the winter to protect them from the cold. Another reason is that moisture might enter the hive which, according to P1, can destroy the whole colony. Moisture leading to Utsot and mold in the hive and feed is mentioned as a problem by all three respondents, why they also point out the importance of ventilation.

They explain that the bees can regulate the temperature in the hive themselves and informs that the clustering is how the bees are keeping the heat during winter. P2 says that keeping warmth in the hive is not a big problem because of this, P3 explains that a cold outside temperature is preferable. All three respondents inform that drastic temperature changes and warmer days may trick the bees to leave their winter cluster too early. The bees might leave the hive to empty their stomachs outside the hive and dies in the cold or snow. Furthermore, they explain that when bees are in cluster, they are not using much energy, but they get unsettled by temperature variations and start to move more and as a result use more energy and feed. Then the feed might run earlier than wanted, and too much feed is not good either. P1 even states temperature changes to be one of the worst dangers during winter.

P1 explains that Varroa mites are very common and means that all beekeepers are affected by it. Another disease is American foulbrood. In short, P1 explains that Varroa mites are very common but not a too severe problem, and that American foulbrood are rare but more critical. He says that during autumn, formic acid as well as oxalic with sugar and water can be used to prevent Varroa. P3 says that Varroa can weaken the bees, which makes them more receptive to viruses, which in turn can kill the bees. When hive is affected by American foulbrood, the consequences are bigger as you need to kill and disturb the entire colony and hive, P3 says. P1 tells that American foulbrood cannot be identified without opening the hive as it only appears in the brood box. P1 informs that mice like the sweet beeswax might entering the hive via the bee entrance and during spring when the bees are starting to leave the hive, birds can sit outside pecking and eating them. P3 explains that it is hard to prevent any present mice to enter the hive but if they do, the bees are accepting them and think that birds might disturb the bees a little but perceives it as a negligible problem.

None of the three respondents think that foreign objects in the hive would affect the bees significantly, but they explain that bees want to cover cracks and irregularities with wax. Bees are not as likely to build on flat surfaces they inform, and P1 suggest that if a camera would be used, the lens should be well integrated or behind some sort of glass.

About the structure of the beehive, P2 thinks that a Langstroth hive is good, and that the only disadvantage is the weight. He explains that when using four boxes placed on a stand, the topmost box is getting very heavy, especially since that box is always filled with honey. There are hives made of Styrofoam which are lighter and are easier to lift, but they are too light in a storm and are not as durable, P2 informs.

4.3.2 Evaluation of questionnaire

In total 82 respondents answered the questionnaire. The free text question regarding wintering problems was formulated as

"What are, according to you, the main problems, or dangers for bee colonies during winter?"

where the respondent could type in any word or explanation. The answers from this question, as well as details from other questions, were categorized into ten problem areas:

- External disturbances
- Starvation
- Lack of feed
- Varroa and diseases
- Wintering of weak colony
- Temperature variations
- Moist
- Bad ventilation
- Sabotage
- Problems are dependent on other seasons

An important notation is that external disturbances have a quite wide definition. This is because some respondents simply typed "external disturbances" as a problem, whilst some mentioned animals, mice, birds, and other factors such as roadwork and vibrations disturbing the peace and quiet in the hive as a problem. These were all categorized into the problem area "external disturbances". Furthermore, some respondent's answers that if bees die during winter, it is only dependent on what is done throughout the months before winter. This problem area is not taken into further consideration as the scope of this project is focusing on problems during winter season.

Another free text question was

" *From the perspective of the beekeeper, how could the beehive be redesigned to ease the beekeeping work?"*

The evaluation of this question shows that 23% states that the handling of boxes are heavy, and that the ergonomics could be improved. Some suggestions connected to these answers are that the handles could be improved and that, even if it is not winter related, a possibility to check the brood box without lifting off all the boxes above would ease the work.

The questions that could be ranked with a number from 1-5 were asking how common it is that each problem area is the reason for bees dying during winter season. The summation of the values for each of the seven problem areas that could be ranked are presented in Table , where a higher value indicates a more common or problematic area.

Table 5: Is presenting the summation of how each of the seven problem areas were ranked.

Problem area	Summation of ranking	Comment
Varroa/diseases	234	Not bounded to winter
Temperature/weak colony	210	
Starvation	203	A consequence of other problems
Temperature variations	178	
Moist	175	
Mice	167	
Poor supervision	136	

Table 5 indicates that Varroa/Diseases, Temperature issues due to weak colonies and Starvation are the three main problems during the winter season. As mentioned in theory as well as from the interviews Varroa and diseases is not bounded to the winter season but is a constantly present phenomena, even if the consequences may be prominent during the winter season when many bees are dying. As commonly stated in responses from both the questionnaire and the interviews it is hard make an action about diseases during the wintering since you should never open the hive at that time. What can be done to treat varroa is done in the procedure of preparing for the wintering. Further, starvation is not an independent problem but is rather a consequence occurring from other problem areas. By this argumentation, the three main problems are Temperature/weak colony, Temperature variations and Moist.

The argument that Varroa/diseases is independent is motivated further by performing a factor analysis of the ranked questions. A factor analysis is used to reduce a big number of variables into a smaller set that basically contains the same information. The factor analysis is made in SPSS and the total variance presented in Figure 12. It shows that by using two components it covers 50% of the variance, which is a little too low in terms of making a function analysis. A percentage around 60% is okey and ideally the chosen components should capture around 80% of the variability. The number of chosen components should be the ones with Eigenvalue > 1. It can be seen in the plot in Figure 13 that the two first factors are summarizing most of the information in the data set and that components 1 and 2 are >1 and that component 3 is just on Eigenvalue =1. Component 1 and 2 are used, since two components yield two axes which are easier to analyze.

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.366	33.795	33.795	2.366	33.795	33.795	2.325	33.210	33.210
2	1.136	16.223	50.018	1.136	16.223	50.018	1.177	16.808	50.018
3	.995	14.217	64.235						
4	.842	12.028	76.262						
5	.727	10.391	86.653						
6	.532	7.595	94.249						
7	.403	5.751	100.000						

Extraction Method: Principal Component Analysis.

Figure 12: Presenting the Total variance table from SPSS showing that by using two components 50% of the variance.

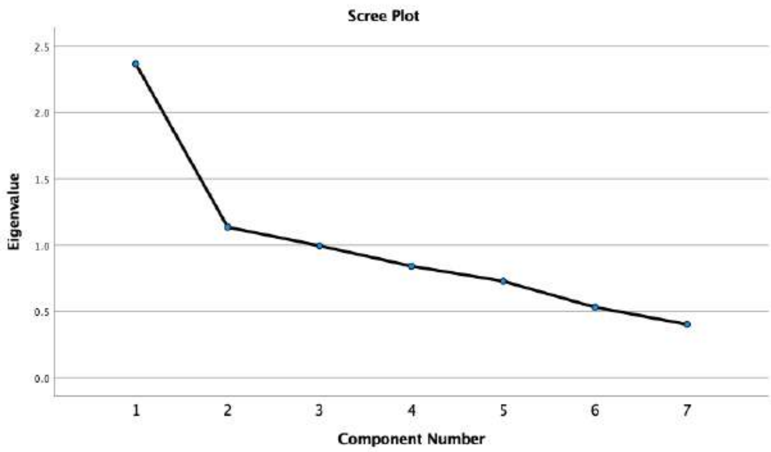


Figure 13: A scree plot illustrating that the gradient of the plot is biggest for the two first components, indicating that the two first factors is summarizing most of the data set.

Even though the total variance is not optimally distinct to get a fully usable analysis, the result can be interpreted in the Component plot in Figure 14. The problems that are positioned close to each other means that they are related to each other. The clusters at 90 degrees from each other indicates that they are completely independent, meaning that Varroa/Diseases is not related to the bigger cluster.

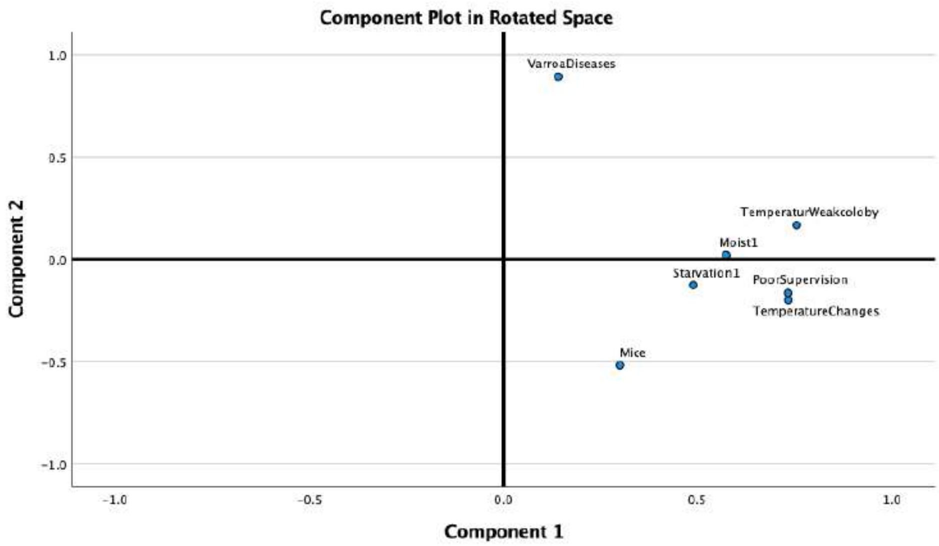


Figure 14: The result from analyzing the ranked questions in a component plot. Problem areas that are Table closely positioned are related to each other whilst problem areas located at 90 degrees from each other indicates that they are independent from each other.

4.3.3 Identified problem areas from interviews and questionnaire

The identified problem areas from the interviews and questionnaire are presented in Table 6 and mentioned reasons and consequences to each problem area are noted.

Table 6: The identified problem areas from the interviews and the free text answers from the questionnaire.

Problem	***Reason***	***Consequence***
External disturbances	Birds picking on hive Animals Vibrations from machine Infestation of mice	A concern in the hive leading to starvation Fallen trees or bigger animals disturbing the hive Bees become curious, are eaten up by birds when going out Mice eating beeswax
Varroa and diseases	Varroa leading to poor immune system and viruses Moist in the hive Poor hygiene in hive and among used tools Spread of diseases trough other bees and tools	Weakened by Varroa Diseases leading to “Utsot”
Weak colonies	Wintering too weak/small colonies Many bees died during winter due to other reasons	Hard to keep up the temperature Old bees die during winter season “Utsot”

Temperature variations		Leaving cluster, energy consumption increases, eats more and the food will not last. Leading to starvation Fools the bees that it is spring. Dies due to snow or when it gets cold again. Death of the queen
Moist	Bad ventilation	Mold Virus growth
Bad ventilation	Fluster and ventilation-grid covered in snow Dead bees covering the ventilation-grid at bottom	Oxygen deficiency Moist “Utsot”
Starvation	External disturbances Temperature variations Lack of /Portioning of feed	Dead bees at the bottom of the hive
Sabotage	People sabotaging the hive	

5 Problem Selection

From observations and interviews with Linköping's Beekeeping Society in combination with literature studies and insights from the questionnaire, 11 main problems are identified. The symptoms of each problem, possible tools to detect the issues and actions that could be taken to handle it are listed in Table 7. Below the table motivations follow to why each problem was chosen or not. In this section, the infestation of mice problem is separated from External disturbances and "Varroa and diseases" are separated into Varroa and American foulbrood.

Table 7: The identified problems, symptoms, suggestions for detection and possible measures. Green color represents the selected problems, and yellow color indicates that the problem somehow will be covered.

No.	*Problem*	*Symptoms*	*Tools to detect*	*Measurements*
1	American foulbrood	Changes in beeswax Bad odor Pheromones Visible	Spectroscopic measurement Gas-sensor IR-camera	Clean/burn beehive
2	Varroa	Visible Pheromones	IR-camera Gas-sensor	Formic acid Oxalic acid Thymol
3	Temperature variations	Irregular food intake Dead bees outdoors	Temperature sensor/thermometer	Regulating temperature
4	Moist	Mold	Spectroscopic measurement	Ventilation
5	External disturbances	Vibrations from outside	Vibration-sensor	Barriers
6	Bad ventilation	Dead bees at bottom Utsot	Spectroscopic measurement	Ventilation
7	Wintering weak colonies	Small amount of winter bees Utsot	Spectroscopic measurement Camera	Regulating temperature Join colonies
8	Heavy and non-ergonomic handling of hive	Pain among beekeepers		Lift from side
9	Portioning of feed, Starvation	Dead bees at bottom		
10	Infestation of mice	Nest building in hive Eaten beeswax Bees get eaten	Camera Weight scale	Barriers
11	Sabotage	Broken or stolen hive		

Problem 1: American foulbrood is a serious disease and can lead to destruction of both the hive and colony of bees. The spores attack the larvae and is difficult to detect as cleaning bees removes dead larvae's before covering the cells. When multiple cells have identifiable symptoms, it's usually too late to save the colony. Since the disease is no longer as common in Sweden and is not mainly present during the winter season, this was not chosen as a focus area.

Problem 2: The Varroa appears to be a constant issue for the beekeepers and is treated each year with different acids. However, if a lot of Varroa would be detected during the wintering season, no additional actions would be performed. Therefore, Varroa was not chosen as a focus for this project.

Problem 3: During winter and early spring, outdoor temperatures can vary drastically over a short period of time. Bees consume as little energy as possible when it is cold outside, which requires less food. When the outside temperature rises, the need for food increases, making it more difficult for beekeepers to ensure adequate food supplies for the bees, which can lead to starvation. In addition, temperature fluctuations can cause bees to leave the hive too early in winter and die from cold or snow. From the ranked questions in the questionnaire this problem was one of the main problem areas that are connected to the winter. This issue has been chosen because it is clearly connected with the survival of bees during the winter and possible solutions are within the competences of the project group in thermal regulation.

Problem 4: Moisture has been pointed out as a problem as it can lead to mold in the hive. Mold is dangerous for bees and can lead to their death. This aspect has also been partly chosen to be included in the scope as it's a problem connected to the temperature in the beehive.

Problem 5: External disturbances was an issue frequently mentioned by the respondents of the questionnaire. This could include sounds and vibrations from the environment, where birds picking on the beehive and lawnmowers nearby were some given examples. An important note is that the definition of this problem is wide and includes several smaller topics which is a contributing factor to the high percentage. In the interviews the beekeepers did not think these factors have any high severity level. The problem was not chosen because it is not clearly limited to the winter and are not considered as the most problematic issue.

Problem 6: The ventilation is essential to avoid moist and mold in the beehive. During the winter, the entrance and ventilation grid can get covered by snow, reducing the ventilation in the hive. Bad ventilation could also be a consequence of dead bees covering the ventilation grid at the bottom of the hive. This problem was not chosen but could indirectly be improved if temperature regulation would result in a smaller number of bees dying during the winter season.

Problem 7: A critical factor for the survival of the bees during the winter is that the colony is fit enough and that there are enough of them. It can be difficult for the beekeeper to identify whether the colony is large enough as there could be many summer bees left going into wintering. Those will not survive the winter and dies in a near future. Another reason why colonies reduce in quantity during the wintering is because they are weakened by varroa or viruses. If the colony is too weak or too small, they can have a tough time keeping the temperature in the hive, resulting in the bees freezing to death. Like temperature variations and moist, this problem area was considered as the top three most problematic of areas connected to the winter in the questionnaire. This problem was not directly chosen to specifically investigate since it is the beekeepers' responsibility to not wintering too weak colonies but will be partly solved by regulating the temperature to help small colonies keep up the temperature and thus improve the chance of surviving the winter. They can then be merged with another colony in the spring.

Problem 8: The process of extracting honey is a part of the beekeeper's preparation for the wintering season. The boxes are heavy to lift when they are filled with honey, a problem that has been addressed by the beekeepers both from interviews and the questionnaire, especially as many are elderly. The project group has competence in design and ergonomics, thus improving lifting and interaction with the has been an area chosen to focus on.

Problem 9: It is the beekeeper who make sure that the portioning of feed is enough for the wintering, and it is explained in one of the interviews that during normal circumstances around 16-20kg of feed is normally enough. As presented in Table starvation is mentioned as the top three largest reason to why bee colonies die during the winter season, but as mentioned earlier "Portioning of food" and "starvation" is rather a consequence from the other problems explained. For example, temperature variations and general concerned environment in the hive are common reasons for starvation. Therefore, this problem is not chosen, but might be positively affected.

Problem 10: Invasion of animals is not uncommon during the wintering season. It's mainly mice that are small enough to get through the entrance and use it as a winter residence. There are existing barriers that can be mounted to prevent the mice getting inside the hive. This issue has not been lifted as a critical issue for the survival of the bees during the winter and was thereby not chosen.

Problem 11: Sabotage is a rare problem and is not a fundamental reason why bees die during the winter season and by this reason this problem was not chosen.

Problem selection summary: The two chosen problems to solve are nr 3 - *Temperature variations* and nr 8 - *Heavy and non-ergonomic* handling of hive. Problems that are partly chosen or will be positively affected by the two chosen problems are nr 4 - *Moist*, 6 - *Bad ventilation* and 7 - *Wintering weak colonies*. The main problems are defined as two tasks to solve, where the relations between the issues are visualized in Figure 15.

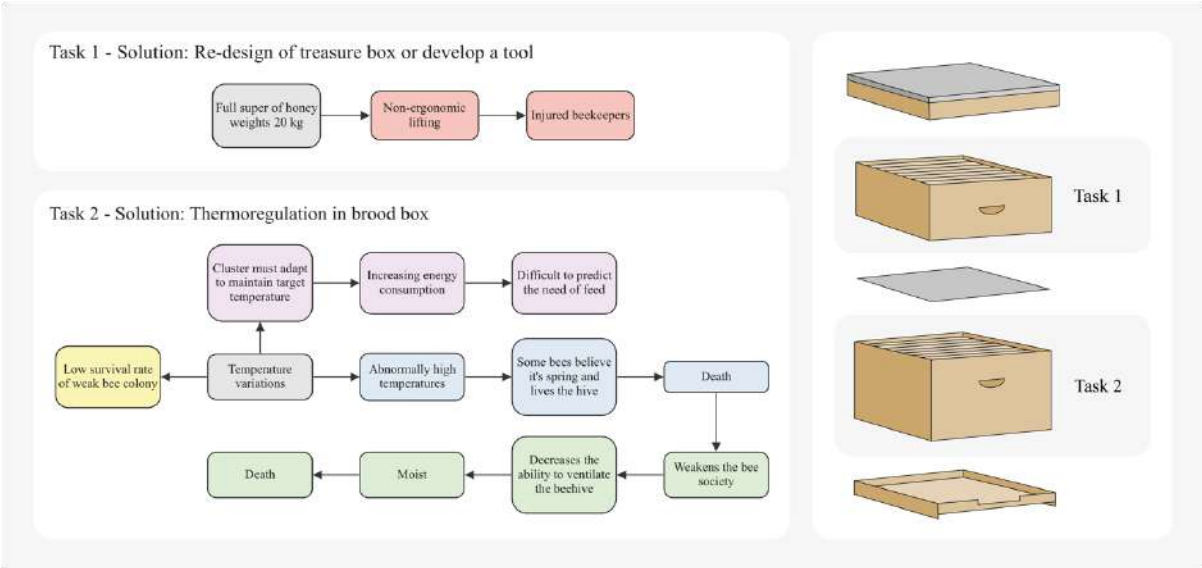


Figure 15: The two tasks with relations between the problems and what part of the hive they target.

The first task targets the treasure box, which gets heavy when it's filled with honey prior to the winter season. For the second task, the brood box is in focus to look minimize the temperature variations during the winter.

In conclusion, it was decided that problems **4** and **8** were chosen and will thus be the problems that will be looked at further in the work.

5.1 Ergonomic interactions with the hive

There are processes within beekeeping when the treasure boxes are lifted down, i.e., when they honey are be extracted, in the process of overwintering and when checking the health and status of the queen at the lowermost brood box.

Each of the treasure boxes that are lifted down contains about 10 frames filled with honey. Every honey-covered frame wights about 2 kg, resulting in a total wight of more than 20kg for each box. Usually, up to four treasure boxes are stacked on top of each other, with a brood box standing at the bottom. Further, the hive is usually placed on a construction or a hive-stand a bit up from the ground. This results heavy lifting from a quite unergonomic height.

5.1.1 Calculation of recommended lifts for Beekeepers

According to the NIOSH guide for the recommended lift one can make without risk of injuries (see the chapter *Manual lifting*) can be calculated. The variables used for testing can be seen in Table 8, which has been measured or approximated with the beekeepers.

Table 8: Variables used for the NIOSH equation with explanations.

Variable	Explanation
$H_m = \frac{25}{45} = 0.556$	H = 45 cm *Distance between feet and gripping position*
$V_m = 1 - 0{,}003\ \lvert 40 - 75 \rvert = 0.895$	V = 40 cm *Height of the lowest position of the lift*
$D_m = 0{,}82 + \frac{4{,}5}{87} = 0.872$	D = 87 cm *Difference between the highest and lowest position of the lift*
A_m = 1	Set to 1 – *the lift is not twisted*
C_m = 1	Set to 1 – *there are good grips*
F_m = 1	Set to 1 – *there are few lifts during a short period*

Thus, the approximated recommended lift of the treasure box is:

$$L = 23 * 0.556 * 0.895 * 0.872 * 1 * 1 * 1 = 9.98 \text{ kg}$$

5.1.2 Ergonomic interactions during honey extraction and overwintering

The overall process can be divided into two types of ergonomic interaction with the hive, which are “Lifting down the boxes” and “Carrying the boxes”.

Lifting down the boxes:

The beekeepers explain that before the hibernation and final honey extraction the aim is to position all bees at the brood box. To achieve this, the day before, all treasure boxes except the first one is lifted down and the bees on the frames are shaken and brushed off down to the bottom treasure box. Between the brood box and the first treasure box a “bee-emptying-bottom” are placed, this special bottom is leading the bees down to the brood box, but they are not able to travel up to the treasure box again. This procedure includes heavy lifting from uncomfortable heights, about 130cm above ground.

Carrying the boxes:

Each frame filled with honey, without any bees are gathered and put into an empty box one by one. When this external box is filled with honey frames, it will be carried to the extractor or somewhere waiting to be extracted. This bulky box has again a weight up to above 20kg.

On the second day, the bees that are still in the treasure box are brushed down to the ground and are then able to enter the brood box via the bee entrance. These remaining frames will again be placed in an empty box that is then carried to storage or directly to extraction.

5.1.3 Ergonomic interactions throughout the year

Other common activities related to ergonomics for the beekeepers include checking the brood box, often to see how the queen is doing. As the brood box is in the bottom, all the other boxes must be lifted down just to open the box and thereafter lifted back in place again.

Another activity consists of reorganizing the treasure boxes as they get filled with honey. The bees build honey from the bottom and up. When the box right on top of the brood box is filled with honey, a new box with empty frames replaces it and the filled box is moved upwards. This means that heavy boxes filled with honey must be moved up and down.

5.2 Thermoregulation problem

There are different critical factors for a bee colony to survive the winter. Things as the size of the colony, the weather, and the food play a big role in the health of the bees. To begin with the bees does not leave the hive during the winter, this partly because of the lack of food but also that they would not survive the coldness. To survive the coldness, they form a cluster to protect their queen. The movement of the wings creates heat, and the further in you reach into the cluster, the hotter it gets. The coldest of days on the year, it is required a large and healthy colony to keep one tight and large cluster.

5.2.1 Food consumption

While it is time for preparing the bees for the winter, the beekeeper places a box of sugar solution in top of the brood box. Since it is impossible to predict the weather during the winter, a roughly calculated amount of food is given. However, the bees adjust its size of the cluster depending on the outer temperature. The hotter the temperature is, the larger they tend to keep its cluster. A larger cluster results in more movement which in its turn result in more energy consumed and an increased food intake.

By knowing the size of the colony together with the ability to control the temperature within the hive would it be possible to intentionally adjust the size of the cluster. This would result in the possibility to calculate the average energy consumption as well as the average food intake, and thereby know the amount of sugar solution that is best for the bee's health and prevent starvation.

5.2.2 Heavy temperature changes

As described earlier in this section the bees adjust its cluster according to the outer temperature. In most cases, if the colony is not too small or weak, the bees can survive the coldest of days.

One common problem is that the bees get tricked by abrupt weather changes. This means that often during spring, when the weather as well as the temperature changes a lot, bees believe that it is warmer outside the hive than it is. The bees cannot survive the coldness and dies if they are leaving the hive. Which in its turn results in a weaker colony further on.

If the outside temperature could be stored and then be looked at over time, it would be possible to have a continuous temperature within the hive and then neglect the abrupt changes. The previous week, or other fair period, can give a median which then could be the target temperature for the heating system. The heating systems role will then be to delay and lower the temperature tops and bottoms.

5.2.3 Mold

Mold are fungi and thrive in areas with high moisture and can therefore grow in hives, which usually are moist. Bees can maintain the right moisture content in their hives, but sometimes i.e., in humid weather, they can fail to regulate it. There are a couple of reasons why this could happen, but some of the most common are bad ventilation, worn-out products, dead bees, woof fragments or other waste.

The upside of a scattered colony, i.e., not a tight cluster, is that the bees get more room to flap. Through movement does a natural ventilation get rid of several problems such as moist and mold within the hive. Another reason to bad ventilation is a weak colony. By regulating the temperature, the health of the hive and the size of the cluster could be adjusted. This means that it is theoretically possible to amend the ventilation by regulating the temperature. This solution could result in a reduced mold but also virus growth and Utsot.

6 Product Specifications

Several functions linked to identified needs from previous chapters are converted into product specifications in two Construction Criteria Lists, one for ergonomics and one for thermoregulation. Each function is formalized as a short informative sentence and graded due to its level of importance as Required (R) or Desired (D).

The brood box is rarely moved, and it is mainly the treasure boxes that are lifted, transported, and considered heavy. Hence, only the treasure boxes are considered in the ergonomic issue. The Construction Criteria list for the ergonomic issue can be seen in Table 9.

All treasure boxes are removed during the winter months, thus only the brood box demands thermoregulation. The Construction Criteria list for thermoregulation can be seen in Table 10.

Table 9: Construction criteria list for ergonomic solution (R - Required, D – Desired)

1.	**Function**	**R/D**
1.1	Easy assembly and disassembly	R
1.2	Reduce manual lifts over 10 kg	R
1.3	Reduce number of manual lifts	D
2.	**Function-determining properties**	
2.1	Low unit cost	D
2.4	Easy to use and adapt into current routines	R
2.6	Adaptable to other parts	R
2.7	The concept should not generate more corners/slits (leading bees sealing it with beeswax/propolis)	R
3.	**Service life characteristics**	
3.1	Resistant to all kind of weather	R
3.2	Easily demountable	D
3.3	The frames shall be easily accessible	R
3.4	The components should be easily accessible for maintenance	R
3.5	Extend the products lifetime	D
4.	**Manufacturing features**	
4.1	Manufacturable in the university's workshop/machine park	D
4.2	Lower the material usage	D
5.	**Distribution characteristics**	
5.1	Shippable unit	R

6.	**Delivery and planning features**	
6.1	A prototype	R
7.	**Safety/ergonomic features**	
7.1	Easily manageable	R
7.2	Ease the movement of carrying the box	R
7.3	Good grips	R
7.4	Lower the weight	D
8.	**Aesthetic properties**	
8.1	Meet form criteria, traditional hive	D
9.	**Law features**	
9.2	Exclude hazardous substances	R
10.	**Economic features**	
10.1	Meet the budget criteria	R
10.2	Affordable unit for beekeepers	R
11.	**Scrapping and recycling properties**	
11.1	Increase end-of-Life potential	D

Table 10: Construction criteria list for thermoregulated brood box (R- Required, D-Desired)

1.	**Function**	**R/D**
1.1	Monitoring the temperature inside the brood box	R
1.2	Monitoring the temperature outside the brood box	R
1.3	Decrease the temperature inside the brood box	R
1.4	Increase the temperature inside the brood box	R
1.5	Maintain the temperature inside the brood box in the range of -2,5 °C and +2,5 °C from the mean temperature of the four past days	R
1.6	Not generate vibrations	D
1.7	Diminish the growth of bee wax on components	D
2.	**Function-determining properties**	
2.1	Low unit cost	D
2.2	Be able to adjust temperature	R
2.3	Resistance against common external stresses	R
2.4	Adaptable to other parts	R

3.	**Service life characteristics**	
3.1	Resistant to all kind of weather	R
3.2	Easily demountable	D
3.3	The frames shall be easily accessible	R
3.4	The components should be easily accessible for maintenance	R
3.5	Extend the products lifetime	D
4.	**Manufacturing features**	
4.1	Manufacturable in the university's workshop/machine park	R
4.2	Lower the material usage	D
5.	**Distribution characteristics**	
5.1	Shippable unit	R
6.	**Delivery and planning features**	
6.1	A prototype	R
6.2	Basis for how META HILIGHT can be implemented	D
6.3	A full-scale prototype of a beehive with implemented temperature regulation system	D
7.	**Safety/ergonomic features**	
7.1	Easily manageable	R
7.2	No components that can provide a risk to start fire	R
7.3	Minimize sharp ends	D
7.4	Low risk for the bees to be overheated/cooled	R
8.	**Aesthetic properties**	
8.1	Meet form criteria	D
8.2	Shall be able to implement in beehive	R
9.	**Law features**	
9.1	Meet environmental laws	R
9.2	Exclude hazardous substances	R
10.	**Economic features**	
10.1	Meet the budget criteria	R
10.2	Affordable unit for bee harvesters	D
11.	**Scrapping and recycling properties**	
11.1	Increase end-of-Life potential	D

7 Idea generation

The two questions we addressed during the idea generation session were based on our problem areas ergonomics and temperature. Five group members participated in the first part of the idea generation, of which two acted as facilitators in the exercises in addition to participating themselves. The first question was defined as "*How could the ergonomics when interacting with the hive be improved?"*, and the second as *"How could the temperature be kept stable in the hive?"*. The structure of the session is presented in Table 11.

Table 11: Idea generation methods with estimated time (excluding discussion) and goal of each step.

No	***Method***	***Time***	***Goal***
1	Speedstorming	6 min	Warm up, generate many ideas
2	Analogies	10 min	Facilitate thinking in different perspectives
3	Dark Horse	5 min	Trigger ideas outside of the box
4	Affinity Diagram	10 min	Collect and categorize ideas
5	Tree Diagram	–	Narrow down ideas and structure them

The *Speedstorming* was carried out by placing the two written questions on each side of a table and the participants brainstorming individually for 3 minutes per question. When both sessions were completed, a short presentation and discussion about the solutions was held.

For the method *Analogies* four questions were used. Each question got 2 minutes to come up with ideas, and like the *Speedstorming,* a short presentation and discussion about the solutions was held when the session was finished.

Dark Horse was used to get the last few ideas out on paper. Each question got 2 minutes of time followed by a short discussion of solutions, alike the previous methods.

1. How would a child solve the problem?
2. How would a rich person solve the problem?
3. How would the old beekeepers solve the problem?
4. How would an industrial beekeeper solve the problem?

From step 1-4 a large number and variety of ideas were generated. Those were collected on a whiteboard, where identical ideas were put on top of each other, and similar ideas placed close to each other and categorized. To get a clearer picture of the result, the ideas for the two problem areas were put in a Tree Diagram, see Figure 16 and Figure 17. This was done with the tool Miro to be able to access the result digitally.

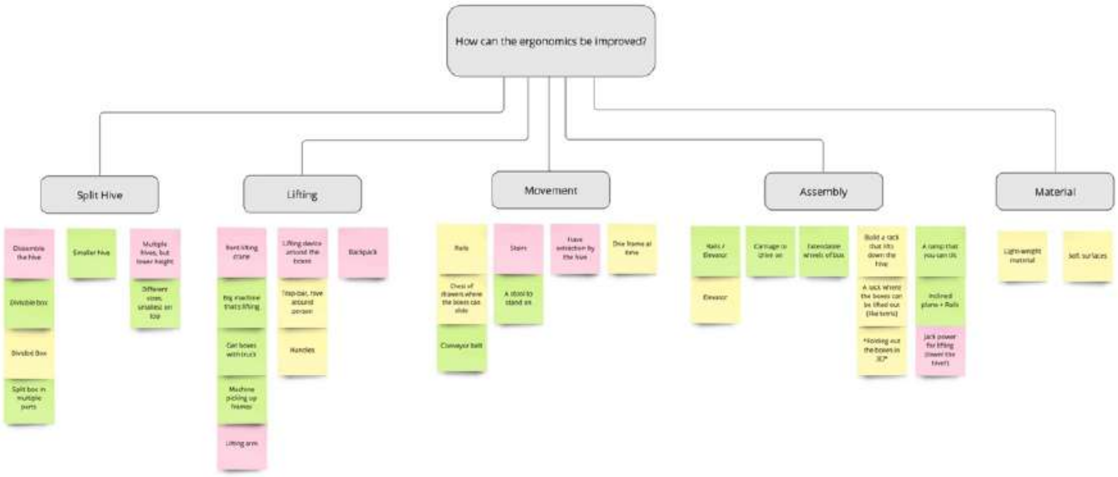


Figure 16: Tree diagram of ideas connected to ergonomics.

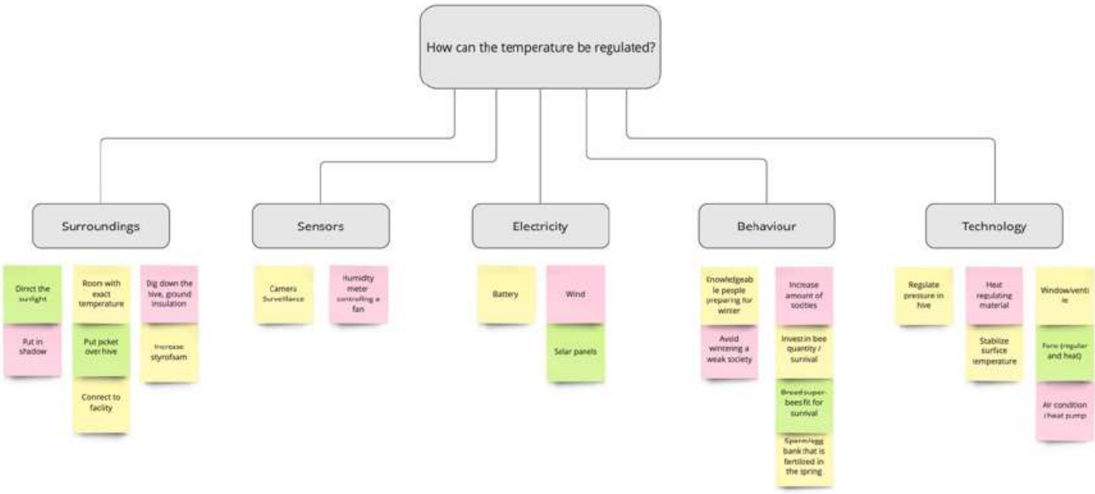


Figure 17: Tree diagram of ideas connected to temperature.

8 Concept generation

This chapter explains the process of generating concepts for two tasks as well as presenting the generated concepts.

8.1 Ergonomics

For the ergonomics task, various functions and solutions was combined into six concepts out from the reduced concept tree, see

Figure 18.

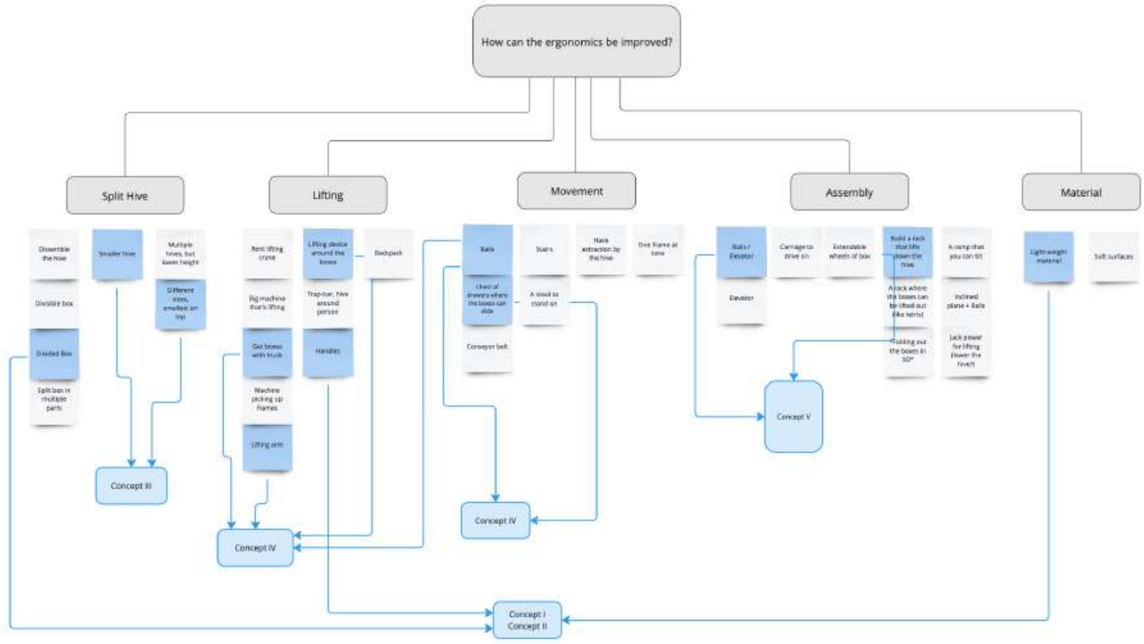


Figure 18: Affinity Diagram of the five ergonomic concepts.

The generated concepts are defined as:

Concept I: Divisible box (horizontal split)

Concept II: Divisible box (vertical split)

Concept III: Block towers

Concept IV: Truck/Lifting device

Concept V: Industrial drawer

Concept VI: Rails and elevator

The initial sketch for each concept is presented in Appendix 2 – Ergonomic Concept sketches.

8.2 Thermoregulation

The reduced concept tree resulted in two concepts of the system setup for the thermoregulation task, see Figure 19. Those two concepts are explained in further detail below.

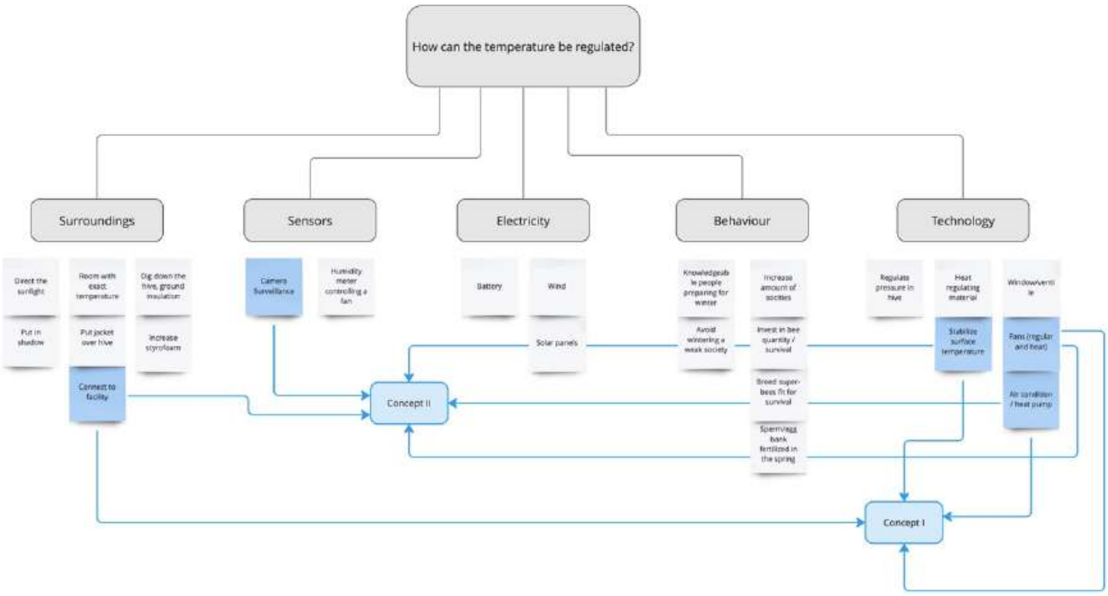


Figure 19: Affinity Diagram of the two thermoregulation concepts, with the main difference of implementing a camera in Concept II.

8.2.1 Implementing in beehive

There are a couple of approaches that are possible for this problem. We have chosen to focus on regulating the heat within the walls. In a regular hive there is isolation, but by replacing the actual isolation and placing it on the outside, we could use the space within the walls to create a closed system to regulate the temperature around the hive, see Figure 20. This benefits an even distribution of heat around the entire hive and helps create a natural low-pass filter. If heat would have been applied directly on to the hive from different spots, it would be hard to estimate the temperature within the entire hive which means difficulties choosing measurement spots to get a correct and wanted temperature. Measurement within the hive also forces a solution on where this placement should be. Both because of the continuous movement of the cluster and the bees' instinct to build vax on everything, the measure of temperature within the hive would be inaccurate. The temperature in one corner and in the middle of the cluster could vary a lot and therefore there is more important to adjust how the bees perceive the temperature. The perception could therefore be essential for the behavior of the bees.

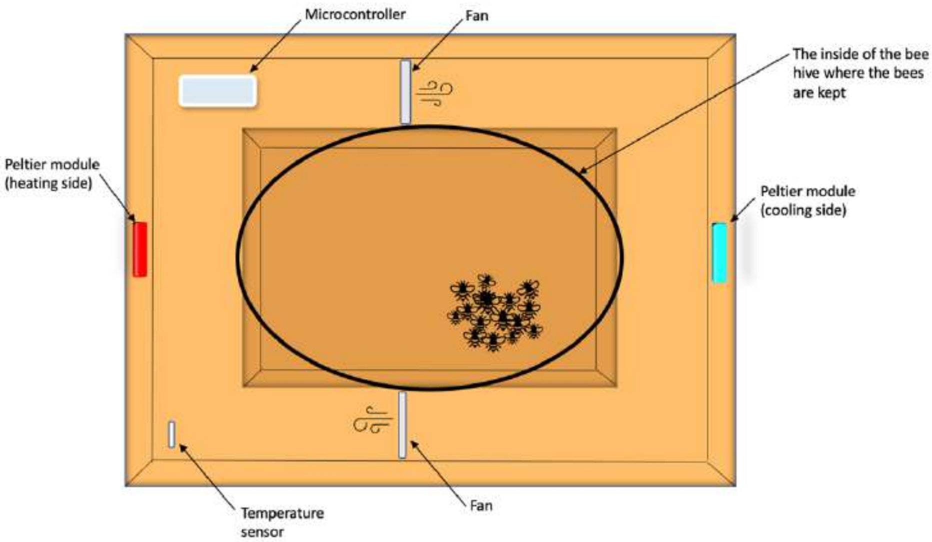


Figure 20: Illustration of beehive with implemented heating/cooling system seen from above

8.2.2 Concept I

The system setup of concept 1 consists of heat sensor placed outside the beehive with the task to measure and store temperature over time. The mean temperature of the past four days will continuously be calculated, within the microcontroller, and stored as a target temperature for the heat regulation inside the walls of the beehive. The heat sensor inside the beehive will in turn send information about the temperature to the Arduino that will compare the actual in-hive temperature with the target temperature. Depending on the result, the Arduino will send a signal to relay 1 or 2 that triggers one of them to open, which will result in either heating or cooling of the beehive. The fans will only be running during cooling and heating operations. Figure 21 is a schematic illustration describing the configuration of the thermoregulation system and Figure 22 is a schematic illustration describing the logic of the system.

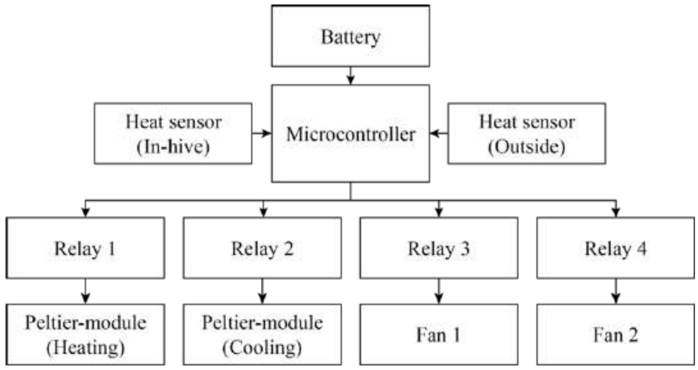


Figure 21: A schematic illustration describing the configuration of the thermoregulation system

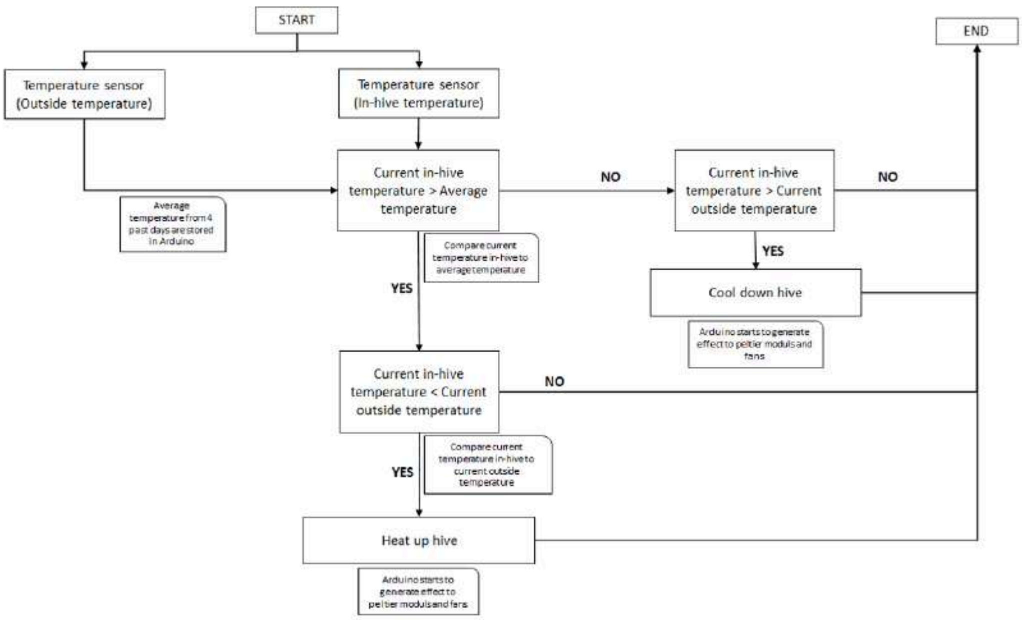


Figure 22: A schematic illustration describing the logic of the system

8.2.3 Concept II

The system setup for concept 2 is similar to concept 1 with the only difference that instead of heat sensors inside and outside the beehive a camera, and an image processing software, will detect changes in the cluster and with that information either decrease or increase the temperature inside the walls of the beehive. Schematic illustrations for this concept can be seen in Figure 23 and Figure 24.

For this concept thermal patterns from bee colonies must be obtained to compare the patterns inside the beehive. In this concept the outside temperature would also have been measured by using a sensor, this is to draw comparisons about how the thermal patterns of the bees inside the hive change and are affected by the temperature changes outside the hive. To detect the thermal patterns an infrared thermal camera needs to be used. As a heating/cooling mechanism the same Peltier module would be used in this concept as in concept 1.

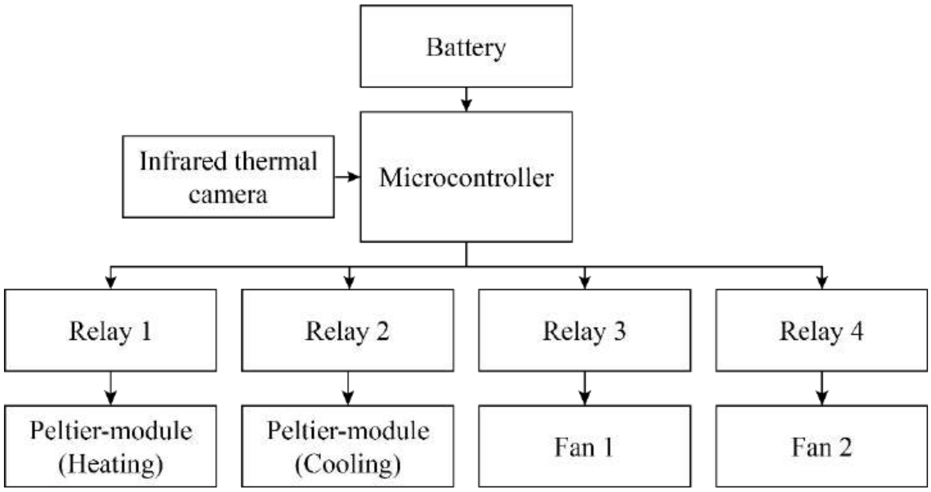


Figure 23: A schematic illustration describing the configuration of the thermoregulation system

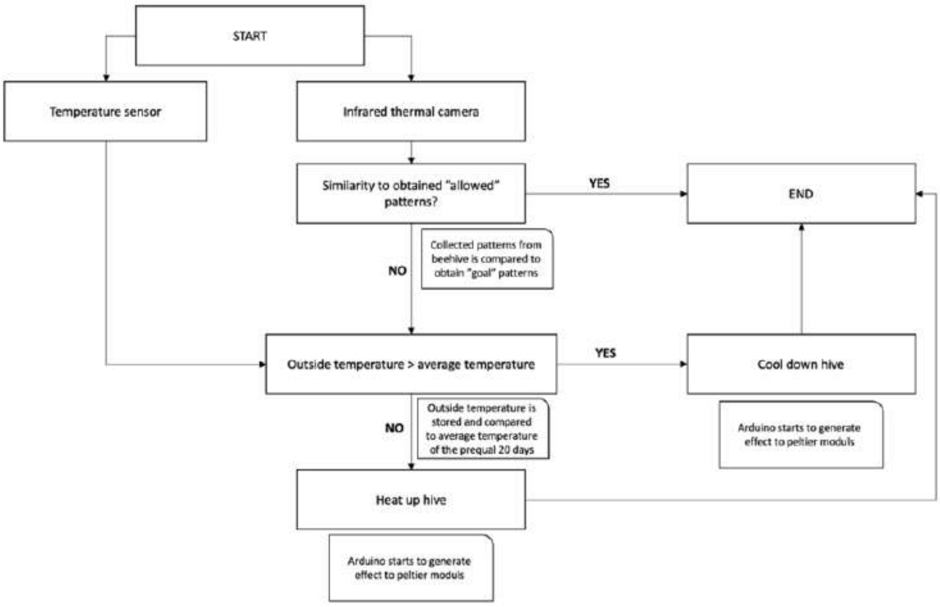


Figure 24: A schematic illustration describing the logic of the system

9 Concept selection

In this project, the approach of the two tasks, ergonomic and temperature, differs from each other and therefore the concept selection method does as well. The concept selection for ergonomics is done as described in method section 2.7. The temperature task is more restricted regarding feasible solutions. This limits the number of possible concepts and therefore elimination is used to choose between the two concepts.

9.1 Ergonomics

The first step was to get a general view of the main functions partly by identifying pros and cons with each of the six concepts described in section 8.1, which is presented in Appendix 3 – Pros and cons for Ergonomic concepts.

The next step was the criteria weighting method. The chosen criteria are the ones that are relevant in a construction perspective and were marked with R as Requirement in the Construction Criteria list for Ergonomics. These criterions are presented in Table 12.

Table 12. The criteria's used in the criteria weighting method and concept selection.

	Criteria
A	Reduce manual lifts over 10 kg
B	Affordable unit for the beekeepers
C	Easy to use and adapt into current routines
D	Easily manageable
E	Good grips
F	Adaptable to other parts
G	Resistant to all kind of weather
H	The frames shall be easily accessible
I	The components should be easily accessible for maintenance
J	Shippable unit
K	The concept should not generate more corners/slits (leading bees sealing it with beeswax/propolis)
L	Reduce number of manual lifts
M	Ease the movement of carrying the box
N	Easy assembly and disassembly

The weighting of the criterions are shown in Appendix 4 – Result of the Criteria weighting method - Ergonomic. From this weighting it is stated that criteria A, L and M are ranked as most important. The weightings for all criterions are used in the selection table in the next step of the concept selection, which is the datum-method where each concept is compared to the current beehive that is borrowed from Linköping's Beekeeping Society. For each of the criterion, every concept is compared to the current hive and given a -, 0, or + depending on how the concepts compares to the current design, as seen in Table 13. The weighting of each criterion is then decisive in summing up the value of the concept.

Table 13. Concept selection table for ergonomics.

Criteria		Concept					
	W	I	II	III	IV	V	VI
A	5	+	+	+	+	0	+
B	4	0	0	-	-	-	-
C	4	-	-	-	-	+	0
D	4	+	+	+	-	+	+
E	4	+	+	+	+	+	+
F	3	-	0	-	0	0	-
G	2	0	0	0	-	0	-
H	2	0	0	0	0	0	0
I	2	0	+	0	0	0	0
J	1	0	0	0	-	-	-
K	1	-	-	-	0	-	0
L	5	-	-	-	+	+	+
M	5	+	+	+	-	0	0
N	2	0	0	-	-	-	-
∑ +		18	20	18	14	17	18
∑ 0							
∑ -		13	10	19	22	8	12
∑		5	10	-1	-8	9	6
Ranking		4	1	5	6	2	3
Develop further?		NO	YES	NO	NO	YES	NO

As presented in Table 13, concept II, “Divisible box (vertical split)”, is given the highest sum followed by concept V, “Industrial drawer”. According to this result, these are the two concepts that will be developed further. Concept II is decided to be the focus and a prototype will be built to facilitate user tests. Concept V is a more advanced construction and requires more time and a higher budget and will therefore be investigated conceptually and discussed in further studies.

9.2 Thermoregulation

The first step in the concept’s selection step was to see that the two concepts meet with all criterions from a constructions perspective in the criteria list found in Table 10, that are marked with R as requirement. These criterions are presented in Table 14.

Table 14. The criterions that are stated as required from a construction perspective.

	Criteria
A	Increase and decrease temperature
B	Reduce temperature fluctuating
C	Adaptable to other parts
D	Resistant to all kind of weather
E	Automatic functioning
F	Manufacturable in the university’s workshop
G	Shippable unit
H	Easily manageable
I	low risk for overheating/cooling for the bees
J	No component that can provide a risk to start fire

K	Shall be able to implement in beehive
L	Meeting the budget criteria

The result of the weighting of these criterions are shown in Appendix 5, where criteria A, B E and K are ranked as most important. These weightings are then used in the next step the concept selection matrix where concept 1 is used as reference.

Table 15. Concept selection matrix

Criteria		**Concepts**	
	W	**Concept 1**	**Concept 2**
A	5	0	0
B	5	0	0
C	2	0	-
D	2	0	0
E	4	0	+
F	2	0	-
G	2	0	0
H	1	0	0
I	1	0	0
J	3	0	0
K	5	0	-
L	3	0	-
Σ+		0	1
Σ0			
Σ-		0	4
Σ		0	-3
Ranking		1	2
Develop further?		YES	NO

As seen in Table 15, concept 1 has the highest score and will therefore be developed further. After comparing both concepts concept 1 is the most beneficial and the only adaptable to use. To obtain thermal patterns by using infrared cameras is difficult, time-consuming and requires access to bees to obtain patterns from which this project does not have. Concept 2 requires severely more advanced components, skills, and a higher budget. Infrared cameras are also very expensive and needs to be further developed against implementing in the bee industry before making this type of system. After the concept selection was done concept 2 was decided to be only conceptual.

10 Prototyping

Prototypes for both tasks were built to test the design and function of the technical solutions. The built prototype of the dividable box enables user tests and weight comparisons to the current box, and the prototype for the thermoregulation task provides the possibility to measure the efficacy of the system when heating and cooling the hive.

10.1 Ergonomic Prototype

The prototyping of the dividable box begun with measuring the dimensions of the current treasure box. The intention of the prototype was to create an identical box to the existing one to avoid changes of dimensions for the frames and brood box. According to the theory, the existing handles were not ergonomic due to the thin grip surface. Therefore, thicker grips were used for the prototype. Eccentric locks were used to hold the box together, where the ones available in the workshop were used. A CAD model was created with the tool Fusion 360, a rendered image of the model can be seen in Figure 25. From this, drawings of the box were produced, see Appendix 6 – Drawings of dividable box.

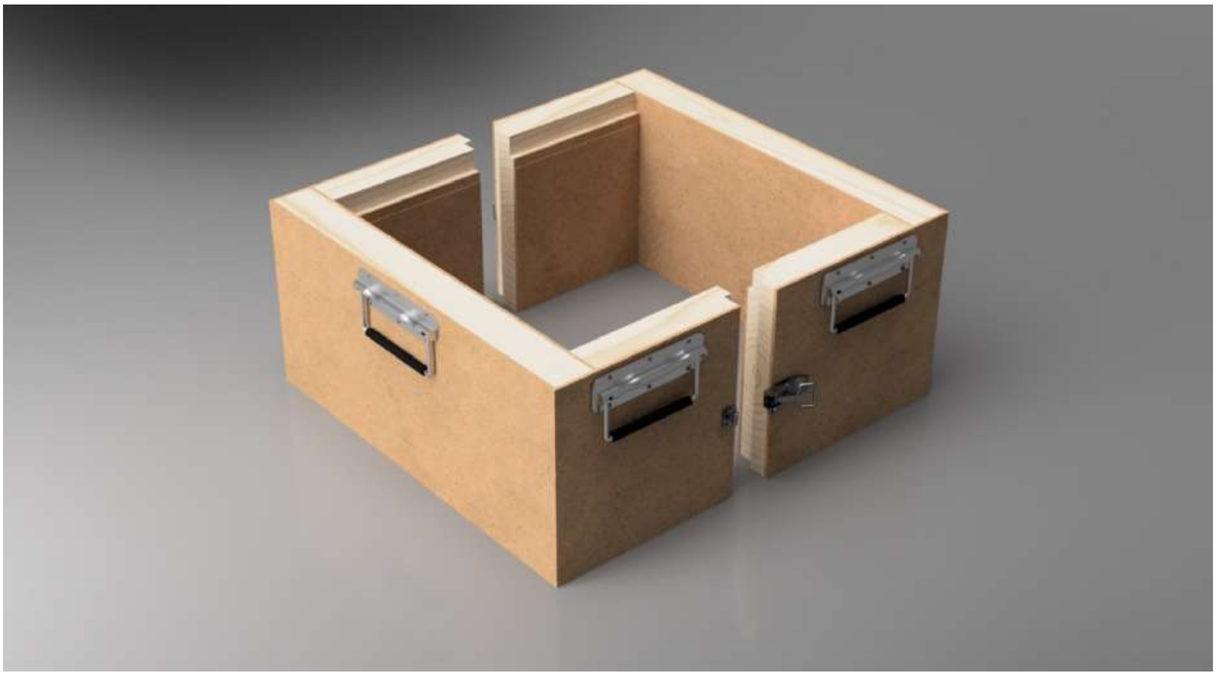


Figure 25. Rendered CAD model of dividable box.

The drawings were handed over to the workshop where certain adjustments were made, and ambiguities cleared up. The main changes that differed from the drawings was that insulation of Styrofoam was added in the empty spaces between the walls in the hive, alike the currently used box. The reason behind this was to make the wooden boards more stable. Moreover, the split was thought to become more stable if the notch was in the middle so that the two parts could hook into each other, see Figure 26.

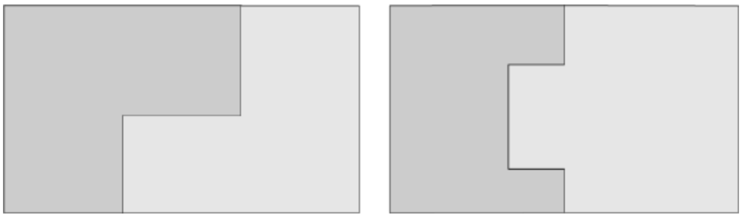


Figure 26. Dividing line for the box, as the drawings (left) and as produced (right).

When the box had been manufactured in the workshop, the handles and the eccentric locks were assembled with screws. The result can be seen in Figure 27.

Figure 27: Final prototype of dividable box. Clipped together (left) and divided (right).

As there would be a risk of the frames falling out when lifting the divided box, small stops were glued to prevent this from happening, see Figure 28.

Figure 28: Stops preventing frames from falling out.

10.1.1 Testing of ergonomic prototype

The tests consisted of weight comparison between the currently used treasure box versus the built prototype box, as well as user tests. The aim with the user tests was testing the functionality and generating a comparison and verification by the reactions from the test persons. The preparations begun with discussions about how to conduct the tests, documenting a step-by-step plan, and asking people if they would be interested to participate. The user tests were carried out with beekeepers at Linköping's beekeeping society as they have the subject specific knowledge required to give as fair a response as possible. Also, the contacted people are somewhat elderly and has the desired physical conditions. The ergonomics group decided two persons to be enough testing the prototype. The next step in preparing the tests was to find a solution for how weights, that should correspond to the weight of ten honey-filled frames, should be attached to the box. The solution was to mount wooden strips on the inside wall of the prototype box, where two plastic boxes was hung up on. In these plastic boxes weights were placed, see Figure 29, with 10 kg in each which corresponds to 5 frames in each side of the box.

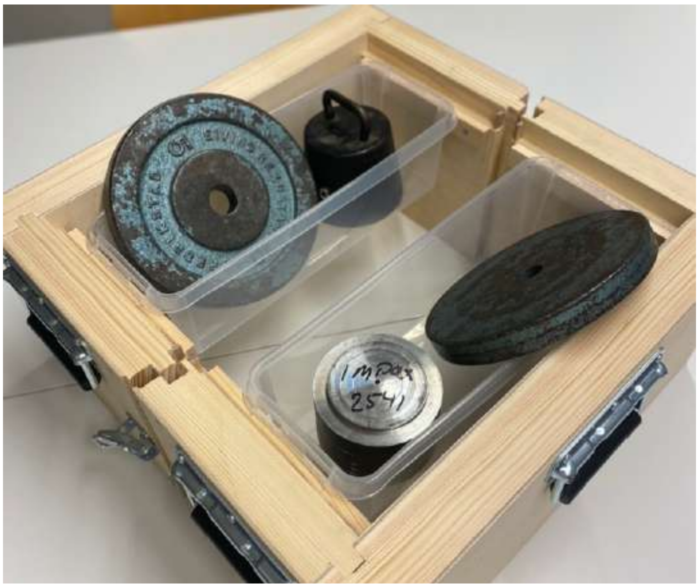


Figure 29: A picture of the build prototype of the dividable box prepared for the tests. The weights correspond to the weight of ten honey filled frames.

The first test was to weight the boxes to enable a comparison in weight. First the borrowed box was weighted, followed by the built prototype box, followed by only one half of the built prototype. All these weightings were conducted without the external weights and without the wooden strips.

The user tests were made at the premises of Linköping's Beekeeping Society and two beekeepers were participating in the tests. The external weights were placed in the prototype box, which in turn was placed on top of three other boxes to the actual height where the topmost treasure box usually is. The tests persons were asked to perform the lifting of the boxes in the same way as they regularly do, and in the meanwhile communicate their reactions and thoughts. They were told that the prototype box was dividable and that they should use that function, but it was not demonstrated exactly how they should do it. An empty box was placed on the floor nearby the others as an unloading spot where the lifted box should be placed upon. The procedure of the tests was:

1. Lift of the whole box and place it on the unloading spot

1.1 Lift the whole box back to its start position on top of the other boxes

2. Separate the two halves of the prototype box and lift them of separately and place them on the unloading spot

2.1 Lift the halves back to the start position on top of the other boxes and lock them together again

This procedure was performed by the two test persons one after another. The test persons were filmed whilst performing the tests to enable a comparison of the ergonomic movements when lifting of the whole versus the half box. Both test persons have agreed to anonymously be used as references in this report and to be filmed. Thy are informed that the films will only be looked at by the project group, and otherwise their faces will be blurred.

10.2 Thermoregulated Prototype

To test the chosen concept for thermoregulation a prototype was constructed. Its construction and functionality are described below.

10.2.1 Thermoregulation model

To test the hypothesis about regulating the air inside the wall of the hive a smaller prototype was built. Since the only variable is whether the inside air can be controlled a full beehive was not constructed. Instead, a smaller wooden box with similar design was constructed. This meant the principle of cooling/heating the air could be tested with smaller and cheaper components, as well as using less material for construction. Two Peltier element was place on opposite sides, with fans placed on the two remaining sides. The fans are there to spread the cooled air inside the hive evenly.

The box was made from 4 mm thick MDF. Although it is not quite the same as the usual plywood exterior it is more similar than, for example, a plastic box. The Peltier elements were available at the university and chosen to minimize the project cost. Since the Peltier modules works within a temperature span, meaning if it has a maximum difference in temperature between the cold and hot side, it was important to disperse heat/cold from the cold side. Thus, if the prototype is trying to cool down, the excess heat from the other side of the Peltier module has a heat sink to stop it from reaching an excessively high temperature.

To decrease the thermal conductivity of the walls, the box was coated with a layer of insulation for some of the tests. This will help to keep the loss of heat within the hive and not disperse into the outside air as fast.

10.2.2 Thermoregulation system

The final system includes two Peltier modules where one has the cooling side against the hive and the other the heating side against the hive. It also includes 2 DHT22 temperature and humidity sensor, two CPU fans, a microcontroller (Arduino UNO), one Arduino Four Relay Shield, two Peltier modules HP-127069 and a battery pack. Relays 1 and 2 are connected to the two different Peltier modules by the power source to control when the system is supposed to cool down the hive vs heat up the hive. The fans are connected to relay 3 and 4 via the power source and are both turned on when one of the Peltier modules are activated. The temperature sensors are connected to the microcontroller and provides data on the outside temperature and the temperature inside the hive. Figure 30 shows the CAD model of the thermoregulation system implemented in the thermoregulation model. Figure 31 illustrates how all the components are connected in the system. To provide how the microcontroller shall control these components the computer sends the code to the microcontroller and receives data from the temperature sensors. More on how the code was developed is described below.

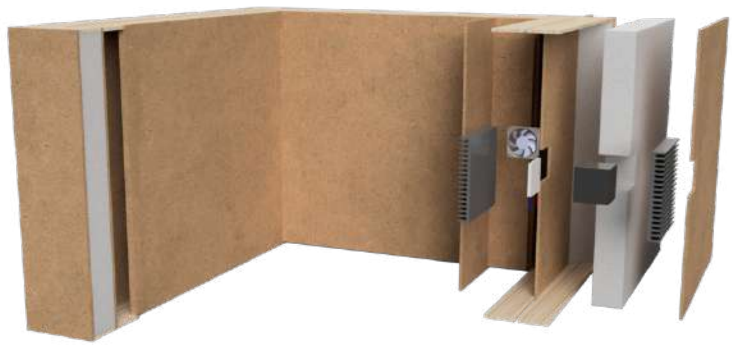


Figure 30: CAD model of thermoregulation system

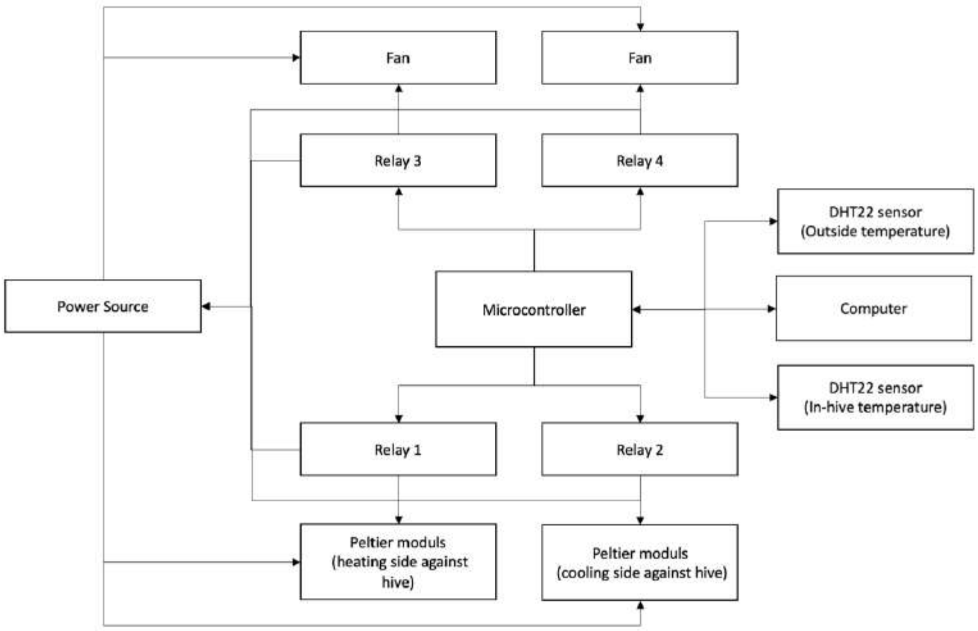


Figure 31: Sketch of how the components is connected in the system

10.2.3 Code structure

The microcontroller, an Arduino Uno in our case, is the brain of the whole thermoregulation system. The code that controls the communication between the microcontroller and the other components in the system were developed in Arduino IDE. The fundamental idea of the code is to tell the temperature sensors to start measuring, calculate a mean value of the previous four days outside temperature and compare the current wall temperature with the mean outside temperature and the current outside temperature. Depending on the obtained information from these calculations, the microcontroller switch on the Peltier module dedicated for decreasing the temperature or the Peltier module dedicated for increasing the temperature. To avoid the occurrence of the illustrated behavior in the left side of the Figure 32, the Peltier modules only becomes active if the current wall temperature is in between the mean outside temperature and current outside temperature. The code can be found in the Appendix 7 – Code structure for thermoregulation.

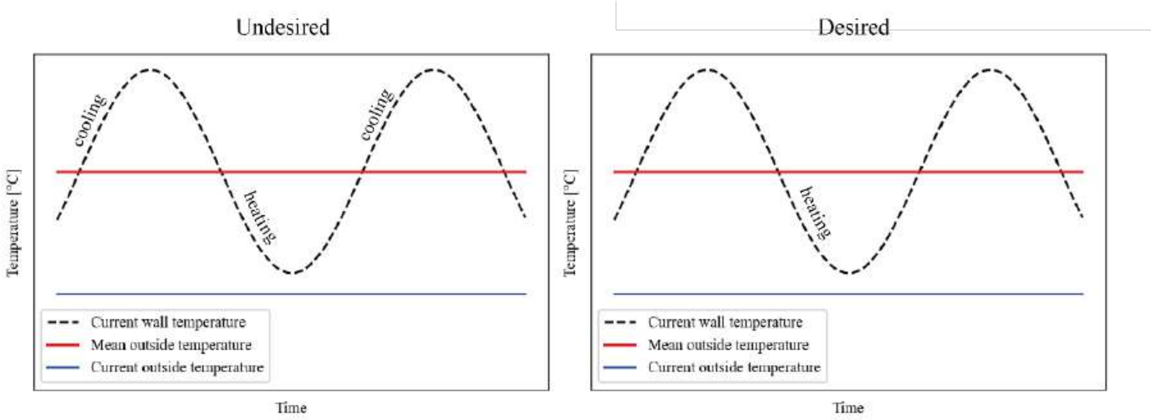


Figure 32: Illustration of undesired and desired regulation behavior of the thermoregulation system. The blue line demonstrates a low outside temperature and the red line a higher target temperature. The left graph shows an undesired scenario where the Peltier module, for cooling, becomes active even though the outside temperature will force the wall temperature to decrease naturally. The right graph shows a desired scenario were the becomes active when necessary.

10.2.4 Testing of thermoregulation prototype

In these tests the goal is to see the efficacy of the system in heating up and cooling the hive, and to see how the temperature differs with and without isolation. Each test had a duration of 30 minutes where the temperatures were read every 10th seconds. After 30 minutes had passed the data that was stored in Arduino was exported to excel. To get the desired comparable data the placement of the sensor and outer circumstances changed between the tests. As shown in Figure 33, placement 1 are the intended one for future usage, and placement 2 to verify the heat distribution. During all tests the hive is provided with electricity through an adapter power supply 5V and 0,5A.

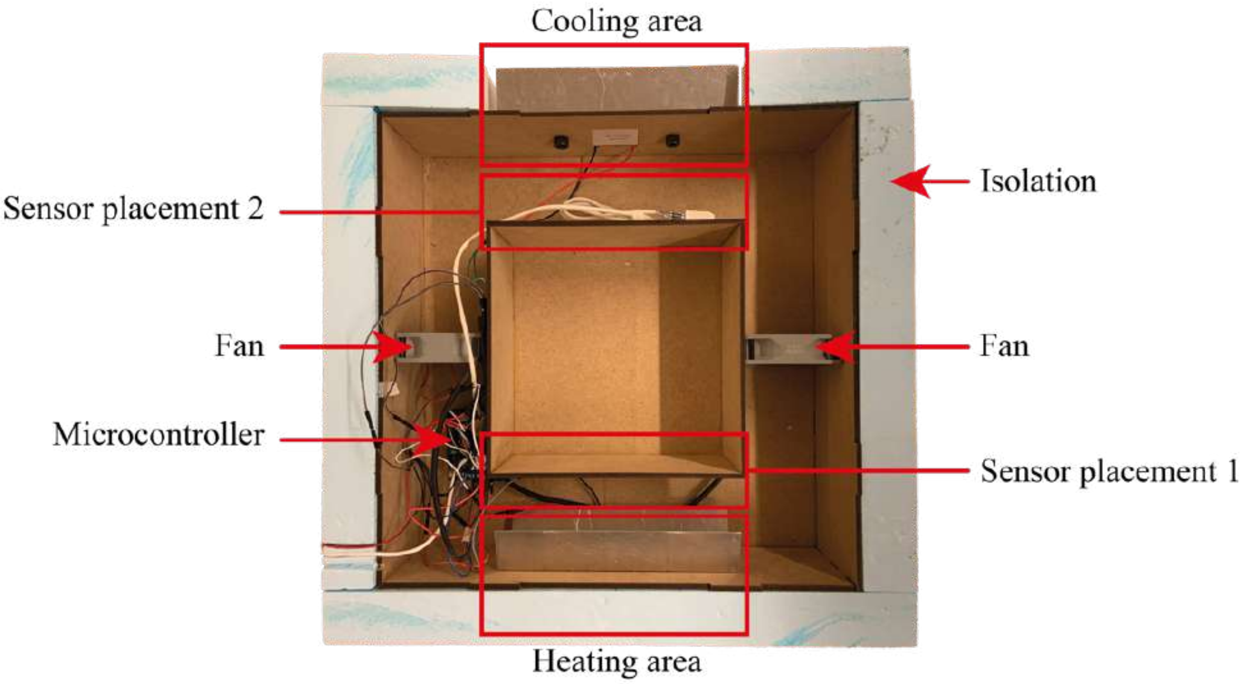


Figure 33: The prototype where the components used in the system can be seen.

Below a summary of the computed tests are illustrated in Table 16.

Table 16: Summary of computed tests

Test	Cooling /Heating	Isolation [YES/NO]	Placement of in-hive temperature sensor [1,2]	Duration [min]	Location	**Starting** outside temperature [°C]	**Starting** in-hive temperature [°C]	**Goal** in-hive temperature [°C] or [max, min]
1	Heating	NO	1	30	Inside	20,5	21,4	Maximum
2	Heating	NO	1	30	Outside	4,1	5,3	Maximum
3	Heating	YES	1	30	Outside	4,5	5,4	Maximum
4	Heating	YES	2	30	Outside	4,5	5,4	Maximum
5	Heating	YES	1	30	Outside	3,6	5,2	6
6	Cooling	YES	2	30	Outside	?	?	Minimum
7	Cooling	YES	2	30	Inside	19,9	19,6	Minimum

Test 1- Initial test

In the initial test the goal was to heat up the hive during the interval of 30 minutes. The starting in-hive and outside temperatures can be seen in Table 16. The test set up can be seen in Figure 34.

Figure 34: Illustrates test 1 held inside

Test 2 Heating up hive – outside

In this test the goal was to heat up the hive during the interval of 30 minutes when the hive was placed outside. The starting in-hive and outside temperatures can be seen in Table 16. The test set up can be seen in Figure 35.

Figure 35: Illustration of test 2 and the set up can be seen how the tests were conducted outside

Test 3 Heating up hive with isolation – outside

This test was conducted in the same way as test 2 where the only difference was that in test 3 the hive was surrounded by isolation. In Figure 36 the hive with isolation can be seen.

Figure 36: Illustrates test 3 where the isolation can be seen.

Test 4 Heating up hive with isolation – outside and changed place of sensor

This test was conducted in the same way as test 3 but in this test the in-hive temperature sensor was moved from place 1 to place 2. This to see that the temperature was regulated all around the hive, and to see the fans efficacy.

Test 5 Heating up hive with fixt temperature setting – outside

In this test the setup of the hive and the sensors were the same as in test 3 but in this test the goal temperature was fixed at 6 Celsius degrees. This means that when the in-hive temperature is below 6 degrees the system heats up the hive and when the in-hive temperature reaches above 6 degrees the systems stop. This to see the efficacy of the sensors and how fast the temperature changes when systems stop.

Test 6 Cooling down hive + isolation – outside

In this test the hive was placed outside but instead of heating up the hive the goal was to cool down the hive. In Figure 37 the set up for test 6 can be seen.

Figure 37: Set up for test 6

Test 7 Cooling down hive + isolation – inside

The same test as test 6 was then conducted again but this time inside.

11 Result

This chapter presents the results from the tests of the two prototypes. The ergonomic results consist of a weight comparison, feedback from user tests and movement comparisons from user tests while the thermoregulation results consist of graphs illustrating the temperature data.

11.1 Ergonomics

In this section the results from the tests for the ergonomic prototype box is presented. As explained in 10.1.1, the first test was a weight comparison between the currently used treasure box and the built prototype box. The second test was the user test where beekeepers at Linköping's Beekeeping Society tried to use and lift the prototype box and compare the procedure and feeling to the currently used treasure box.

11.1.1 Weight comparison

The current box was weighted to 5,4 kg and prototype box was weighed to 7,4 kg, where each half weighted 3,7 kg. According to interviews and theory, each box contains ten frames which in turn has a weight up to 2 kg each when filled with honey. Thus, the total weight for the current box, with ten frames is 25,4 kg. The total weight for the prototype box, with ten frames is 27,4 kg, and the total weight for a separated half of the prototype with five frames is 13,7 kg. As presented in Table , the prototype box weights 2 kg more than the current box and one half of the prototype box weights 11,7 kg less than the current box.

According to the calculations in section 5.1.1, the approximated recommended lift of the treasure box is 9,98 kg. The top three rows in Table 17 shows how much more than the recommended lift each box weighs.

Table 17: The results and comparisons of the weights for the currently used treasure box with the build prototype box as a whole and when divided into half.

	Current box	*Whole prototype*	*Divided prototype*
Weight of empty box	5,4 kg	7,4 kg	3,7 kg
Weight of honey filled frames	20 kg	20 kg	10 kg
Total weight	25,4 kg	27,4 kg	13,7 kg
Weight compared to current box		2 kg (7,8%) more	11,7 kg (46%) less
Weight compared to approx. recommended state	15,42 kg more	17,43 kg more	3,72 kg more

11.1.2 Movement comparisons from user test films

The two beekeepers conducting the tests is called T1 and T2 and screenshots from the user test films are used for movement comparisons. The lifting process of the whole box from highest point, putting it to lower height and back on hive can be seen in Table 18. The movements are staggered, and the lift looks heavy. The heavy box is placed down with a thud, and the test person is perceived having to think about the position of the back and knees to avoid injuries.

Table 18. Process of lifting whole box from highest point, putting it to lower height and back on hive.

	1. Lifting box down	2. Turning and walking with box	3. Fold to put down box
T1			
	4. Squating to put down box	5. Lifting box up	6. Final placement of box
T1			

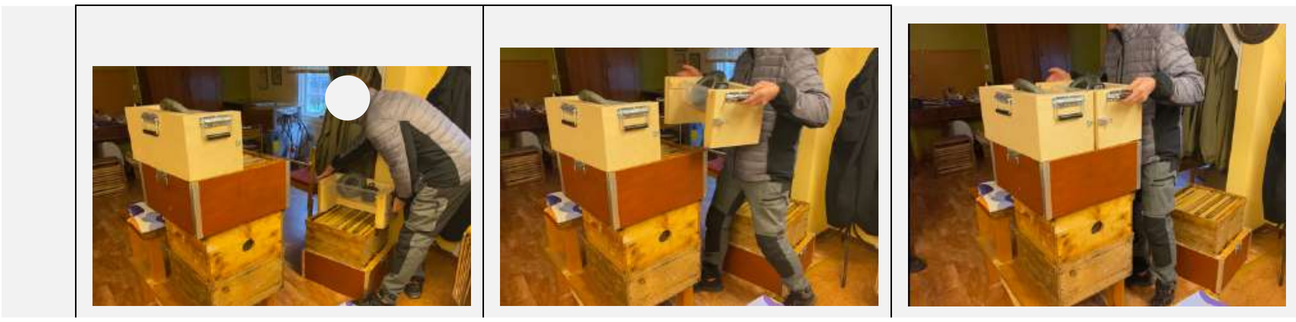
	1. Lifting box down	2. Turning and walking with box	3. Folding to put down box
T2			
	4. Squating to put down box	5. Lifting box back up	6. Final placement of box
T2			

The second process consists of the same process, but instead for the divided box, see Table 19. When lifting the divided box up and down, the entire movement looks easier and smoother. Overall, none of the lifts are twisted, which is positive from an ergonomic point of view. When half the box is lifted, the distance between the arms and the handles is smaller and thereby ends up closer to the body, which is an ergonomic improvement.

Table 19. Process of lifting divided box from highest point, putting it to lower height and back on hive.

	1. Testing pulling the box apart	2. Pulling the box apart	3. Lifting the box down
T1			
	4. Lowering the box	5. Bending to put down box	6. Lifting box back up
			

	1. Testing pulling the box apart	2. Pulling the box apart	3. Lifting the box down
T2			
	4. Adjusting placement of box	5. Lifting box back up	6. Final placement of box



11.1.3 Feedback from user tests

As a first reaction, the test persons say that the prototype box is like their boxes in the design, and that it is very well built with a solid and stable structure. They inform that these boxes with insulation in the treasure box mainly was profitable when beekeeping started to be a popular activity, back when some of the seasons generally was colder. They say that today, some beekeepers use very simple treasure boxes that is four planks mounted into a box.

User experience

The test persons said that the lift felt easier, and that the weight reduction was clear. They point out the handles to be a very positive improvement. The mounted handles on the porotype box are spring loaded, which the handles on their current boxes are not. The test persons said that the lift felt more stable thanks to the spring-loaded handles. Also, they said that the plastic cylinder on the mounted handle improved the grip and gave a nicer feeling as the handle did not press into palm. Another mentioned advantage with the design was that when you lift of the half box, the heavy side of it is closest to your body, and the box is therefore automatically leaning backwards. This means that you do not have to make an effort tilting the box slightly backwards to get a more comfortable hold or to keep the frames in place. Furthermore, the test persons stated that the small stops prevented the frames from falling off, and that the spacing between them was equal to the spacing between the other frames, as seen in Figure 38.

Figure 38: A picture of the prototype box filled with ten empty honey frames to illustrate the fitting of the frames and that the mounted stops create a desired spacing between the frames.

Procedure compared to current routines

The test persons says that this concept requires some extra steps in the procedure of lifting of and on the box but thinks that it might be usable. They explain that it is generally hard to implement new thinking ideas among beekeepers that likes to keep old and proven routines. They say that it would be good if this new separation routine would implemented directly by a new beekeeper.

A problem identified by the test persons is that due to the location of the bee entrance and preferred direction of the frames, this separation of the box makes the user to stand in front of the bee entrance when lifting of one of the halves, which is nor preferable. But they say that you could lift of both halves from behind the beehive by just pushing the second half closer to you first. Overall, they mention that this concept requires some new movements, but adds that the differences are small and easy to adapt to.

Design of the box

When the first test person opened the eccentric lock, the whole movement of the hoop was not fulfilled, which helps bending the box apart. When we showed this, they both gave positive reactions to that function as it helps separating the halves even if there is some propolis in the slot. The test persons suggest a straight dividing line through the box, i.e., a straight interface instead of the type seen in Figure 26. They inform that they do not think a straight interface would be a problem or risk an increased air entrapment. Instead, they say that the eccentric lock will be enough to keep the box together. One of the two main reasons to why they prefer a straight interface is that it will be easier to remove any propolis built by the bees in the gap. The other reason is that when they separated the box, by first opening the first side fully, the notch hooked into each other a bit which complicated the separation on that second side, which is seen in Figure 39: The opening when separating the box by bending the hoops in the eccentric locks unevenly (left) versus evenly (right).

. It was stated that the opening was slightly different depending on how the locks were opened, which can be seen in Figure 39, where the right picture shows how the opening looks like when separated more evenly.

Figure 39: The opening when separating the box by bending the hoops in the eccentric locks unevenly (left) versus evenly (right).

The test persons informs that the handles advantageously can be placed about 5 cm further down, mainly to make it possible to place the top/roof on the box without the handles being in the way. They say that it may give a feeling of a little extra push when lifting the box as well.

11.2 Thermoregulation

Below the data taken from tests 1-7 can be seen in the graphs represented in Figure 40-46. In the graphs the temperature can be seen on the y-axle and the time duration of the test can be seen on the x-axle. The graphs show the two different curves for the outside temperature and the temperature inside the hive (between the walls where the system is placed).

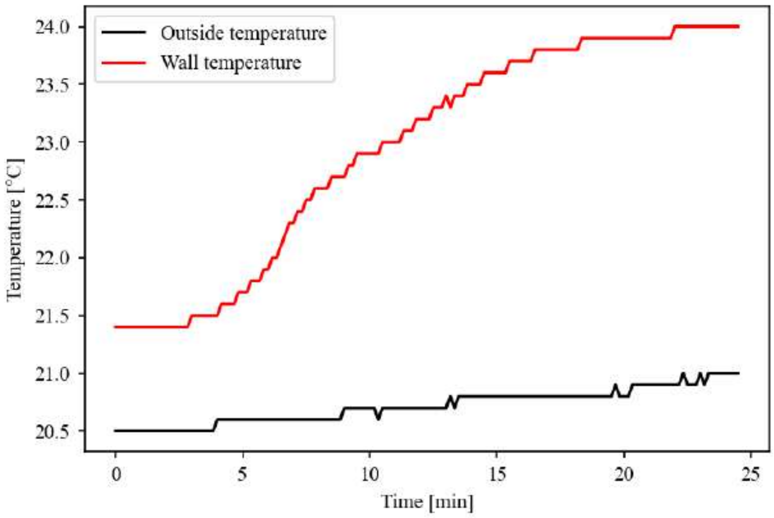


Figure 40: Test 1, initial heat test to confirm if it the system works at all.

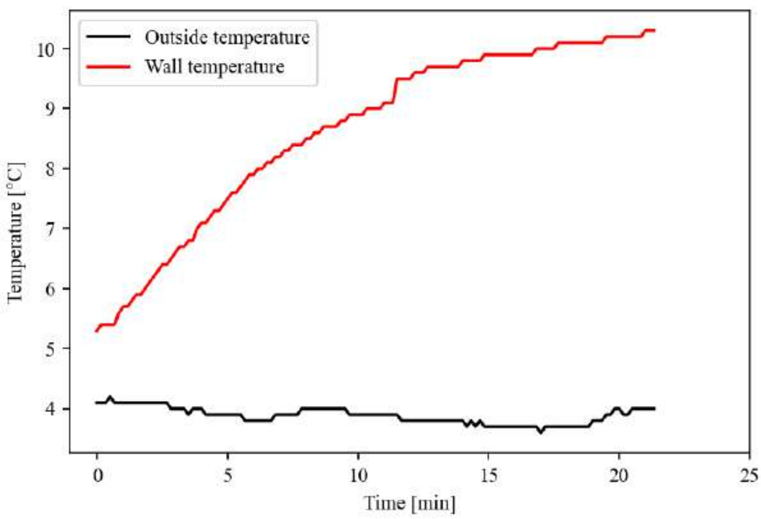


Figure 41: Test 2, heating up non-isolated hive outside.

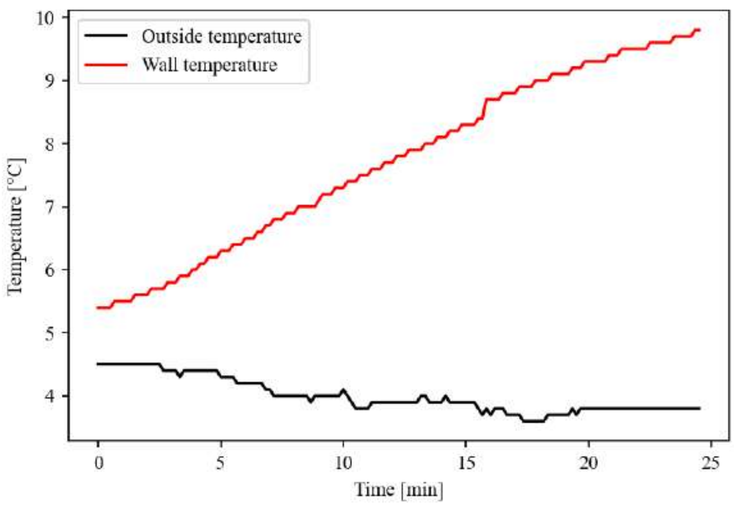


Figure 42: Test 3, heating up isolated hive outside.

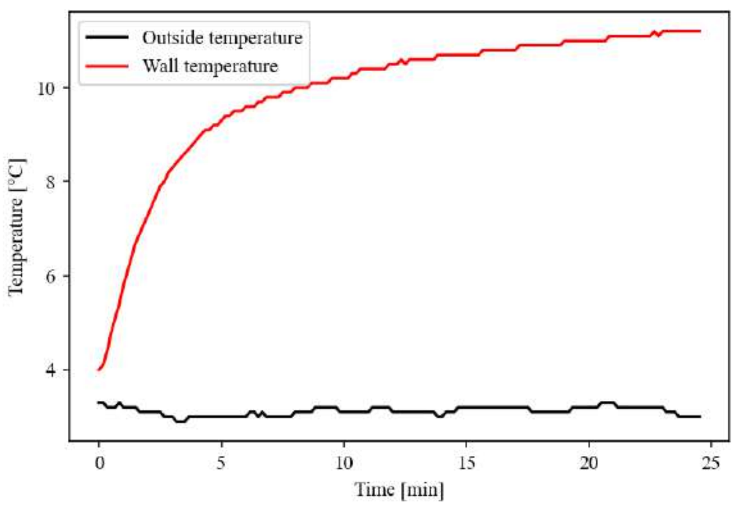


Figure 43: Test 4, heating up isolated hive outside and temperature sensor were placed on the opposite side of the operating Peltier module.

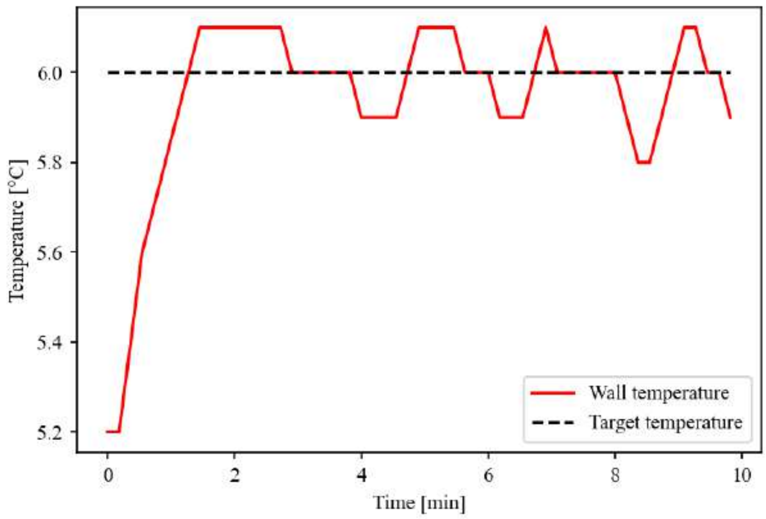


Figure 44: Test 5, heating up isolated hive with fixt temperature setting outside

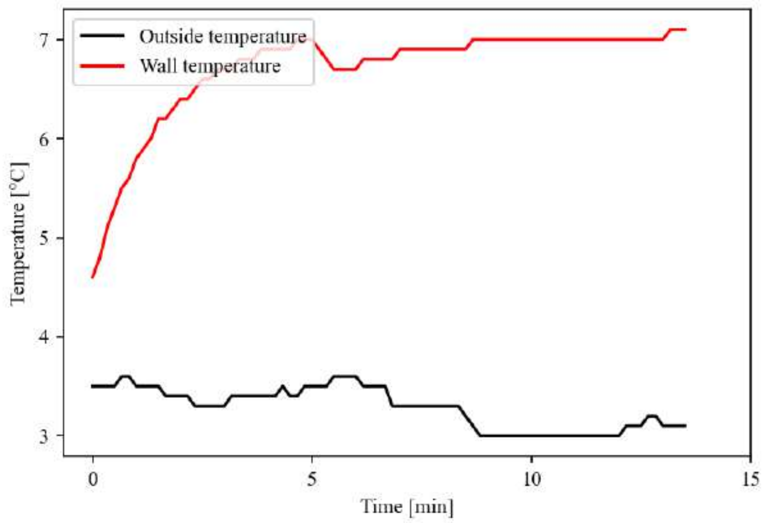


Figure 45: Test 6, cooling down isolated hive outside

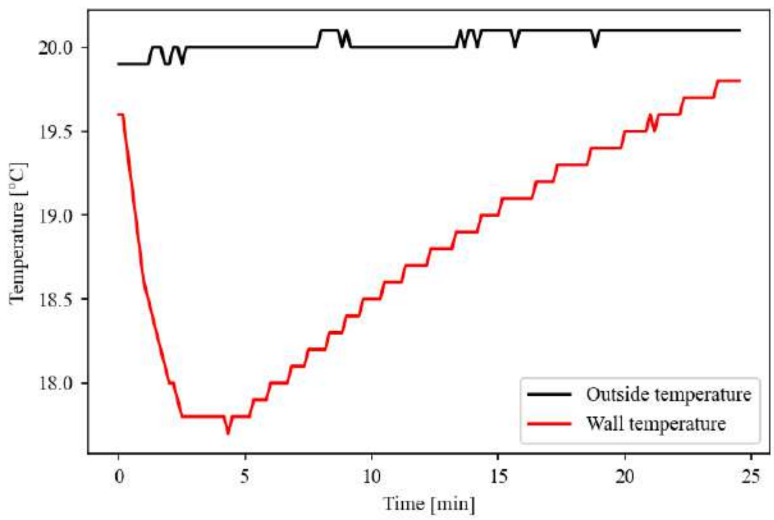


Figure 46: Test 7, cooling down isolated hive inside

The system managed to increase the temperature acceptably as seen in figure 40, 41, 42 and 43. The regulation test, seen in Figure 44, also showed great results and where able to regulate the temperature as intended. Unfortunately, the cooling tests, illustrated in Figure 45 and 46 failed and could not perform as the group hoped for. **Fel! Ogiltig självreferens i bokmärke.** seen below provides the actual number provided from each test and gives a clearer view of the performance of the system.

Table 20: Presentation of the actual number provided from each test. The red, yellow, and green colored boxes indicate that the obtained values do not, nearly and does correspond to the stated goal values in the report.

	Initial outside temperature	Initial wall temperature	Final outside temperature	Final wall temperature	Final temperature difference	Target temperature difference error	Maximum deviation from target temperature
Test 1	20,5	21,4	21	24	3	4,5	-
Test 2	4,1	5,3	4	10,3	6,3	1,2	-
Test 3	4,5	5,4	3,8	9,8	6	1,5	-
Test 4	3,3	4	3	11,2	7,8	0,3	-
Test 5	-	-	-	-	-	-	0,2
Test 6	3,5	4,6	3,1	7,1	4	11,5	-
Test 7	19,9	19,6	20,1	19,8	0,3	7,8	-

12 Discussion

This chapter will contain discussions and reflections regarding both two problem tasks. The approach and result will be discussed, and future improvements will be raised.

12.1 Problem identification and method

Because of the lacking experience of beekeeping and of bees in general, the project consisted of a large and long pre-study. This was however important to get an understanding of what is important for bees to stay healthy, the procedures of handling bees and in what areas we could implement improvements. It became very important to get the opportunity to watch the beekeepers at Linköping Bee Society to get a thorough understanding of the different steps and the possibility to ask questions related to experience. To be able to visit them on several occasions eased the identification of problems, as the general knowledge had processed from time to time.

The customer need identification was partly made with an eye to the Linköping Bee Society. The risk with opinions based on perceptions is that the problems could become very personal and based on feelings. Local problems and incidental events may sometimes not be the actual reason behind an experienced problem. During the work it has also become clear that most of the beekeeper’s experiences steps in the process that they see as problematic, but they are on the other side satisfied with how the process in done. Many of the elder beekeepers values the traditional ways and dismisses complex solutions. The interviews were however important, and the goal was to ease the work of hobby keepers. Therefore, were the opinions of the interviewed people weighted heavy in the problem selection phase. After the decision to look at the people working with bees as a hobby, we took into consideration both what a reasonable cost could be but also what the target group looks like.

During the preliminary studies of the project, it became relatively clear that many beekeepers do not consider there to be many problems for the bees and like to have it their way, the "right" way. For temperature regulation, the concept is probably more attractive for industrial beekeepers as this gives more profit due to less loss of bees during winter. For hobby beekeepers it would probably be more interesting to develop a system that they can implement in their own hive instead of having to buy everything as a unit. However, over time if the concept were to become more established and start to be used, interest would probably increase among hobby keepers. Nevertheless, the system needs to be developed more if one looks at the energy consumption, the energy consumption needs to be reduced for the system to be considered worth investing as a hobby beekeeper. For the ergonomics problem, the interest is probably the opposite, many elderly people do beekeeping as a hobby and to be able to reduce these heavy lifts and minimize injuries to the keeper is probably something that an elderly keeper would have appreciated and considered worth investing in. It is also a solution that does not affect their beekeeping in any major way except when extracting honey and serves with a positive impact.

The initial problem description was a purely focused project that overlooks the winter with help of META-HILIGHT. But after pre-studies was it considered that the work to prepare the hive before the winter was as important as the conditions during the winter. This made it possible to work with two separate problems without changing functions that are dependent of each other. The focus on META-HILIGHT was also significantly reduced after the pre-study as the technology and the concepts developed were not as compatible as hoped.

12.2 Ergonomics

Discussions regarding the method and results for the ergonomic task will be described in this chapter.

12.2.1 Method

The overall method was not optimal as the observations at Linköping's beekeeping society would have been more beneficial later in the process, which was not possible due to the wintering of the bees. More thorough observations of the lifting techniques should have been looked at earlier on in the process, which instead were made along with the testing. Ergonomics is a broad area, which made it difficult as many factors play a role in a good lift and the context also plays a role. As the two tasks first were defined halfway through the project, there was limited time for research on ergonomics. More thorough research might have resulted in more well-adapted methods and detail knowledge on the way of thinking when designing an ergonomic solution.

The test group consisted of only two people who were experienced and older, as they could give us feedback on potential problems with the box that would not be possible to realize without their expertise. However, an experienced beekeeper already has routines and preconceived notions about how a beehive should look, which would have made it interesting to also include more inexperienced beekeepers. Also, female test subjects could have given a different result, they are generally shorter and have lower muscle strength in the upper body.

12.2.2 Results

The weight comparison tests shows that the lift for the dividable box, one half at the time, is 11,7 kg less compared to the lift of the currently used box. This yields a weight reduction of 46%, which is almost a reduction of half the weight. However, the prototyped dividable box when clipped together is 2 kg heavier than the currently used box. One reason for this could be that the current box could not be disassembled, resulting in a more solid design for the prototyped box than the currently used box. Another contributing factor to the weight is there are 6 handles compared to the previous 2, where the new handles also are slightly bigger. The workshop thought adding insulation inside the walls of the box would help the walls keeping its form. However, the beekeepers did not think insultation was as important as it has been before and that many beekeepers today only use simple wooden boards. The box must be solid where the handles were mounted and thereby also requiring more material with more handles.

It is possible to reduce the amount of material in the construction and if the dividable functionality would be adapted to a design optimized box, the weight would be further reduced.

When using the dividable function of the prototype, a weight of 13,7 kg is lifted at the time, as presented in Table 15. The calculated recommended weight for this kind of lift is 9,98 kg, which means that the prototype for the dividable box concept is 3,72 kg heavier than desired. However, it is important to keep in mind that the recommended lifting weight is a theoretical value that is approximately calculated and should not be seen as an absolute ideal value. The capability of doing heavy lifts is highly variable from person to person depending on factors such as technique, height, age, and muscle mass. The project goal for the ergonomics task, to reduce the weight of the treasure box to 10 kg, is partly attained. However, the result reduces the weight significantly and further improvements can be made to decrease the total weight. As the overall ergonomic interaction has been improved, the impact goal is considered to have been achieved. When all five honey frames are filled with honey, the goal of reducing the weight to 10kg is not reached. On the other side the frames are not always filled with honey when lifting the treasure boxes, meaning that in real case scenarios, the goal will sometimes be reached even without design changes, since the honey is a big contributing factor to the total weight.

The workshop though that the current dividing line results in a more stable and substantial box, which was the initial thoughts with the drawings as well. However, the beekeepers thought that it would be easier with a straight cut to be able to open the box to avoid the surfaces hooking into each other. The eccentric lock helps to separate the box, a feature that beekeepers did not use at first. When they tried to take advantage of this, the opposite side instead got stuck so they needed to adjust to get it to come loose. When we later tested opening the box in this way, however, there was no problem that the protruding parts of the interface caught on each other because the parts still detached from each other. The dividing lines used for the drawings, something in between the two standpoints, are believed to be the best solution, but more tests would be required to confirm this.

Something that is important for the dividable box is to have the right technique to open both sides just enough. This is something that beekeepers are believed to have the capacity to learn and add to their routines, but a factor that both this and previous studies mention is the difficulty of changing attitudes. The perception is that older and more experienced beekeepers have more difficulty adapting to changes in beekeeping and possibly see more problems than benefits with new solutions. This type of product could therefore be easier to implement with newer or younger beekeepers.

In the construction criteria list for the ergonomic task, all criterions expect for one marked as a requirement are considered being attained for this concept. The criterions that are considered to have been achieved extra well is “(E) Good grips” and “(M) Ease the movement of carrying the box”, as both these aspects were highlighted by the test persons. This is a positive result since these criterions were given the highest and second highest rankings, as seen in Appendix 4. The criterion that was not met is “(K) The concept should not generate more corners/slits”, since this concept contains two more slits trough the walls of the treasure box. This criterion is however ranked as one of the least important ones. The most important criterion, both according to the project goal and the ranking of criterions is “(A) Reduce manual lifts over 10 kg”, is achieved conceptually as explained further up in this chapter.

12.3 Thermoregulation

One aspect that is important to address regarding the concept selection is the group's lack of knowledge regarding temperature regulation systems. The temperature regulation problem was chosen as it was considered to be one of the major concerns as well as a problem whose solution could solve other sub-problems such as ventilation. However, something that affected the project in the beginning of the concept-phase was that no one in the project had advanced previous knowledge regarding control technology, sensors, heat theory, electrical engineering among other things related to the field. This affected the concept generation and made it difficult to come up with many functional concepts. Something that also limited the concept generation was that the system was supposed to be able to heat and cool the hive. This limited the choice in heating/cooling sources to choose from, which led to both concepts containing Peltier modules. In the concept selection process, it became clear that concept 2 only would be further investigated conceptually, as the concept exceeded both the chosen and given limitations of the project and therefore concept 1 was chosen.

12.3.1 Method

To get relevant test data within the time limit and budget, the hive was downscaled. With a smaller prototype, in different material, slightly different dimensions, and a down-scaled thermoregulation coupling, there are pros and consequences. The reasoning was that only the principle needed to be tested, and that the Scaled downed prototype would give an accurate enough representation of the real-life conditions in which the concept would operate. The biggest advantage was the reduction in material and component cost. A smaller prototype meant simple Arduino components available at the university and local stores could be used.

The biggest drive for the concept was to be able to cool down at peak early spring temperatures, which sits at around 10-15° C. Unfortunately, the tests were conducted during December and the outside temperature shifted between 3-7° C instead. This meant that the Peltier element would need to reach close to freezing temperature to cool down the hive. This also means the hot side needs to reach a lower temperature since the Peltier element only ever reaches a certain difference in temperature. This might mean the element could have operated better at a slightly higher temperature, mostly since now it is working closer to its minimum possible temperature. For a more ideal test run the same tests should have been conducted in spring, during longer durations. Alternatively, it could have been moved to different temperature environments every half hour, for example inside and outside, to simulate day and night temperatures. This was originally the idea, however since the prototype eventually had to be powered via an electric outlet since batteries got drained in 5-10 minutes with the setup, this was no longer possible.

To get more accurate results would it be interesting to see the prototype in additional environments. It would especially be interesting to see how the code and prototype would adjust if it moved from the colder test environment to the warmer inside. If time was sufficient could the test be much longer and be kept going over a day, and usual temperature changes would occur during the day.

Since the tests could not be conducted with real bees in the prototype are some key factors that could not be accounted for. The main idea is that if the bees' sense that the inner walls are cold, they won't leave their cluster, however this is not guaranteed since it has not been tested.

12.3.2 Results

The factor that differed the most from intended usage was the time interval. Since there was no time for days long testing and there was a lot of different tests to be done, the tests were opted for 30 minutes. This was deemed enough time to see significant change in temperature. Seeing the results this turned out to be true. Within half an hour the temperature could be raised by 7,8°C at most.

The choice of fans was limited by supply and cost at the provider. Ideally, a pair of smaller fans would have been used to decrease the width of the prototype, and therefore the total volume of air that had to be heated/cooled. It would also look more like the standard beehive, where the walls are closer to 40mm wide. Although a narrower airway could have affected the airflow, making it harder to spread the air around, it would ultimately be a problem of creating more streamlined airways. The focus of the project however is the regulation of temperature, so this detail was deprioritized.

One problem that was discussed about having fans in the walls was the vibration. The aim is to have a system that the bees do not "notice" and if the fans had created vibrations and noises in the walls this would have been a problem as it could cause distress to the bees. The fans used did not create a disturbance as they were not audible from outside or inside the hive, which was positive, but this is good to bear in mind if the system is to be further developed to the actual size of a hive as other fans might be needed. It is then important to find fans that are stable and do not create noise or vibrations.

In the testing phase some possible source of errors can be mentioned. One of these are the placement of the sensor inside the hive. The result may differ depending on where the sensor is placed. This was tested by computing test where the sensor was moved between two different locations inside the hive. Although if for example the Arduino template was close to the sensor in some of the tests it can have affected the results since the components transfers some heat and the sensors sometimes show results of high sensitivity.

Another source of error is the sensors themselves. It was noticed before doing some of the tests that the sensors needed some time to "cool down/warm up" before computing tests. This was mostly noticed when moving the sensors from inside where the temperature was around 20 degrees to outside where the temperature was around 3 degrees. Also, in some cases the sensors showed different temperatures although they were placed in the same place and should reflect the same data. This may affect the results in testing since the sensors shown some lack of trust worth.

One improvement for the testing would have been to place a sensor inside the hive where the bees are located. This is to see how the heating/cooling of the walls affects the temperature inside the hive. Although this would not reflect the actual temperature that would have been inside the hive if actual bees were to be there. This because the bees themselves reflect heat when clustering and just on their own. Nevertheless, it would have contributed to the testing phase to get a wider perspective on how the inside temperature on the wall affects the inside of the hive where the bees are.

The fact that the cooling subsystem did not work as intended could have various explanations. The group considers the restrictive maximum heat difference between the cold and hot side of the Peltier module to be a likely cause of failure. In short, the hot side of the Peltier module becomes so warm that the maximum heat difference restricts the cold side from achieving an ideal temperature. To overcome this obstacle, an idea would be to implement heatsinks on both sides of the Peltier module and additionally apply fans on the heatsinks to achieve even more effective heat transfer.

13 Conclusion

The project aimed to fulfill two separate goals regarding two different problems and answer a couple of key questions related to its content. The thermoregulation solution is supposed to regulate the temperature within the walls so that the walls temperature lowers the drastic and abrupt temperature changes. By reference from last year's temperature the concept should be able to increase and decrease the temperature by at least 7,5°C. After testing it could be seen that the prototype managed to increase the heat by 7,8°C in test 4 and, 6°C respectively 6,3°C in test 3 and 2. Test 6 and 7 however shows that the prototype is not good enough to keep the hive cooled. This was arguably the most important aspect of the concept, which means a more energy efficient cooling method would need to be introduced to make the concept work as intended. Either by adding more Peltier elements or by adding a different cooling method all together. In test number 5 we set a target temperature to keep the hive within a maximum deviation of 2,5°C from the target temperature. This resulted in a 0,2°C deviation at most which could be seen as a success.

The second goal was to reduce the total weight of the treasure box and limit the lifts to be maximum 10 kg. The impact goal, which partly is about improving ergonomics and reducing safety risks within beekeeping, was aimed to be improved by redesigning a more ergonomic concept for the beehive. The prototype of the dividable box, when lifted one half at the time, is slightly heavier than the calculated recommended lifting weight. When compared to the currently used box, a weight reduction of 46% is reached. The result is considered to be reached as the weight reduction is improved compared to the current state and small adjustments can be made to reduce the weight of the box further. Furthermore, ergonomic improvements were identified for the dividable box compared to the heavier currently used box when analyzing the movements in the films from the user tests.

This two redesigning's of the beehive will increase the bees and the beekeeper's wellbeing. By reducing the weight of the treasure box beekeepers will easily avoid injuries caused by heavy lifts and therefore be able to execute their hobbies in their older ages. By eliminating the temperature regulations this will result in less bees dying during the winter and help eliminating the other subproblems mentioned in problem selection.

The first two, and the last key questions are investigated in the report and are referred to in the theory chapter. The questions and the answers are listed below:

1. *What are common dangers for a bee colony and reasons why they die during winter?*

The reasons why bees die during the winter are many and varied. The ones focused on in this report are the sudden and abrupt temperature changes as well as food and size variations of the bees' cluster. All the investigated reasons can be found under problem selection.

2. *What are common 'pains' among beekeepers? What is difficult or boring to do?*

The most frequently mentioned pain among beekeepers noticed from both interviews and the questionnaire is that the boxes are heavy which forces beekeepers to perform heavy lifts. These heavy lifts are often performed from a height above shoulders and yields unergonomic movements that may be a risk for their physical health.

3. *How can the beehive be redesigned to better avoid those dangers for a bee colony and 'pains' among beekeepers?*

By implementing both concepts, damage to beekeepers and bees will be reduced. By automatizing the hive with a temperature regulation system, the probability of bees dying during winter will be reduced as the solution to the temperature regulation also serves as a solution to the ventilation problem and if a weak colony is inoculated. The ergonomic concept can help beekeepers throughout the year to reduce the heavy lifting that occurs when extracting honey. So, through these two concepts, the hive can be automatized and redesigned to avoid dangers for bee colonies and pain among beekeepers.

4. *What is META-HILIGHT, what does it do, and how could that technology be used to create a Beehive 2.0?*

META-HILIGHT is a tech company that develops state-of-the-art light sensors using special controllable META-surfaces. For exact details, read chapter 3.9. Implementation of sensors into the concept of a self-regulating beehive could allow detection of movement inside the hive. The sensors could determine whether the cluster is moving excessively or not and thereby provide more information on how the hive should be regulated in a better way. A challenge with placing the sensors inside the hive is that the bees cover any irregularities with wax. If the sensors could be placed seamlessly in the wall of the hive, or behind some sort of glass, it is possible that they would be left alone. However, another option would be to make sure the sensors work even with a layer of wax over them.

14 Future studies

For both tasks in this project, one concept has been chosen to build and test whilst another concept has been selected as a possible solution for future studies. These two concepts will be discussed in this chapter.

14.1 Ergonomics Concept V

Concept V, “Industrial Drawer” got a high score in the ergonomic concept selection but was not chosen to construct in this project due to budget and time limitations. Therefore, a conceptual solution is presented in this chapter.

The main idea with the concept is like a regular drawer, where each box would be possible to pull out separately, see Figure 47. The main benefit with this solution is that a lower placed box in the hive would be possible to pull out without having to lift down the boxes on top of it, and thereby significantly reduce the total number of lifts.

Figure 47: CAD model of Concept V – “Industrial Drawer”.

This concept requires a technical solution that lifts the stacked boxes above the one that is intended to be pulled out at least a few millimeters, by using some sort of bending or leverage technique, advantageously integrated in the scaffold. As the “drawer” contains heavy boxes up to 25 kg each, this construction must be well anchored into a wall or the ground to be stable and secure for the user. For the same reason, the rails where the boxes are placed on, which enable the extendibility of the boxes, must be strong and durable enough.

During the project it emerged that generally, older beekeepers are skeptical about departing from old routines but are probably those who would need an ergonomically profitable solution the most. This concept is beneficial and worth adopting for customers that has an openness to changing their habituated routines within beekeeping and trying new things, can place it somewhere not to unstable in nature and considers the beneficials be more important than a slight increase in price. When showing and discussing this concept with teachers within product development area that also are beekeepers, they were very positive about this concept. They also think that the boxes are heavy, and even if this concept still requires some heavy lifts, they did see the overall potential and liked the idea of reducing the number of lifts. This concept was explained for the two test persons at Linköping's beekeeping society when conducting the user tests. They understood the idea of the concept but said that their biggest concern was the big risk of accidently squeezing the queen to death when pushing the drawers back and forth. They explained that you often kill bees between boxes, but if you happen to kill the queen who is in one of the two the bottom drawers, the whole colony is destroyed. They think that in this concept, it is more difficult to keep track of where the queen is before opening and closing the drawers.

14.2 Thermoregulation Concept II

As stated in the concept selection, concept 2 was chosen to be investigated conceptually due to the time-limit for this project course, project budget, limitations in components and other circumstances. The concept requires a camera with a specialized lens to be able to identify thermal patterns. This type of technical solution exists but is expensive and not as minimalistic as wanted when implemented inside a beehive. Investigating this technical solution could be something interesting for META HILIGHT since automatic beehives, mostly in industrial beekeeping, are being developed on a global level. There certainly is an interest in finding solutions to help beekeepers and bee- organizations/companies. When developing this lens, it needs to be small and within a budget for beekeepers (if wished for a solution not only implemented in companies).

In this project, the sensors are placed in the wall and are therefore not exposed to bees building wax on them. For future studies and further development of this concept it would have been preferable to place components (e.g., sensors and cameras) inside the hive to get more detailed results. Due to the bees' cover regulations in the hive with wax, the placement of the components is of great importance for a future study. Some kind of preventive solution would have had to be made to place the components in the hive with the bees. For example, behind some kind of glass cover, or using more developed components specialized to work even if they are covered with wax. If META-HILIGHT considers developing sensors or other components to be used in the bee industry the information stated above should be considered. Further, META-HILIGHT could be especially good in this matter since there is not much space in a beehive and that most commercial cameras used today may be too big. A big advantage with META-HILIGHT is that they have the potential of developing very small optical devices. In general, if META HILIGHT is interested in developing components for the bee-industry, there are plenty of opportunities. To prevent parasites from killing bee colonies, META HILIGHT can develop camera lenses that will detect these types of different patterns in the hive. This could be crucial for the future of a bee colony if parasites are detected in time and prevent death.

This concept also requires access to bees to obtain thermal patterns from. These patterns would be used as references when creating the temperature regulation system. The patterns should reflect the indicators on how bees cluster depending on weather changes. The concept also requires a longer period of development since it's beneficial to collect patterns during the winter to get the most relevant result and then for the next winter to test the actual prototype.

If successfully developing this temperature regulation system and implementing inside beehive the next step is how to attract customer value. This may be a solution of most interest for industrial beekeepers. Creating an automatic beehive is relevant since it costs less for the companies rather than to have employees checking in on the bees and they can also have full control in monitoring the bees. For hobbyist beekeepers the interest may be harder to catch if the beehive exceeds a much higher price than a regular hive. When creating this system this must be considered before developing. For hobbyist beekeepers there may be a higher interest in only purchasing the system to implement in their own hives instead of buying the whole unit as one.

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Appendix

Appendix 1 – Summarized answers from interviews

Person 1.

P1 has had bees for ten years and has always used Langstroth hives in his beekeeping. During winter season P1 is visiting and checking on the hive each ten days but points out that you should try to disturb the bees as little as possible. He explains that you should not open the top cover during winter since the cold is a big risk for the bees and that it is bad if moisture enters the hive as it can lead to mold. He explains that he has experienced the moisture and mold issue and that the whole colony died consequently to this and means that ventilation is important.

Regarding the climate P1 informs that the bees can regulate the temperature inside the hive by themselves and tells that the time around early spring is most tricky due to variations in the outside temperature, since the bees are then flying out to empty their stomachs outside the hive. Further, P1 tells that you should never overwinter a weak colony and informs that sometimes it may appear to be enough number of bees, but that some of them are "regular bees" that will naturally die during the upcoming winter months and that there are not enough winter bees (i.e., bees that are born just before winter). Also, varroa and lack of feed can weaken a colony during winter.

P1 tells that it is most important to check if there is enough feed in mars/April and says that the feed may run out if the bees use more energy than expected due to cold temperatures and or other circumstances. Later in the interview, he confirms that there is a clear connection between temperature and consumption of feed since more feed is needed when cold. If the bees are running out of feed at that time in spring P1 is placing an additional frame with feed in the hive. The feed that he is using are bought ready-mixed and consists of icing sugar and water. Further, he explains that the bees can be given too much feed which should be avoided since it can lead to Utsot which in turn results in a dirty hive and unhygienic atmosphere. In that case the hive needs to be cleaned.

P1 explains that pesticides are like toxic for the bees and by this reason many beekeepers are doing eco-friendly beekeeping which means that a radius of 3km must be controlled and ecological as well.

Regarding questions about pests and disturbing animals P1 explains that Varroa mites are very common and means that all beekeepers are affected by it. Another disease in American foulbrood. In short, he explains that Varroa mites are very common but not a too severe problem, and that American foulbrood are rare but more critical. He says that formic acid as well as oxalic with sugar and water can be used to prevent Varroa mites, with methods performed during the autumn. Further he explains that a bee colony with varroa mites can be identified by discovering bees without wings, or by finding mites on the bees if it is at a critical stage. Also, one can make use of a varroa plate to count the dead mites falling on it. P1 tells that American foulbrood cannot be identified without opening the hive as it only appears in the brood box among the larvae as a stinky and sticky mass in the cells. He explains that the beeswax is the greatest spread risk and that the handling of the frames is crucial. He thinks it is a good idea to keep the beeswax fresh by re-waxing often as the spores stick to dark and old beeswax. If a hive is infected by American foulbrood the whole hive needs to be burnt and the hives in the surrounding area needs to be controlled as well. Beyond pests like mites and diseases P tells that his hives are mainly affected by mice and birds. The mice like the sweet beeswax and are entering the hive via the bee entrance, but that there are barrier grids to buy. Further, he explains that during spring when the bees are starting to leave the hive, birds can sit outside pecking and eating them.

P1 has never been a victim of sabotage but have heard about a few hives that has been sabotaged or opened by humans. He says that the Linköping's beekeeping society are keeping the hives locked and strapped.

P1 do not think that foreign objects in the hive would be an issue but says that bees may be sensitive to smells. P1 informs that bees want to seal all cavities and corners. He would place an object such as sensor/camera on a flat wall and says that some hives have a display window, where the bees are not building. Further he says that he would place a camera in the sealing with fish-eye effect as there is not much space on the walls because of all the frames. Also, he thinks it would be an idea to put a sensor on the queen as she is the most important bee for the survival of the colony. P1 points out weight, humidity, and temperature as interesting factors to measure. He says that a scale could be used to measure if they are eating during winter or if they are alive. Regarding influence of light P1 is telling that bees are following the circadian rhythm depending on light and might be affected if it is big amount of light, but that they should most likely not be directly affected by little light.

Person 2.

P2 has been a beekeeper for 20 years. He had bees as a child, has always had an interest in bees and finds beekeeping being important for the diversity and for the usage of the honey in the homes. P2 has 13 hives at home and explains that he has built some of them himself and he says that Langstroth hives are most common. P2 is almost never visiting the hive during winter, but if he does so he is checking that there are no animals such as badger or marten disturbing the hive. He adds that mice might be an issue, especially if the bee entrance is near the ground and without grid but says that they do no harm as they are only eating on the beeswax which the bees are letting them to do.

P2 explain that the wintering of bees is done when there is no nectar left in the nature. During the winter P2 is not doing anything with the hive as the bees are clustering and should be disturbed. He points out moist to be the main threat for a colony during winter and explains that the bees generate moisture, hence grid for ventilation is of big importance to avoid rot and Utsot. Further he explains that moisture is most often caused when the colony is too small and do not have the capacity to get rid of the moisture.

P2 explains that the clustering is how the bees are keeping the heat during winter and says that the outside temperature is not a big problem because of this. To the following questions about temperature and climate he is adding that warmer temperatures too early can result in a higher consumption of feed, and that mild winters is no good. This is because when bees are in cluster, they are not eating much but if it is not cold enough the bees are not clustering and therefore eating more feed so that the feed might run earlier than wanted, he says. Also, he explains that warmer days in early spring might trick the bees to even leave the hive and that he then has found dead bees in the snow since they do not cope with the cold.

The kind of hives that are made of Styrofoam are lighter, which make them easier to lift but the weight might also be too light in a storm and are not as durable, P2 informs. Furthermore, he says that he has half-boxes where the height of the box and frames are split into half and is a way to get lighter boxes.

Regarding diseases and pest's P2 informs that they are affected a lot and explains that no beekeeper is free from this. Varroa and American foulbrood are most common and tells that American foulbrood causes the most damage and can be identified by open cells in the brood box where the larvae has turned into a sticky mass. Varroa can be identified by wingless bees or if it is bad, the mites can even be detected on the bees.

About the structure of the beehive, P2 thinks that a Langstroth hive is good, and that the only disadvantage is the weight. He explains that when using four boxes placed on a stand, the topmost box is getting very heavy, especially since that box is always filled with honey.

P2 do not think that the bees are reacting on unfamiliar objects and refers to research where cameras are used in the hives and the bees does not seem to care. He mentions that the bees might build some on such object, but do not think they would cover a sensor for example if the surface were plain and solid.

Person 3.

P3 has been a beekeeper for 9years and has nine Langstroth hives. He explains that he is not visiting the hive during winter season until a warmer day Mars/April to check if there is enough feed left. The only reason he might visit the hive earlier is to remove snow from the bee entrance, or dead bees from the bottom grid, to facilitate ventilation and reduce the risk of mold. He explains that the feed may begin to mold if it is humid inside the hive why ventilation is important. There is not much more to do during winter, he says and explains that you can listen to the bees but if they are dead, they are. You should avoid opening the top cover as the cold is a danger for the bees, he says. He states temperature changes to be one of the worst dangers during winter, when the bees are enticed to leave the hive.

P3 informs that it is better to merge two weak colonies (few in number) into one for the wintering, instead of wintering a weak colony. Also, if a colony gets smaller during winter because of death you can merge two colonies into one in the spring as well, he informs.

Regarding the climate in the hive, P3 says that keeping the warmth in the hive is not a big issue and explains that it is better that it is cold. The cluster with the queen in the middle is keeping the temperature by themselves. The bees take turns to be positioned inner and outer in the cluster, that slowly moves around in the hive. P3 says that if the bees are weakened by varroa, or if the colony is weak, it might be harder for them to keep up the temperature. Again, he states that when the outer temperature changes drastically from one day to another, the bees might leave the cluster and the hive and dies in the cold or snow the upcoming day, which he thinks is a big issue. Also, the queen might start to lay eggs to early as consequence of this he says.

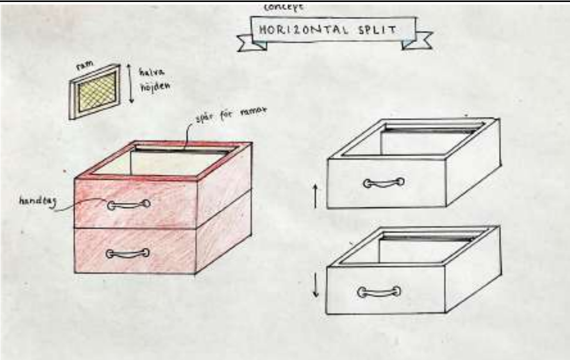
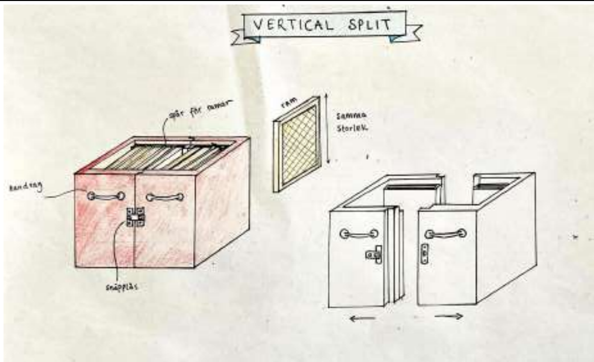
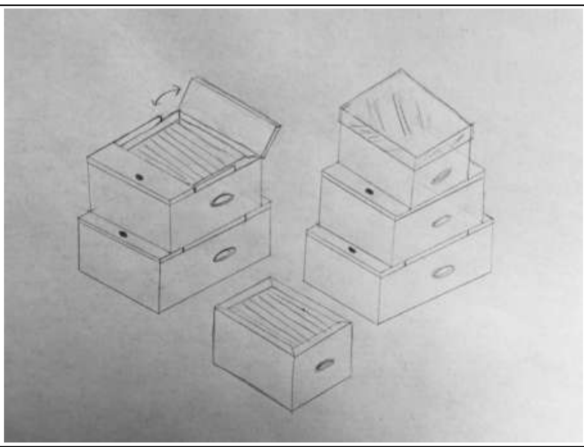
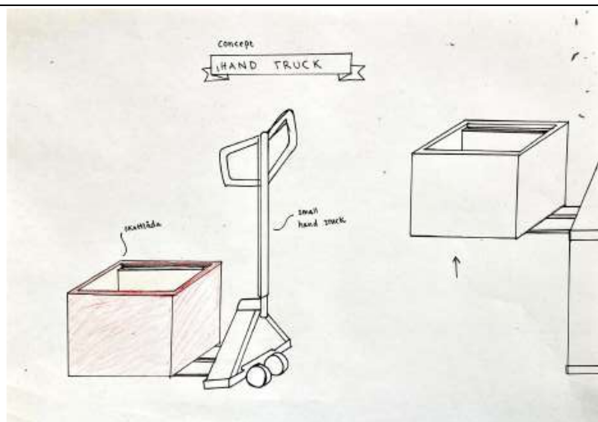
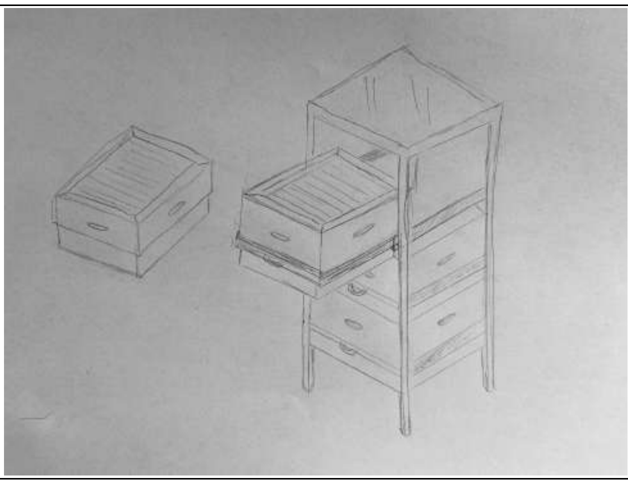
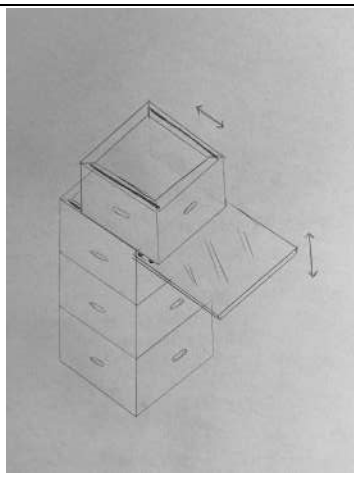
Regarding diseases and pest's P3 says that he never experienced American foulbrood but says that Varroa mites is a common and severe problem that needs action by the beekeepers. Varroa can weaken the bees, which makes them more receptive to virus diseases, which in turn can kill the bees. He is adding that when the hive is affected by American foulbrood, the consequences are bigger as you need to kill and disturb the entire colony and hive. American foulbrood can be identified by the smell or by the eye. P3 says that he never experienced mice as a problem, and explains it is hard to prevent any present mice to enter the hive but if they do, the bees are accepting them. Sometimes he discovers birds picking on the hive which might disturb the bees a little but perceives it as a negligible problem.

P3 is giving the bees about 20kg feed (Bifor) for the winter and says that it is usually enough. He explains that the bees get unsettled and disturbed by temperature variations, which requires them more energy as they leave the hive to poop outside, which they normally do not do when cold, are hungry when they return, and consumes more feed as a result.

If P3 would improve something with the hive, he would do something about the ergonomics and heavy lifts. If there are four-five boxes on top of each other, the topmost ones are very heavy to lift. He informs that the lifts are done when extracting the honey, and when checking the queen. To topmost box is always heavy and filled with honey as the bees are filling it up first. When checking the queen, you need to lift off all the other boxes first, and then put them back again.

P3 do not think that the bees would be very affected by a foreign object in the hive but says that they build propolis/wax on holes, cracks, and irregularities. They are not as likely to build on flat surfaces he says, and suggest that if a camera would be used, the lens should be well integrated or behind some sort of glass, preferably from above so that the movement of the cluster could be registered. The bees do not like presence of too much light, he adds.

Appendix 2 – Ergonomic Concept sketches

<table>
<tr><td>I: Dividable box (horizontal split)</td><td>II: Divisible box (vertical split)</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>III: Pyramids</td><td>IV: Truck/Lifting device</td></tr>
<tr><td></td><td>
</td></tr>
<tr><td>V: Industrial drawer</td><td>VI: Rails and elevator</td></tr>
<tr><td></td><td></td></tr>
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Appendix 3 – Pros and cons for Ergonomic concepts

	Concept	Pros	Cons
I	**Dividable box (horizontal split)**	• Reducing the weight up to 50% • Lower weigh for both lifting and carrying the box • There are current routines and tools already used to remove built propolis when lifting off boxes • Are not affecting current routines	• Not standardized frames, since they are of other dimensions (shorter in height) • Bees building beeswax/propolis in the slip/gap • An extra activity when lifting off the box - unlock the clasp and remove propolis with tool
II	**Divisible box (vertical split)**	• Reducing the weight up to 50% • Lower weigh for both lifting and carrying the box • There are current routines and tools to remove built propolis when lifting off boxes • Are not affecting current routines	• Bees building beeswax/propolis in the slip/gap • An extra activity/effort when lifting off the box – unlock the clasp and remove propolis with tool
III	**Pyramids**	• Lighter boxes higher up, reducing heavy lifts from higher heights	• Smaller bee colonies, requires more hives to have same amount of honey - Limits the size of each colony - Frames get full faster, need to extract honey more often • Bees building beeswax/propolis in the slip/gap
IV	**Truck/lifting device**	• Eliminates all kinds of manual lifting and transportation of the box	• Expensive and complicated technology • Difficult to manage in terrain
V	**Industrial drawer**	• Eliminates the forward-leaning movement in the manual lift • Easy to inspect desired box without a need of lifting off other boxes • Reduces number of manual lifts throughout the year	• Needs to be well anchored to be safe and not tilt due to the heave boxes • Hard to build fully, might be conceptual in CAD • Precision important, no gap between boxes • Construction solution to ease the fiction then drawing out the boxes, upper boxes need to be lifted a bit • There are still some heavy lifts when moving extracting honey
VI	**Rails & Elevator**	• Removes all kind of lifts from uncomfortable heights'	• Technically advanced and expensive • Sensitive to weather

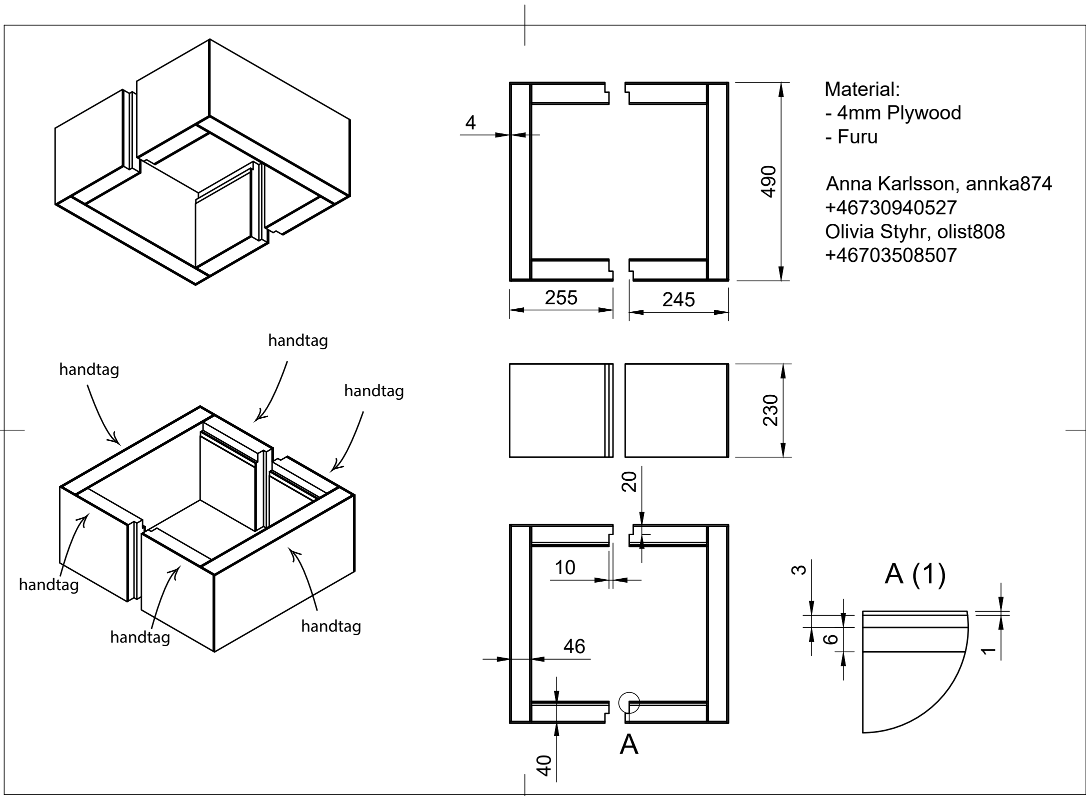
Appendix 4 – Result of the Criteria weighting method - Ergonomic

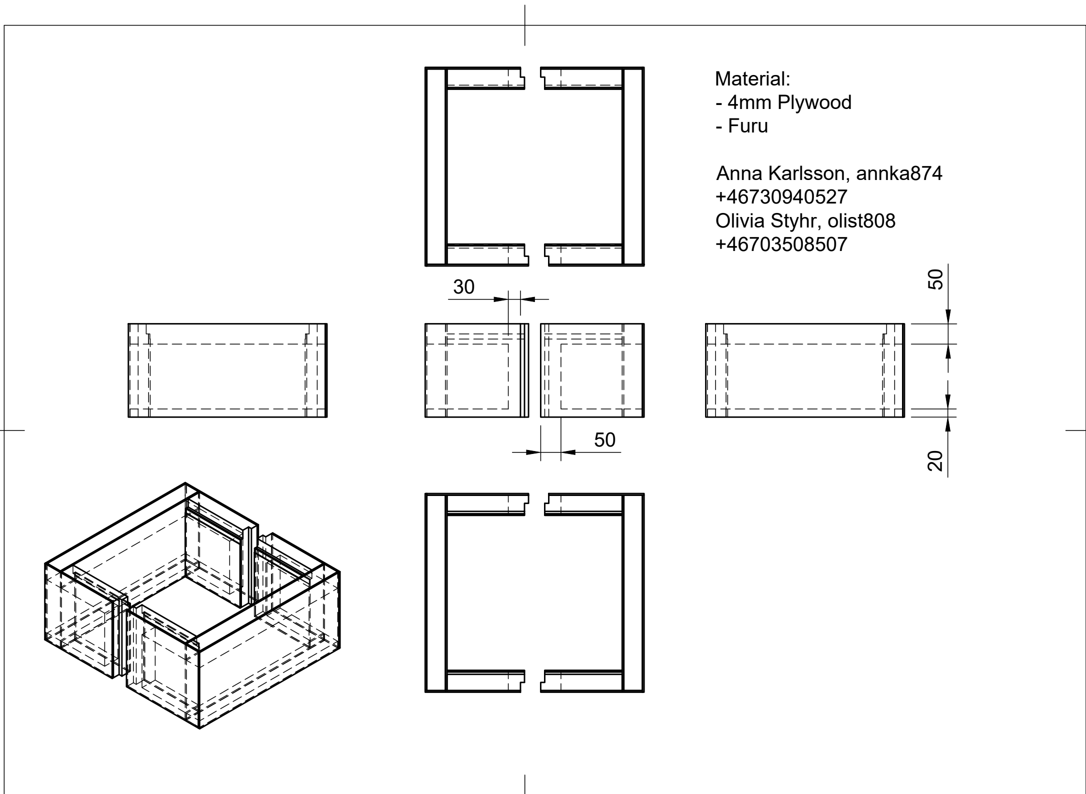
Criteria	A	B	C	D	E	F	G	H	I	J	K	L	M	N	∑	∑ NORM	RANK	W
A	X	2	2	2	2	2	2	2	2	2	2	1	2	2	25	15%	1	5
B	0	X	1	1	1	1	2	2	2	2	2	0	0	1	14	9%	2	4
C	0	1	X	1	1	1	2	2	2	2	2	0	0	2	14	9%	2	4
D	0	1	1	X	1	2	2	2	2	2	2	0	0	2	15	9%	2	4
E	0	1	1	1	X	2	2	2	2	2	2	0	1	2	16	10%	2	4
F	0	1	1	0	0	X	2	2	2	2	2	0	0	2	12	7%	3	3
G	0	0	0	0	0	0	X	1	1	2	2	0	0	1	6	4%	4	2
H	0	0	0	0	0	0	1	X	1	2	2	0	0	1	6	4%	4	2
I	0	0	0	0	0	0	1	1	X	2	2	0	0	1	6	4%	4	2
J	0	0	0	0	0	0	0	0	0	X	0	0	0	1	0	0%	5	1
K	0	0	0	0	0	0	0	0	0	2	X	0	0	1	2	1%	5	1
L	1	2	2	2	2	2	2	2	2	2	2	X	1	2	21	13%	1	5
M	0	2	2	2	1	2	2	2	2	2	2	1	X	2	20	12%	1	5
N	0	1	0	0	0	0	1	1	1	1	1	0	0	X	6	4%	4	2
														∑	163	100%		

Appendix 5 – Result of the Criteria weighting method – Temperature regulation

Criteria	A	B	C	D	E	F	G	H	I	J	K	L	∑	∑ NORM	RANK	W
A	X	1	2	2	1	2	2	2	2	2	1	2	19	15%	1	5
B	1	X	2	2	1	2	2	2	2	2	1	2	19	15%	1	5
C	0	0	X	2	0	1	0	2	1	1	0	0	7	5%	4	2
D	0	1	0	X	0	1	1	1	2	1	0	0	7	5%	4	2
E	1	1	2	2	X	2	2	2	2	2	1	0	16	12,5%	2	4
F	0	0	1	1	0	X	1	1	1	0	0	1	6	4,5%	4	2
G	0	0	2	1	0	1	X	1	0	0	0	0	6	4,5%	4	2
H	0	0	0	1	0	1	1	X	1	0	0	1	5	3,5%	5	1
I	0	0	1	0	0	1	0	1	X	1	0	0	4	3%	5	1
J	0	0	1	1	0	2	2	2	1	X	0	0	9	7%	3	3
K	1	1	2	2	1	2	2	2	2	2	X	2	19	15%	1	5
L	0	0	2	2	2	1	0	1	2	2	0	X	12	9,5%	3	3
													129	100%		

Appendix 6 – Drawings of dividable box





Appendix 7 – Code structure for thermoregulation

```
#include "DHT.h"
#define relayON        LOW
#define relayOFF       HIGH
#define DHTPIN1 2     // (in-hive) Digital pin connected to the DHT sensor
#define DHTPIN2 5     // (outside) Digital pin connected to the DHT sensor
#define DHTTYPE1 DHT22   // DHT 22  (AM2302), AM2321
#define DHTTYPE2 DHT22   // DHT 22  (AM2302), AM2321
// Initialize DHT sensor.
DHT dht1(DHTPIN1, DHTTYPE1);
DHT dht2(DHTPIN2, DHTTYPE2);
int relay_1 = 4;
int relay_2 = 7;
int relay_3 = 8;
int relay_4 = 12;
float totaltemp = 0;
float temps[4] = {0, 0, 0, 0};
float averagetemp = 0;
int steps = 0;
boolean boo = false;
void setup() {
  // Setup temperature
  Serial.begin(9600);
  Serial.println(F("DHTxx test!"));
  dht1.begin();
  dht2.begin();
  // Setup relays
  Serial.begin(9600);
  pinMode(relay_1, OUTPUT);
  pinMode(relay_2, OUTPUT);
  pinMode(relay_3, OUTPUT);
```

```
  pinMode(relay_4, OUTPUT);
}
void loop() {
  delay(2000);
  // Read temperature as Celsius (the default)
  float temp_in = dht1.readTemperature();
  float temp_out = dht2.readTemperature();
   // Check if any reads failed and exit early (to try again).
  if (isnan(temp_in)) {
    Serial.println(F("Failed to read from DHT in-hive sensor!"));
    return;
  } else if (isnan(temp_out)) {
    Serial.println(F("Failed to read from DHT outside sensor!"));
    return;
  }
  temps[steps] = temp_out;
  steps = steps + 1;
  totaltemp = temps[0] + temps[1] + temps[2] + temps[3];
  if (boo == true) {
    averagetemp = totaltemp / 4;
  } else {
    averagetemp = totaltemp / steps;
  }
  Serial.print(F(" Current in-hive temperature: "));
  Serial.print(temp_in);
  Serial.println(F("°C "));
  Serial.print(F(" Current outside temperature: "));
  Serial.print(temp_out);
  Serial.println(F("°C "));
  Serial.print(F(" Stored temperature 0: "));
  Serial.print(temps[0]);
   if (steps == 1) {
```

```
    Serial.println(F("°C (New)"));
  } else {
    Serial.println(F("°C "));
  }
  Serial.print(F(" Stored temperature 1: "));
  Serial.print(temps[1]);
   if (steps == 2) {
    Serial.println(F("°C (New)"));
  } else {
    Serial.println(F("°C "));
  }
  Serial.print(F(" Stored temperature 2: "));
  Serial.print(temps[2]);
   if (steps == 3) {
    Serial.println(F("°C (New)"));
  } else {
    Serial.println(F("°C "));
  }
  Serial.print(F(" Stored temperature 3: "));
  Serial.print(temps[3]);
   if (steps == 4) {
    Serial.println(F("°C (New)"));
  } else {
    Serial.println(F("°C "));
  }
  Serial.print(F(" Stored steps: "));
  Serial.println(steps);
  Serial.print(F(" Total stored temperature: "));
  Serial.print(totaltemp);
  Serial.println(F("°C "));
  Serial.print(F(" Average stored temperature: "));
  Serial.print(averagetemp);
```

```
  Serial.println(F("°C "));
  if (steps == 4) {
    steps = 0;
    boo = true;
  }
  if (temp_in <= averagetemp && temp_out >= averagetemp) {
  digitalWrite(relay_1, relayOFF); // Heating
  digitalWrite(relay_2, relayOFF); // Cooling
  digitalWrite(relay_3, relayOFF); // Fan 1
  digitalWrite(relay_4, relayOFF); // Fan 2
  Serial.println("(All relays OFF)");
  } else if (temp_in >= averagetemp && temp_out <= averagetemp) {
  digitalWrite(relay_1, relayOFF);
  digitalWrite(relay_2, relayOFF);
  digitalWrite(relay_3, relayOFF);
  digitalWrite(relay_4, relayOFF);
  Serial.println("(All relays OFF)");
  } else if (temp_in < averagetemp && temp_out < averagetemp) {
  digitalWrite(relay_1, relayON);
  digitalWrite(relay_2, relayOFF);
  digitalWrite(relay_3, relayON);
  digitalWrite(relay_4, relayON);
  Serial.println("(Heating)");
  } else if (temp_in > averagetemp && temp_out > averagetemp) {
  digitalWrite(relay_1, relayOFF);
  digitalWrite(relay_2, relayON);
  digitalWrite(relay_3, relayON);
  digitalWrite(relay_4, relayON);
  Serial.println("(Cooling)");
  }
  delay(10000);
}
```