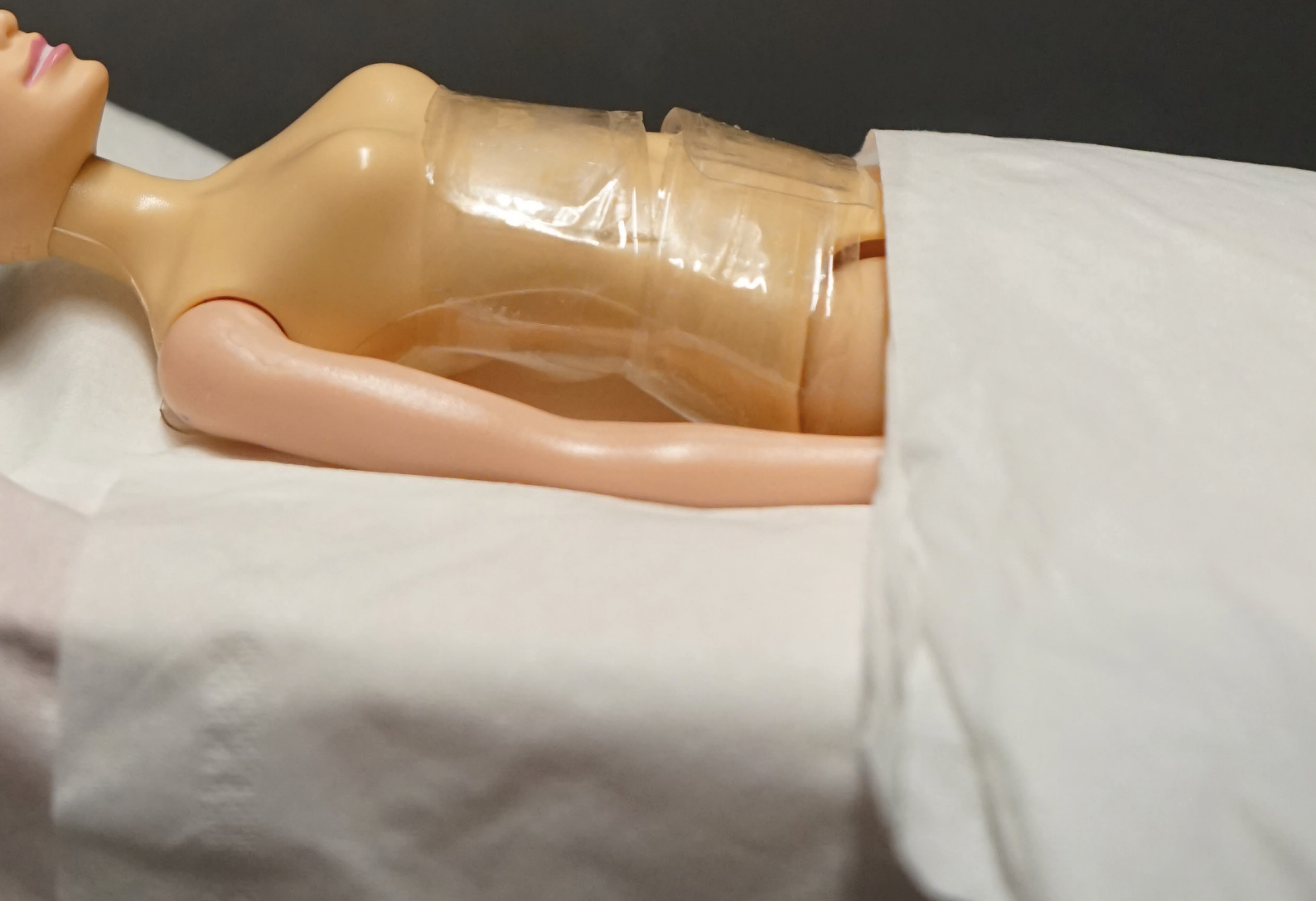
TOWARDS SUSTAINABLE COOLING

Designing Reusable Cooling Pads for ICU Patients



TOWARDS SUSTAINABLE COOLING

Designing Reusable Cooling Pads for ICU Patients

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Delft, 1 April 2026

Master thesis
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EXECUTIVE SUMMARY

Yearly around 300 patients at Erasmus MC receive targeted temperature management as a treatment. Currently, two methods are used at the hospital: the Arctic Sun pads and the Thermogard XP system with Quatro catheter. The Arctic Sun is an external cooling method, whereas the Thermogard is an internal cooling method. A third method was recently introduced: the STx Vest, another external cooling method. All methods involve many disposable products. Amongst medical staff the question was raised whether this treatment can be improved with regard to sustainability. Sustainability in the health sector is low, many disposables are used as opposed to reusables, due to the current profit system as well as hygiene and safety of patients. This thesis aims to answer the research question: How can a safe, feasible, sustainable cooling method for patients receiving targeted temperature management in hospitals be designed?

Research was done into temperature treatment, existing products, and the methods used at Erasmus MC. An overview was made of the three products with regard to four pillars in healthcare: cost, sustainability, workload and experience. The STx Vest scored the best in this comparison. Stakeholders were involved in the process of getting familiar with the existing methods. Requirements and wishes for a product providing targeted temperature management were gathered. After discovering the methods at EMC, pain points were identified to then create a design goal for this project. This design goal is: Creating a reusable external cooling method, with no adhesive layer which is available for all patients at EMC and whose patients can be transferred to surrounding hospitals.

With this design goal in mind, design iterations were started. A triple diamond structure was used during this phase and stakeholders were involved throughout the process to deliver feedback and useful insights. Eventually, the ideation phase resulted in three concepts of which the concept of reusable cooling pads was chosen to continue with. The next iteration with feedback resulted in the concept presented in this thesis: the Clinichill.

The Clinichill is a reusable cooling vest which is made of a mono-material to enhance recyclability value for end-of-life. The vest is made of PE, which is suitable for the chemicals involved in protocols for reusable products used in the hospital. Furthermore this material is relatively cheap, easy to manufacture, water resistant and allows heat transfer easily. The Clinichill is compatible with the machines of the Arctic Sun, to accommodate patients who are transferred to other hospitals whilst receiving target temperature management. The concept is simple in use, it consists of one pad with easy closing of nano tape, which is reusable during treatment of one patient. The main advantage of the concept is its simplicity according to nurses. Doctors find the concept and the process to find such products can be made reusable to be very valuable.

This thesis has proven that a safe, feasible, sustainable cooling method for patients can be achieved and manufactured. By using the Clinichill, Erasmus MC will decrease waste of disposables by 450 kg per year.

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to JC for his guidance, constructive feedback, and support throughout the development of this thesis. His expertise, energy, helpful insights and encouragement were wonderful and made JC a lovely chair to work with.

My appreciation also goes to Marijke for her time, for motivating me and helping me along whenever I got stuck in the process. Her thoughtful comments and helpful insights greatly improved this project.

I am deeply thankful to Nicole for bringing this project to life. Her insights from the perspective of Erasmus MC, her network and ability to link me to valuable persons at EMC was greatly appreciated. Without her willingness to participate and assist, this research would not have been possible.

I would like to thank Erasmus MC and specifically the people at the ICU-6 for providing the resources and academic environment necessary for carrying out this project. The staff was always willing to help me along and give their useful insights.

A special thanks goes to my fellow graduates, ESCH-R colleagues, and the amazing lunches we had on Wednesdays, for their encouragement, discussions, and support during the research process.

Finally, I wish to extend my heartfelt gratitude to my family and friends for their patience, understanding, and unwavering support throughout the entire duration of my studies. Thanks Stijn for your amazing puzzle abilities, thanks Céderic for your infinite help with each problem I shared and thanks Tom for always giving your unfiltered feedback and insights. Thanks to Anna en Leo for the many coffees and laughs throughout the last months and thanks to Jasper for always brightening the day and being there for medical questions and insights. Thanks to my parents for helping me brainstorm and allowing me to let off steam if needed. Your support has been invaluable throughout this project.

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1 INTRODUCTION

This chapter introduces report structure and reading guide. Furthermore, the design brief is explained on which this project is based. Sustainability in Dutch healthcare, the scope of the problem and targeted temperature management as a thesis topic are introduced.

1.1 REPORT STRUCTURE

This report follows the structure of the double diamond method. First, the project diverges in order to get familiar with the scope, after which the scope of the project is narrowed down to one problem. For this problem, potential solutions will be considered in a new diverging phase, after which the project converges towards one solution as the end result. For an overview of the structure, see Figure 1.

1.2 DESIGN BRIEF

Erasmus Medical Centre (EMC) in Rotterdam, the Netherlands, is striving to become more sustainable where possible. One of the areas where improvement is expected to be possible, is amongst the existing cooling methods for patients receiving targeted temperature management (TTM). This area of improvement was identified by nurses in a sustainability workshop on the treatments in ICU-6 at EMC whilst studying the R-ladder, see Chapter 1.6.1.1.

This thesis evaluates current cooling practices through a sustainability lens. This will be done through research, after which a more sustainable alternative will be developed with the help and insights of stakeholders.

1.3 SCOPE

The scope of this project is temperature management treatments in the ICU in Erasmus MC, in the Netherlands. First, the current situation is investigated, after which conclusions with regard to the current treatments are made. The second part of the project aims to design a sustainable method for temperature management to be used at the ICU at EMC, in the future.

1.4 READING GUIDE

A basic level of medical knowledge is assumed, e.g., terms such as veins will not be explained. The topic specific abbreviations used in this thesis are explained below.

OHCA	Out of hospital cardiac arrest
ROSC	Return of spontaneous circulation
EMC	Erasmus Medical Centre, located in Rotterdam, the Netherlands
TTM	Targeted temperature management
ICU	Intensive care unit
ICU-4/6	Intensive care unit, on floor 4/6 of EMC. 4th floor is for neurological patients, 6th floor is for thorax patients
AS	Arctic Sun, an external cooling method used at EMC, produced by BD
STx Vest	An external cooling method newly introduced at EMC, produced by Zoll
TG	Thermogard, an internal cooling method used at EMC, produced by Zoll, previously known as the CoolGard
CPR	Cardiopulmonary resuscitation
High central line	A central venous catheter placed in the neck or below the clavicle
Bedsores	Skin injuries caused by prolonged pressure that reduces blood flow and damages tissue

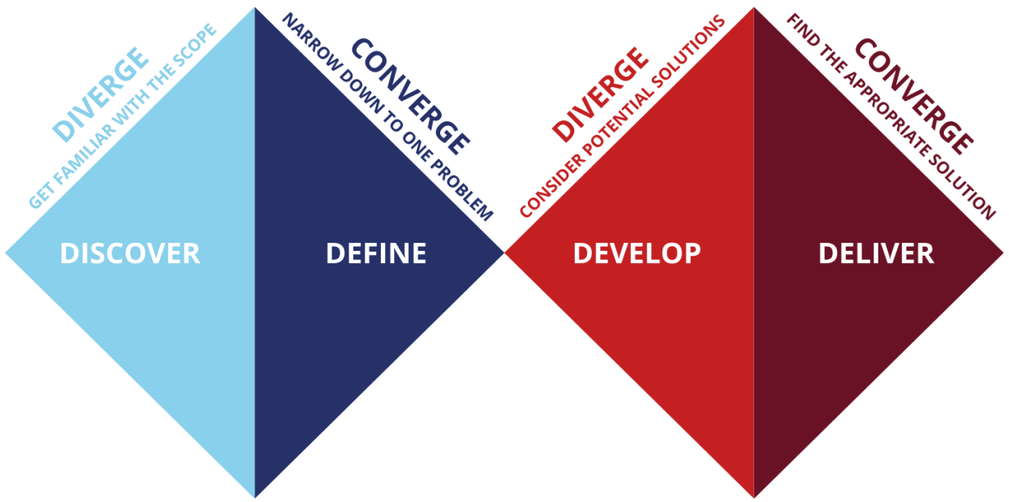


Figure 1: Double diamond structure

1.5 TARGETED TEMPERATURE MANAGEMENT EXPLAINED

Targeted temperature management is used for patients who experience an out-of-hospital cardiac arrest (OHCA). Cardiac arrest is when the heart stops beating due to, for example, an infarction or heart failure, which results in a lack of oxygen in the brain and other organs. If not treated quickly, by for example CPR, this lack of oxygen will lead to the death of the patient. In the Netherlands, approximately 17,000 people experience an OHCA per year. Chances of survival are 23% (De Nederlandse Hartstichting, n.d.).

If patients experience return of spontaneous circulation after CPR but remain comatose, they are taken to the hospital. Neurological outcomes of a patient after an OHCA are greatly improved by temperature control (Rosman et al., 2016), thus targeted temperature management (TTM) is recommended as treatment after cardiac arrest (Glover et al., 2016). The goal of TTM is to preserve brain metabolism by cooling the brain, followed by slow and controlled rewarming. Up until October 2025, guidelines included reaching a target temperature of 36°C as quickly as possible and keeping this temperature, once reached, for a minimum of 24 hours (Look et al., 2017). A newly introduced guideline aims at preventing fever, rather than cooling at the target temperature of 36 degrees.

TTM preserves the metabolism of the brain, because lowering the temperature of the human body: 1) suppresses processes that lead to delayed cell death, 2) reduces cerebral oxygen metabolism, which can reduce the release of amino acids, 3) blocks the effects of excitotoxin exposure such as high calcium and glutamate concentrations, and 4) reduces inflammatory responses. Physiological effects of TTM include shivering. Shivering is an automatic mechanism that generates heat to maintain body temperature, and is therefore undesirable. Sedation with propofol suppresses this mechanism, in some cases muscle relaxants, magnesium, opioids or counter warming with e.g. blankets are needed as well (Post Cardiac Arrest Zorg Op De ICV/Hartbewaking (Versie 3), n.d.).

TTM consists of four phases (see Figure 2): induction, maintenance, rewarming and management. An ideal cooling method should reach the target temperature quickly in the induction phase (within four hours); then allow for accurate maintenance; followed by slow and controlled rewarming and; finally avoid fever, in the management phase, by controlling the temperature. Furthermore, the method should be easy to use, comfortable for the patient and not increase nursing time (De Fazio et al., 2019; Vargas et al., 2015).

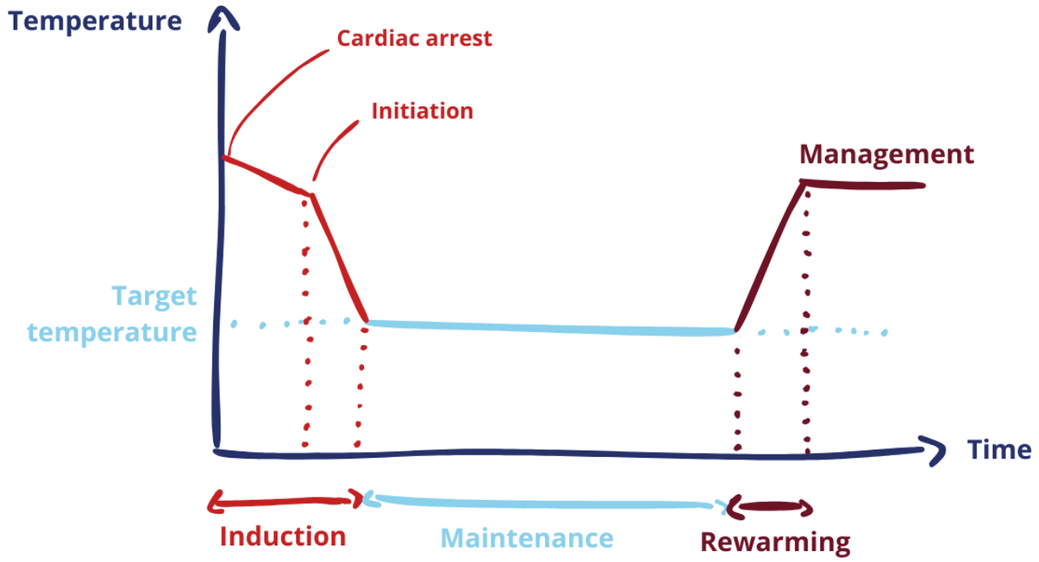


Figure 2: The four phases of TTM treatment (Fukuda, 2016)

1.6 SUSTAINABILITY IN TTM AT EMC

1.6.1 Sustainability in Dutch healthcare

In the Netherlands, sustainability is becoming increasingly important due to climate change, resource scarcity, and the need to safeguard future generations. The healthcare sector contributes significantly to this issue, accounting for approximately 7% of greenhouse gas emissions in the Netherlands (Het Effect Van De Nederlandse Zorg Op Het Milieu. Methode Voor Milieuvoetafdruk En Voorbeelden Voor Een Goede Zorgomgeving | RIVM, 2022). To address this, several initiatives have been launched, including the Green Deal Zorg 3.0: "Samen werken aan duurzame zorg," an agreement between the Dutch government and healthcare organizations to promote sustainable care (Green Deal Zorg, 2025). One initiative that emerged is ESCH-R, which aims to support the transition toward circular hospitals in collaboration with partners such as EMC. ESCH-R applies a systemic and transdisciplinary approach, focusing on high-impact medical consumables by addressing barriers and promoting behavioral change. Currently, ESCH-R is working on the Green ICU, of which this graduation project is a part.

Improving healthcare requires consideration of four key pillars: cost, sustainability, workload, and experience (see Figure 3). The first three are commonly used in healthcare projects, while the fourth—experience—is added in this thesis. This pillar includes the wellbeing and care effectiveness for both medical staff and patients, which are essential for the success of healthcare innovations. These pillars will be used as a guiding framework throughout this thesis.

1.6.1.1 R-strategies

Also known as the R-ladder, the R-strategies are a framework for circular economy. The R-ladder, see Figure 4, forms a hierarchy of actions in order to improve the sustainability of products, for example through minimizing waste, extending product life and conserving resources.

1.6.2 Targeted temperature management as a thesis topic

ESCH-R and the Green Team at EMC keep looking for areas of high impact single-use products which can be reassessed, to continue improving on sustainability. The R-strategies were presented to the ICU-6 (intensive care unit for thorax patients) at EMC. Nurses evaluated and assessed the protocols, products and actions with this R-ladder. One of the areas of improvement identified was the treatment of patients who receive cooling, also known as targeted temperature management, due to the amount of disposables used. Moreover, sometimes the treatment is prepared but turns out unnecessary and is thus not used, or the materials are prepared but have to be thrown away when a patient is transferred to a different hospital. Furthermore, there is quite some unclarity in the protocol, which simply states 'start cooling'. EMC has two different cooling methods, the choice of which currently comes down to personal preference of the medical team, see Chapter 2.4.2.

Since this area of improvement was defined during the workshop, multiple stakeholders have been reassessing

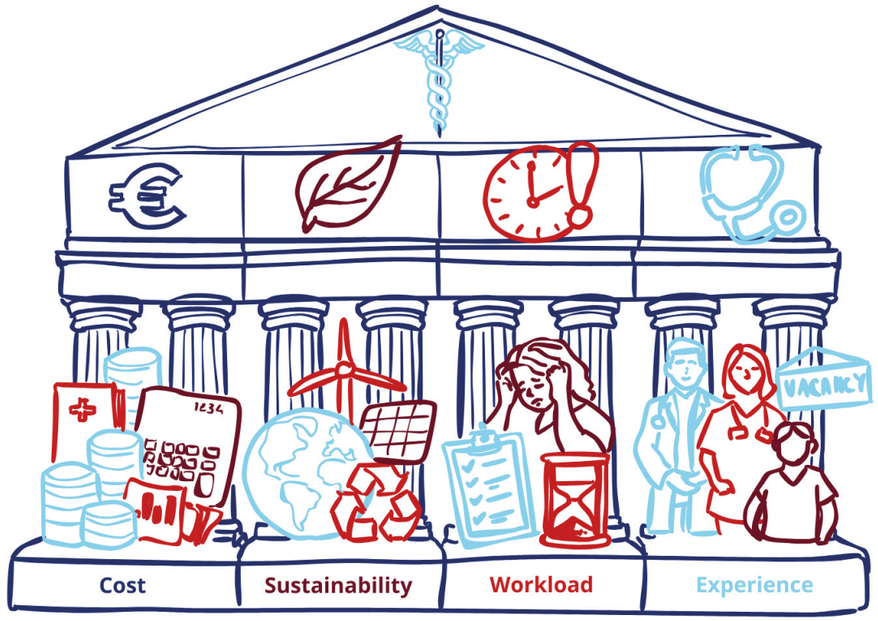


Figure 3: The four pillars of the healthcare system

*Figure 4: R-strategies (*R-Strategies for a Circular Economy, *n.d.)*

this treatment along the R-ladder. A new protocol for the treatment has been implemented last October. Within EMC, a cardiologist-intensivist and neurologist-intensivist are re-evaluating the current treatment and way of working at EMC in order to improve the sustainability impact.

1.6.2.1 Changes related to this topic

During this project, multiple changes in this treatment were introduced, which impacted this thesis.

- At the start of this project, the two different cooling methods used at EMC were included in the scope: the Thermogard XP and the Arctic Sun™ 5000 TTM system along with the ArcticGel™ Pads.
- During the project, a third cooling method was introduced: the STx Vest. Whilst this third product was introduced to EMC a while ago, it is not yet used, therefore this STx Vest was included in the analysis of current methods on a hypothetical basis.
- Furthermore, at the start of this project a different protocol existed than at the end of the project.

1.6.2.1.1 New protocol

The previous guidelines, presented by the European Resuscitation Council in 2021, recommended targeted temperature management for comatose patients after an OHCA, aiming for a temperature between 32°C and 36°C for at least 24 hours. Fever should be avoided for at least 72 hours after ROSC.

On October 22, 2025, new guidelines on cardiopulmonary resuscitation were launched by the European Resuscitation Council. These guidelines were created with the help of the American Heart Association and the International Liaison Committee of Resuscitation (Greif et al., 2025). The new guidelines for post resuscitation care involve actively preventing fever by targeting a temperature of less than 37.5°C for 36-72 hours in comatose patients. Patients with mild hypothermia (a body temperature of 32°C to 36°C) should remain at the temperature they are after ROSC. The guidelines further advise against the use of cooling with large volumes of cold intravenous fluid immediately after ROSC. They recommend surface or endovascular temperature control techniques, with a feedback system based on continuous temperature monitoring.

As a result of these new guidelines, the protocols for post cardiac arrest at EMC are currently being revised. Currently, TTM is still being used, once the protocols are revised by intensivists at EMC, the treatment of TTM will change to fever control. Fever control, as opposed to, TTM allows for a more liberal approach to the cooling protocol. The R-strategies 'refuse' and 'rethink' present itself as possible ways to improve the sustainability within this topic. For example, one of the cardiologist-intensivists at EMC mentioned this new protocol raises the question whether the cooling products need to be prepared immediately upon admission for all patients, or if they can be prepared once risk of fever is identified. This would result in using less products, a 'refuse' strategy.

1.7 RESEARCH QUESTIONS

The main research question of this thesis is:
How can a safe, feasible, sustainable cooling method for patients receiving TTM in hospitals be designed?

In order to answer this question, several subquestions are answered:

Subquestion 1: Cooling as treatment

- What are the physical principles of therapeutic cooling?

Subquestion 2: Cooling methods

- Which cooling methods exist, which are currently used at EMC and what are their environmental impacts?
- What are the advantages and disadvantages of single-use products?

Subquestion 3: Sustainable alternatives

- What factors influence acceptance of new products at EMC, what are the practical barriers to implementing reusable cooling methods?
- Which cleaning, disinfecting and sterilizing methods are used at EMC? Which materials are suitable with regard to these regulations?
- What are the design challenges in making products reusable in a hospital environment?
- How does the use of sustainable cooling methods impact the workflow of stakeholders involved?

2 DISCOVER

This chapter discovers and investigates all related information for this thesis. First, temparature management as a human process is researched, followed by existing methods of temperature management. The history of this treatment at EMC is explained. The different methods used are researched and compared to gain useful insights for the rest of this project.

2.1 HEAT LOSS IN HUMANS

Heat loss in the human body occurs through four mechanisms: convection, conduction, radiation and evaporation, see Figure 5. Radiation is responsible for around 60% of heat loss, through emitting infrared rays from blood vessels underneath the skin surface. Evaporation accounts for about 22% of heat loss. Water vaporization consumes heat, facilitating heat loss. This process always happens when the environmental temperature is warmer than the skin, not only through sweating. Convection, currents surrounding the body, contributes to roughly 15% heat loss. Conduction is responsible for 3% of heat loss. Conduction is heat transmission through a physical connection, i.e. by touching an object. Different mediums have different rates of transferring heat. For example, the conductive heat transfer rate of water is 100 times that of air, thus water transfers heat quicker than air. Radiation and conduction allow heat transfer as long as the skin temperature is higher than the surroundings (Koop & Tadi, 2023).

Temperature management is based on these four principles of heat dissipation. In theory, temperature management is most effective when all four mechanisms are addressed, however most TTM methods are based on one principle for simplicity. For instance, the Arctic Sun Temperature Management System is based on the principle of conduction (Aujla et al., 2016).

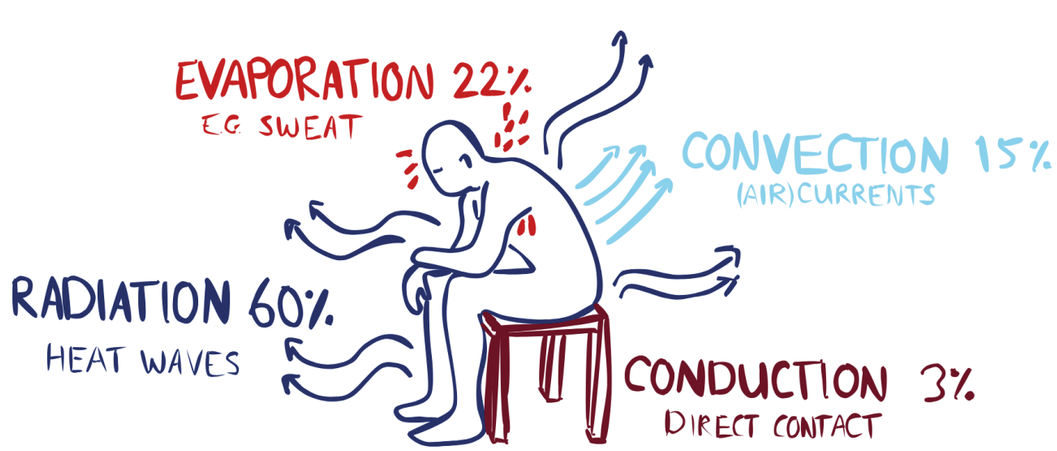


Figure 5: The four mechanisms of human heat loss (adapted from Yartsev, n.d.)

2.2 HUMAN TEMPERATURE MANAGEMENT AND THE IMPACT OF TTM

The temperature of the human body is regulated by the hypothalamus. This part of the brain is responsible for keeping your body in homeostasis, which means it regulates your temperature, blood pressure, hunger and thirst, sleep and mood. It responds to different factors, for example to infectious organisms and injury by releasing fever-producing chemicals that change body temperature (Cleveland Clinic Medical, 2025). Once your body notices it loses heat faster than it can produce heat, causing a dangerously low body temperature, different mechanisms act up to keep the body's core warm, see Figure 6 (NTR, Klokhuis, 2024).

A neurologist-intensivist at EMC explained that this physiological compensation mechanism of the hypothalamus is being overruled during TTM: the machines cool too much for the body to heat itself up.

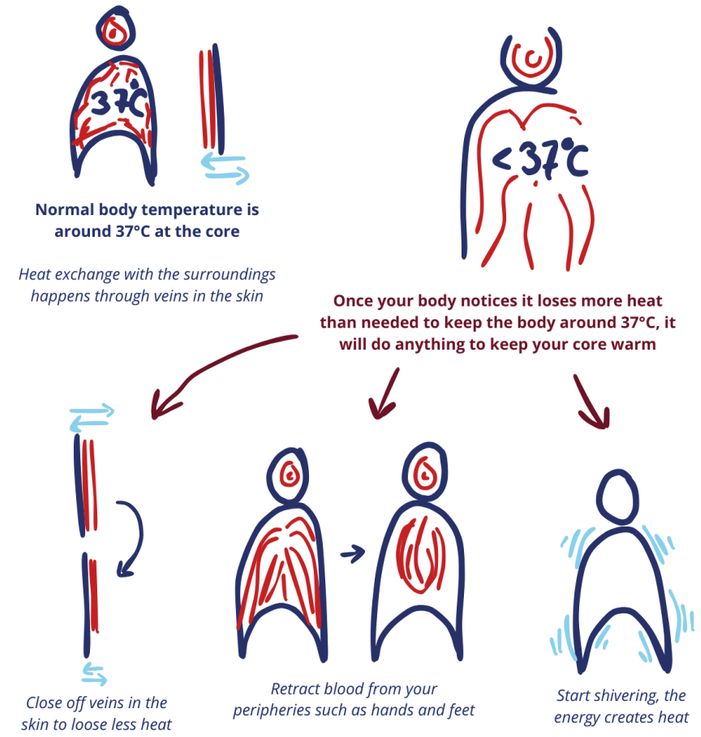


Figure 6: Temperature mechanism in the human body

2.3 AVAILABLE COOLING METHODS

TTM can be delivered by conventional or modern methods, see Figure 7 for an overview of existing methods. Conventional methods, such as wet blankets, ice-packs and administration of cold fluids, are methods which cool passively with no feedback mechanism integrated in the system, and therefore are associated with overcooling (Glover et al., 2016). Conventional methods are easy-to-use, with high availability and low cost. However, they are labour intensive for the nurses, have unpredictable outcomes and result in variations in body temperature, which increase medical risks (De Fazio et al., 2019; Vaity et al., 2015). Thus, modern techniques were developed to improve the treatment. These modern techniques are divided into two categories; internal and external cooling. Modern techniques use temperature feedback control which allows for a more precise treatment (De Fazio et al., 2019; Vaity et al., 2015). Modern devices reach the target temperature more quickly with a more consistent temperature, and have a feedback system implemented. Examples of modern methods include intravascular catheters or surface devices such as water-circulating blankets (Glover et al., 2016).

Intravascular treatment, also referred to as endovascular treatment, requires inserted catheters into a large vein and therefore is considered invasive. The catheters provide a large surface area in contact with the patient's bloodstream, where heat exchange happens. The main advantage of internal cooling methods is precision in treatment, the main disadvantage is risk of infection (Glover et al., 2016; De Fazio et al., 2019; Look et al., 2017). Surface cooling requires application of cooling blankets, ice packs or gel-adhesive pads and is considered non-invasive (Bartlett et al., 2019). The advantages of surface cooling methods is ease of use and rapid initiation of treatment. Nevertheless, these methods bring risk of burns and skin irritation and maintenance of temperature is difficult (Vaity et al., 2015).

Several studies have found that neurological outcomes and mortality rates are similar when comparing external and internal cooling methods (De Fazio et al., 2019; Glover et al., 2016; Look et al., 2017). External cooling without feedback has the lowest chance of beneficial medical outcomes (Ramadanov et al., 2022). Internal cooling has a faster and more stable cooling rate, which shortens the time in hospital, which is linked to improved neurological outcomes (Liao et al., 2020).

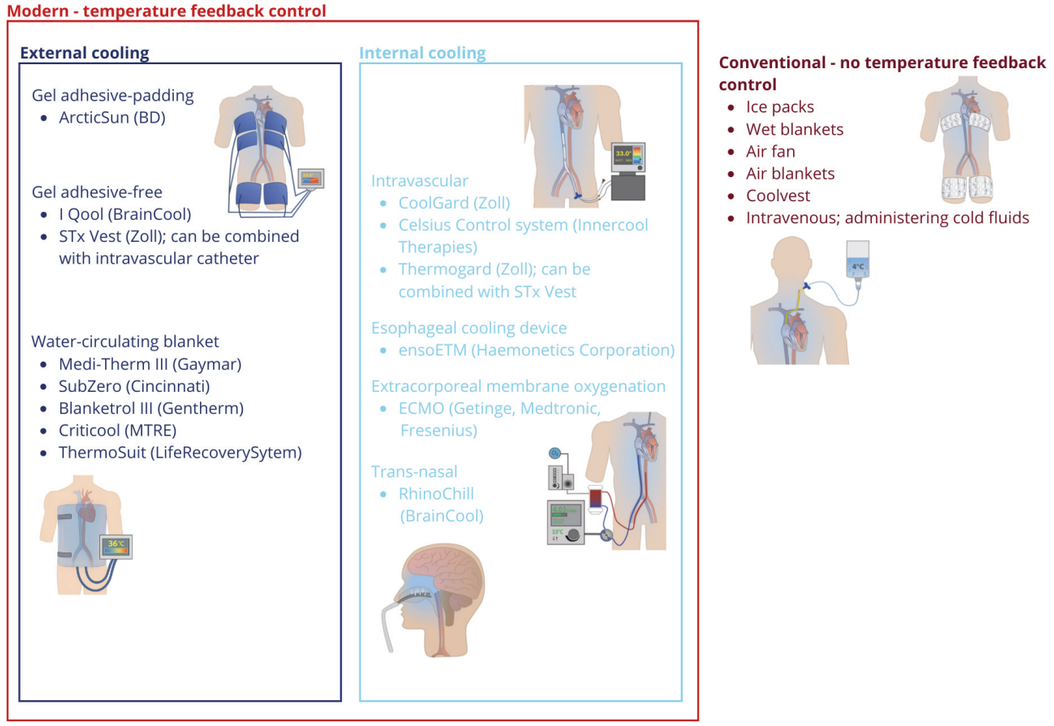


Figure 7: Overview of existing cooling methods, figures adapted from Cooling Techniques for Targeted Temperature Management (n.d.) and complemented by AI

According to a neurologist-intensivist at EMC, internal cooling is no more effective than external cooling in terms of achieving the average target temperature. There is, however, slightly more variation with regard to the average temperature with external cooling, due to the amount of human flesh between the core and cooling mechanism. This has been proven to be clinically unsignificant in studies. Furthermore, intravascular cooling will result in a more constant cooling than external methods can deliver. Because blood is present throughout the entire body, intravascular cooling happens gradually with less variations in temperature. In external cooling, feedback is less direct, which results in wider variations from the target temperature, causing the system to turn on and off more often. However, internal and external cooling methods are equally good at keeping a target temperature in the body's core.

2.3.1 External cooling

Two of the most common external cooling methods are pads and water-blankets. Gel-adhesive pads provide quicker induction and better temperature maintenance than water-circulating blankets (Sonder et al., 2017). Alne (2019) found that gel-adhesive cooling is easier for nurses to maintain, and water-circulating blankets provide less accurate temperature control. Furthermore, gel-adhesive cooling has a higher efficiency, faster cooling rates and smaller temperature variability. However, there are no significant differences in neurological outcomes between both categories (Keum et al., 2021).

Multiple studies have found Arctic Sun to be the superior surface cooling method, since this method is most efficient in reaching the target temperature and thus allows for quicker temperature control. However, shivering occurs more often in Arctic Sun than with water-circulating blankets and skin-irritation occurs due to the adhesive pads. Nevertheless, Arctic Sun is preferred as a cooling method (Aujla et al., 2016; Mayer et al., 2004; Shinada et al., 2013; Islam et al., 2015; Heard et al., 2009).

2.3.2 Internal cooling

There are several internal cooling methods, such as: intravascular (e.g. Thermogard), intravenous, trans-nasal (e.g. RhinoChill) and extracorporeal membrane oxygenation (ECMO). The ECMO is a machine which takes over the functioning of the human lungs and heart.

While trans-nasal cooling is quickly administered and non-invasive, there is no temperature feedback system and the cooling is limited to the brain. There are no differences in functional outcome between intravenous cold fluids and trans-nasal evaporation (Annoni et al., 2021). However, these methods are inferior to intravascular cooling and ECMO. Both have accurate temperature control. ECMO has the fastest cooling time, however, this method is also the most invasive and highly complex. Both methods have risks of complications due the bloodstream being opened up. If there is no need for organ support, intravascular cooling (such as the Thermogard) is preferred, due to being less invasive and complex.

2.3.3 Effectiveness of TTM

A neurologist-intensivist at EMC explained the effectiveness of TTM. Most constant cooling of the body is achieved by cooling the human blood, an adult has around 5 liters. This volume is spread evenly throughout the body, which results in gradual cooling and less variations in temperature.

The feedback mechanism in external cooling is more indirect than internal cooling, due to the amount of fat in a human body, which results in more variation in temperature. However, in both methods the target temperature is perfectly controllable.

The goal of TTM is preserving the metabolism of the human brain by cooling it. Local cooling might seem more efficient for this goal. However, cooling only the brain is much less effective since it is relatively inefficient. Since the body is warm, warm blood flows through the brain. So, when only the head is cooled, essentially, the whole body is cooled via blood in the head, for which much more energy is needed. Furthermore, it might be possible that the temperature feedback mechanism in the brain is negatively affected by local cooling, however, it is unknown whether there are any studies on this. It is most efficient to cool the blood directly, followed by cooling the skin due to the large amount of blood flowing through the skin.

Patients who receive TTM lay underneath a blanket. Initially, this seems counterintuitive since the patients need to be cooled, not warmed. However, if the body is warm at the peripheries (the extremities of the body such as the hands and feet) the brain will think the body is warm enough and will compensate less to keep the warmth in the core. The body will not react with a fever to compensate for the cold, or shivering. This principle is called periphery counter warming.

2.4 COOLING AT EMC

Yearly, around 100-120 people are treated with TTM after an OHCA at EMC. At Erasmus MC, both the Arctic Sun and Thermogard are used, further explained in Chapters 2.4.4 and 2.4.5. During this thesis a third cooling option was introduced, the STx Vest. This vest is not yet in standard use, but the first trials seem very promising.

A different method of cooling is also used at EMC, the ECMO. This machine takes over heart- and lung-function of the patient and is able to cool and warm the blood in this process. This method will not be further investigated in this project, since the main function of ECMO is functioning as the heart and lungs of the patient, cooling is an additional feature of the machine.

During cooling, the target temperature used to be 36°C according to the previous guidelines. The newly introduced guidelines aim for fever prevention. If patients come in at a cooler initial temperature, this temperature is maintained. Every ICU-patient has an internal thermometer in place in their bladder during treatment.

To gather insight into the amount of times patients are treated with TTM at EMC, the purchasing statistics over the period of January the first in 2024 until the 3d of December 2025 were gathered, shown in Figure 8. From these statistics, the amount of treatments per year with the Thermogard can be estimated on 60 times, and the Arctic Sun kits used on around 250.

2.4.1 Cooling treatments at EMC

EMC has two intensive care units , see Figure 9. The ICU on the sixth floor accommodates thorax patients, who have heart and lung issues. The ICU on the fourth floor accommodates patients with neurological trauma and other issues.

An intensivist explained the differences in methods used per ICU. On the sixth floor, both the Thermogard and the Arctic Sun are used, often times the Thermogard is preferred. The Arctic Sun is mainly used on ICU-6 when the patient is being transferred to another hospital, since hospitals nearby do not have the machine needed to use the Thermogard. All thorax patients are anticoagulated with blood thinners, due to their heart problems and the treatment needed. The internal catheter of the Thermogard causes clotting because it disturbs the blood flow, however, since the patients on this floor have blood thinners, this is not a risk. Patients on the fourth floor, mainly neurological patients, have blood in their brain and therefore cannot use blood thinners. Because of this, an internal catheter which triggers a clotting reaction and chance of thrombosis cannot be used at ICU-4. Thus, on the fourth floor, only the Arctic Sun is used as a cooling method.

This results in an interesting situation in which medical staff in ICU-6 can choose which cooling method they will use for their patients, whereas ICU-4 always uses the Arctic Sun.

2.4.2 The choice of cooling method

The choice of treatment lies with the cardiologist-interventionist and intensivist. Apart from this choice being a personal preference, there are several reasons mentioned by doctors at EMC to favour the Thermogard over the Arctic Sun as a cooling method:

1. Thermogard used to be the only option and is therefore most known.
2. Furthermore, doctors think the Thermogard is more effective than Arctic Sun, since cooling is closer to the core, which is closer to the brain.
3. Doctors find it easy to insert the catheter, since they often already have access to the vein after their intervention.

Figure 8: Cooling methods used at EMC with amount of disposables purchased between 1/1/2024 - 3/12/2025 (images: Arctic SunTM 5000-temperatuurmanagement Systeem | BD Nederland, n.d., Quatro Catheter, n.d. STx Vest, n.d)

When a patient is being transferred to a different hospital, only Arctic Sun is possible, since other hospitals do not have the Thermogard XP system.

2.4.3 Single-use vs. reuse in hospital products

The products currently used at EMC are all single-use, including the newly introduced STx Vest. Several reasons exist for clinical products to be designed as single-use and introduce barriers for designing reusable products.

From a manufacturer's perspective, single-use products are advantageous due to higher profitability, as revenue is generated for each unit sold. For hospitals, single-use products reduce infection risk and simplify the workflow by avoiding cleaning and disinfection. However, they are less sustainable and result in increased waste-related costs, which is paid for per kilo.

Single-use products eliminate the risk of infections or contamination between patients due to inadequate cleaning. They ensure that each product is properly prepared for safe use without requiring additional processing. In contrast, reuse introduces complex cleaning and disinfection processes, which increases workload and may not always be reliably validated.

Furthermore, single-use products guarantee a consistent level of effectiveness, whereas reusable products may degrade over time and become less effective than required. These disposable products often consist of complex materials and components, such as integrated channels, conductive layers, and thermal gels, which limit the feasibility of safe reuse due to their inability to be cleaned and disinfected while maintaining the same quality.

Regulations imposed by organisations such as the Medical Device Regulation in Europe further complicate the implementation of reusable products. Requirements such as risk analyses, traceability systems, and strict cleaning and disinfection protocols must be maintained.

Single-use products are directly usable and offer high ease of use without imposing additional burdens related to cleaning or safety procedures. Although reusable products may initially seem cheaper, additional costs arise from cleaning, disinfection, and increased personnel workload.

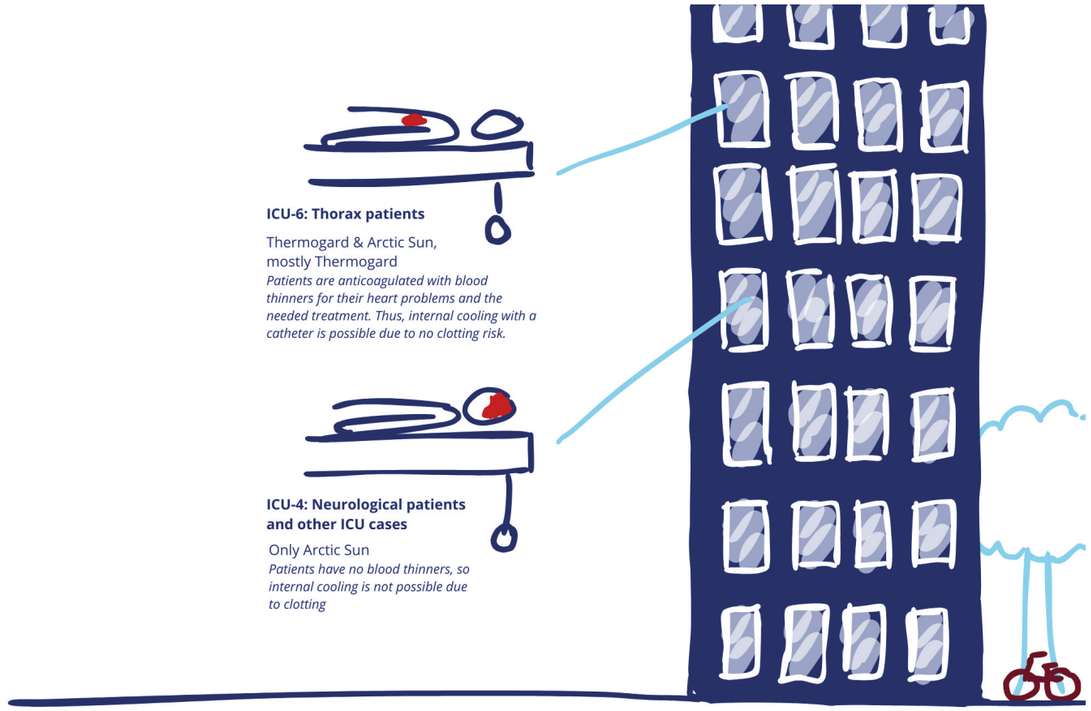


Figure 9: Visualisation of ICUs at EMC and the cooling methods currently used

2.4.4 The Arctic Sun™ 5000 TTM system along with the ArcticGel™ Pads

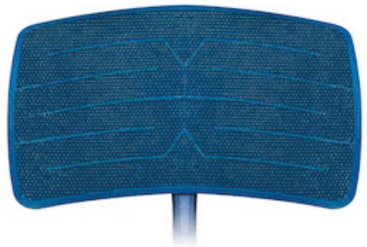
A non-invasive, external cooling method via gelpads, based on the principle of conduction, see Figure 10. Manufactured by BD.

Pads

- Pads with hydrogel technology, they should not be used on irritated skin, such as rashes
- Non-sterile for single-use only
- Each nursing shift, the pads need to be checked on adherence; if the pads no longer adhere to the patient new pads are needed.
- Replacement of the pads is recommended after five days of use.
- Different sized pads are available to accommodate each patient. An extra universal pad is available to cover extra exposed skin.

System

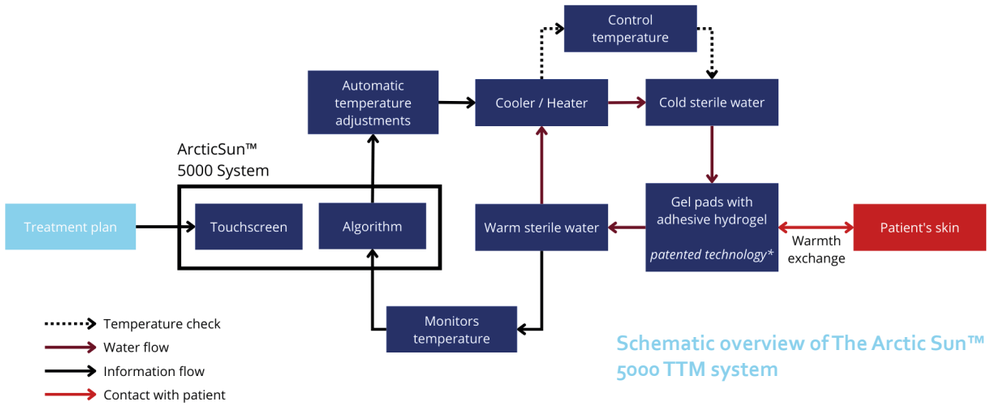
- Automated temperature management, to stay at the target temperature.
- Monitors the core temperature of the patient via a temperature probe. The patient's temperature can be monitored within a range of 32°C to 38.5°C.
- The pads and system have negative pressure, which means air enters the system if there is a leak, instead of water leaking out.



ArcticGel™ Pad

Patient with ArcticGel™ Pads

The Arctic Sun™ 5000 TTM system



Schematic overview of The Arctic Sun™ 5000 TTM system

Figure 10: The Arctic Sun system (AS-images derived from Arctic SunTM 5000-temperatuurmanagement Systeem | BD Nederland, n.d.)

Per patient, two pads are placed on the thighs, two on the torso and one additional universal pad might be used if the patient is large, see Figure 11.

For placement of the pads, two to three nurses are needed, depending on the weight and size of the patient, see Figure 12.

2.4.4.1 About BD

The Arctic Sun system was developed by Medivance, which was acquired by C.R. Brard in 2011, which was then taken over by Becton Dickinson (BD) in 2017. BD is one of the largest global medical technology companies worldwide, with more than 70,000 employees. They aim to develop innovative solutions that help enhance medical help for both patients and healthcare providers. The company partners with organisations around the world and is present in nearly every country to address global health issues. BD aims to lower costs, increase efficiency, improve safety and expand access to healthcare (Our Company | BD, n.d-a.; Our Company | BD, n.d.-b).

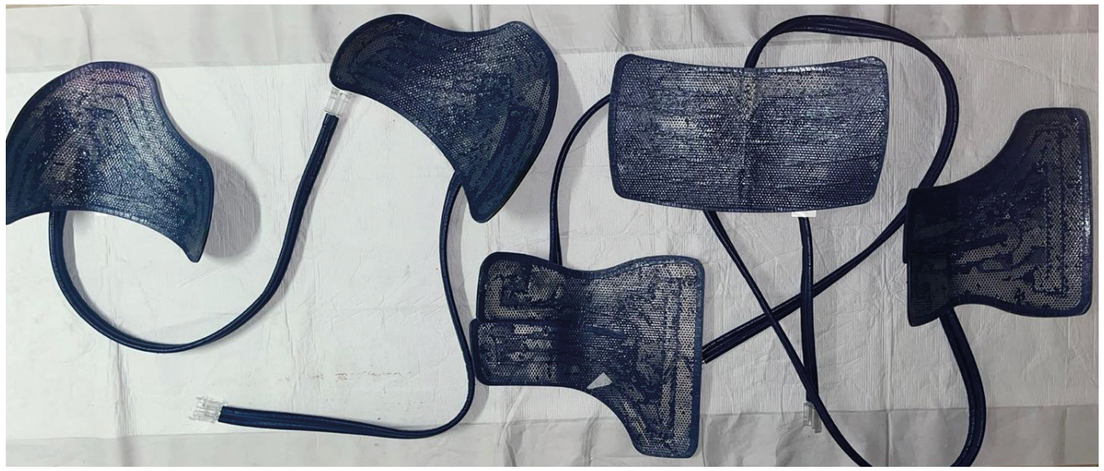


Figure 11: The Arctic Sun pads, after use; on the left: two thigh pads; on the top right: a universal pad; on the bottom right: two torso pads

Figure 12: Placement of pads (Arctic SunTM 5000-temperatuurmanagement Systeem | BD Nederland, n.d.)

2.4.5 The Thermogard XP system

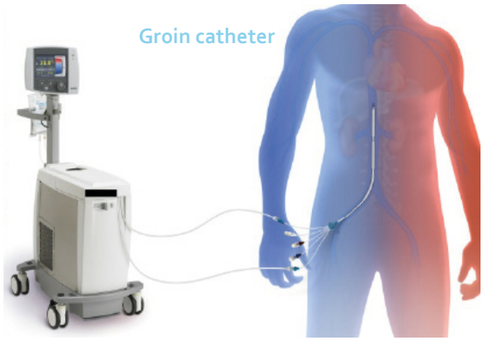
An internal cooling method, Figure 13, via a catheter in the bloodstream, based on conduction. Manufactured by Zoll.

Catheter

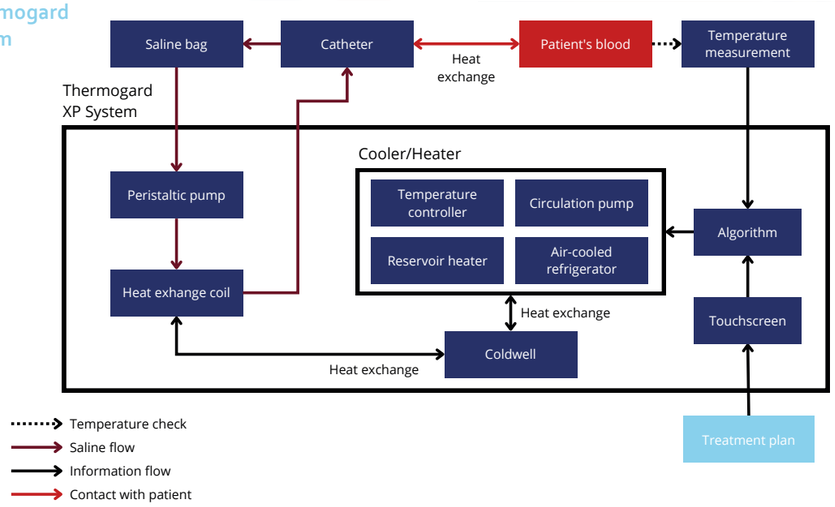
- At EMC, the cooling catheter is inserted in the groin area and placed inside the inferior vena cava, which transports blood from the lower body to the heart, Figure 14. Zoll offers catheters for the neck area as well.
- Inside this catheter is a flow of cooled saline, of which the temperature is controlled by the Thermogard XP system.
- The catheter brings risk of clotting. Therefore, the catheter is removed as quickly as possible, a maximum of 72 hours is possible.

System

- This is a closed-loop control system, the temperature is constantly adjusted, to reach target temperature.
- Each minute, data is gathered of the patient and the system. The temperature of the saline will be adjusted when a change as small as 0.1°C is noticed.
- Consists of three major components: a sterile fluid roller pump, a recirculating chiller, and a temperature control system.
- The system is connected to the catheter by two small tubes, one supplies temperature-controlled saline to the catheter, the other returns the saline to the system.
- The saline is pumped by a peristaltic pump and acts as an intermediate heat-transfer medium between the patient's blood and the system. The flowrate of the pump can be adjusted per patient.
- The patient's temperature is measured and is used as input to regulate the temperature of the recirculating chiller and heater, the temperature is measured via an oesophageal, rectal or foley temperature probe.



The Thermogard XP system



Schematic overview of the Thermogard XP system

Figure 13: Schematic overview of the cooling method and system (image derived from Thermogard, n.d. & Thermogard Temperature System, n.d.)

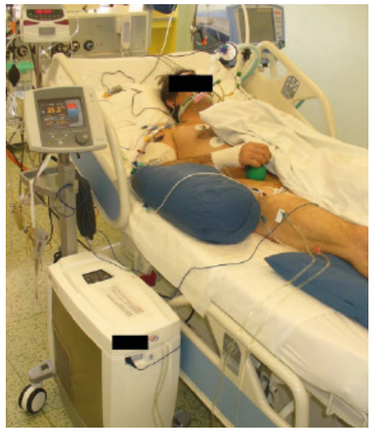
Start-up kit

- The start-up kit is needed to connect the catheter to the cooling machine and allows the cooled saline to flow in the system.
- Consists of a heat exchanger coil, saline delivery lines, connectors, air trap and tubing of the pump.
- These components can be used for seven days, then they must be replaced (ZOLL Circulation, Inc., 2009).

A doctor is needed for placement of the catheter, removal can be done by nurses. Since this cooling method is invasive, the medical staff involved and procedures are sterile, which comes with many materials needed and preparation takes time.

2.4.5.1 About ZOLL

ZOLL strives to make meaningful differences in people's lives through innovative technologies. The company was founded in 1980. Today the company is a global leader in critical care and their devices, services and software are used to treat cardiopulmonary and respiratory conditions worldwide. ZOLL solutions make better outcomes for patients possible, help improve critical care and increase efficiencies. ZOLL is part of the Asahi Kasei Group, which has 50,000 employees worldwide (Company Overview: About ZOLL Medical, n.d.).



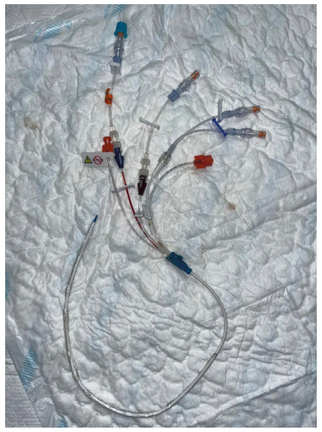


Figure 14: The Quatro catheter and start-up kit, image on the right from (Endovascular Catheter Cooling via CoolGard 3000TM and Icy Femoral CathetherTM, Alsius Corp., Irvine, USA., n.d.)

2.4.6 A third new cooling method: the STx Vest

An external, non-invasive cooling method manufactured by Zoll, also based on the principle of conduction. It has been on the market for a year, see Figure 15.

Vest

- The patient lies with their back and shoulders on the vest, which is wrapped around the torso and connected with stretchable Velcro. Due to this easy attachment, the product can be instantly removed if needed.
- The pads are lined with a non-stick, durable and skin-friendly layer and is non-adhesive. This soft layer is integrated for higher skin comfort, however, as the patient is comatose, this layer does not add any value for the patient, as long as there are no pressure points, according to nurses at EMC.
- The material is impregnatable, so it is not sterile, and for one patient only.
- The vest is available in two different sizes: S/M and L/XL
- The vest can be used for a period of ten days.

Start-up kit

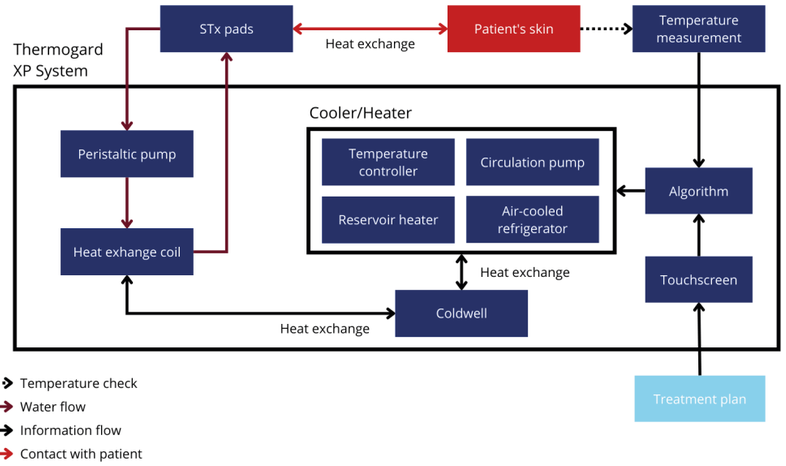
- To connect the vest to the cooling machine, allowing the cooled water to flow in the system.
- Consists of a heat exchanger coil, saline delivery lines, connectors, air trap and tubing of the pump.
- Different from the start-up kit for catheters; this tubing is leak free, to allow easy disconnection of the vest.

System

- The STx Vest uses the Thermogard XP system as well.
- Uses tapwater as a cooling medium, takes 5 minutes to fill. Once the vest is filled, it can be placed around the patient. During filling, it can be placed over patient to start a bit of cooling.

The STx Vest

The Thermogard XP system



Schematic overview

Figure 15: Overview of the cooling method and system (image derived from STx Vest, n.d. & Thermogard Temperature System, n.d.)

The STx Vest is specifically made for fever control of 36°C - 37.5°C, in Germany a patient was successfully cooled to 33°C. Since this cooling method is external, fluctuations in temperature are expected. Depending on the amount of fat patients have, fluctuations will be higher in large patients, 0.5 - 1°C is quite common. Zoll claims no difference in ability to hit target temperature within 4 hours compared to the Arctic Sun (ZOLL, 2025).

Per nursing shift, the skin of the patient needs to be checked for any damage or signs of of bedsores.

Using the STx Vest instead of the Arctic Sun as the external cooling method results in the use of only one system at EMC, which would increase ease of use due to familiarity for medical staff. However, this system is not available in nearby hospitals, thus patients who are being cooled could not be transferred and the Thermogard XP machine is more expensive than the Arctic Sun System, see Chapter 2.6.2.2.

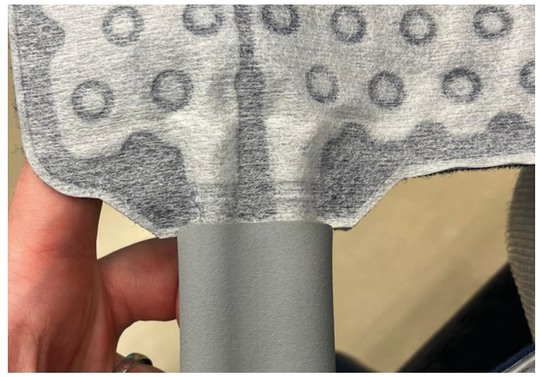


Figure 16: Product details STx Vest

2.4.7 History of cooling at EMC

Apart from TTM, patients are also cooled during surgeries. In the past, other methods have been used for cooling patients in hospitals (Figure 17): lowering a patient on a metal plate into an ice bath, water blankets, water beds, alcohol, wet towels, lying in shaved ice and the Blanketroll, a type of water blanket.

Nowadays, air blankets are used to regulate the temperature of patients undergoing surgery, whereas adhesive water-circulating pads applied to the skin and an internal catheter are used for TTM. Compared to the methods used in the past, the Thermogard and Arctic Sun support a more accurate adjustment and control in case of changes to the temperature or in case of keeping the temperature constant according to people at the ICU.

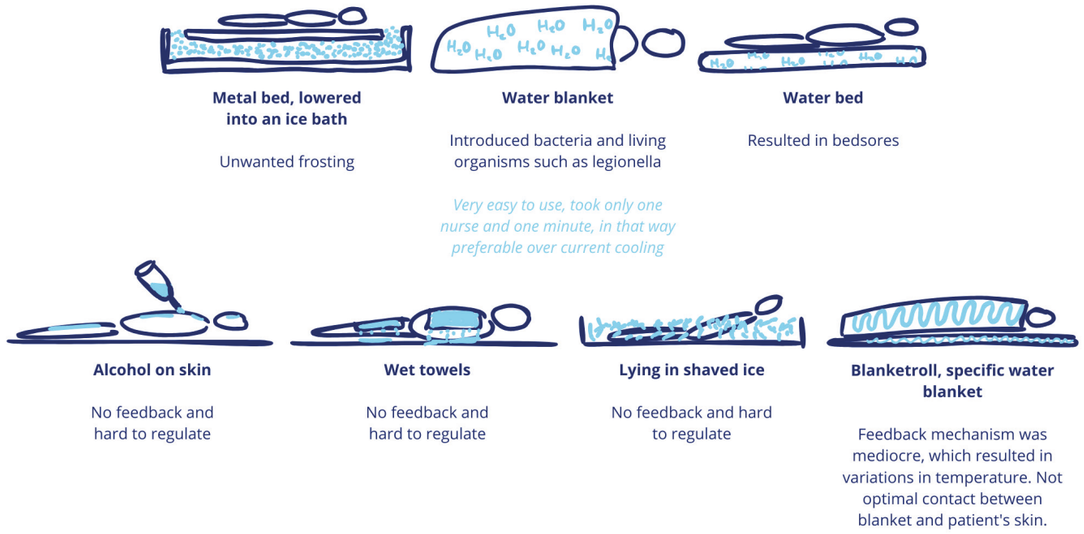


Figure 17: Cooling methods applied at EMC in the past

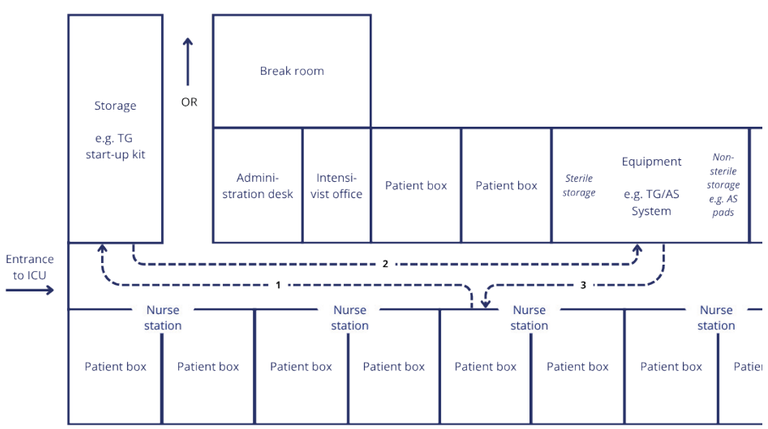


Figure 18: Floorplan of part of ICU-6, route for collecting materials for the TG treatment

Figure 19: Empty patient's box at ICU-6

2.4.8 ICU-6

See Figures 18 and 19 for an overview of the floorplan of ICU-6. The route a nurse would have to walk in preparation of treatment with the Thermogard in case the catheter is placed in the patient box is visualised.

2.4.8.1 People working in the ICU

Many people work in ICU-6, see Figure 20 for an overview. Furthermore, the ICU has close contact with other specialists, such as physiotherapists and dietitians, as well as ward assistants, logistics staff and social workers and spiritual counsellors (Erasmus MC, n.d.). An organogram of the ICU at EMC is included in Figure 21. This combines the people working in the ICU with other stakeholders involved in the hospital.

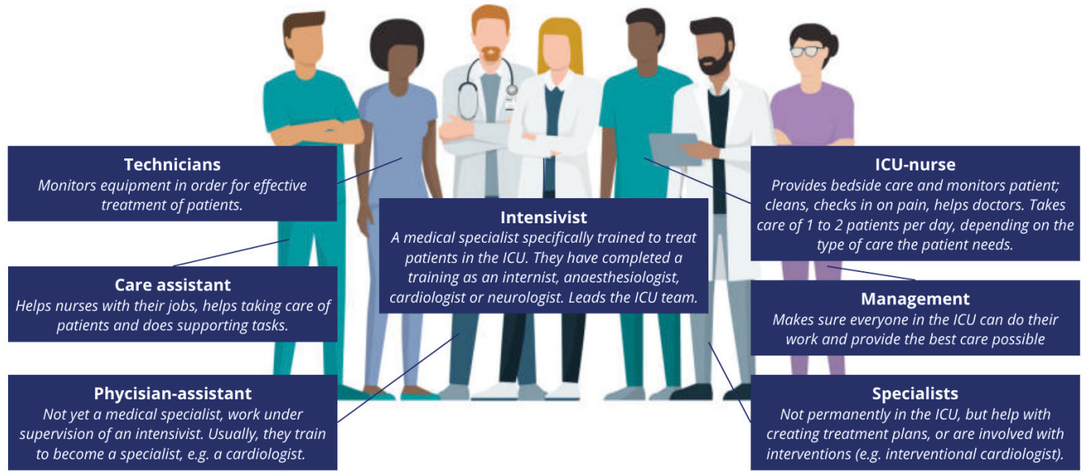


Figure 20: People working in the ICU of EMC

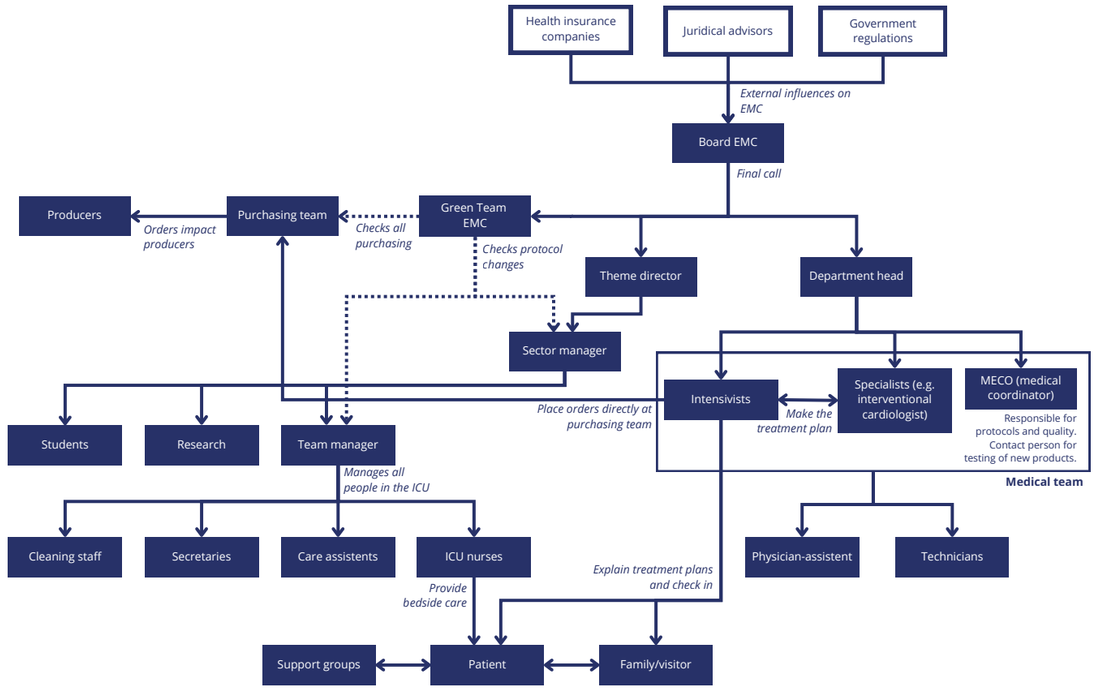


Figure 21: Organogram of the stakeholders, how the different parties are related and how they can influence others

2.4.9 Stakeholders

Many different people and organisations have an interest in, or influence on the cooling method. These people are stakeholders, shown in Figure 22. A power-interest grid is included, Figure 23, to show how these stakeholders relate to the cooling method. The patient is unconscious during the treatment, but nevertheless included as a core user.

The stakeholders and their interest in the cooling method are listed below, based on conversations throughout the project with different stakeholders.

- Patient: wants to receive effective cooling with the best possible outcome, with high comfort.
- Nurses: want a cooling method which is easy to use and comfortable to work with, without heavy physical or emotional burden.
- Doctors (i.e. intensivists): want a safe cooling method which has high treatment results and does not interfere with the needed medical care.
- Board EMC: wants to develop a good reputation of the hospital, aim for as much positive patient outcomes as possible. They want to provide sustainable care at low costs.
- Manufacturers: want to profitably supply the hospital with care solutions which meet ease of use, best possible outcomes and sustainability criteria.

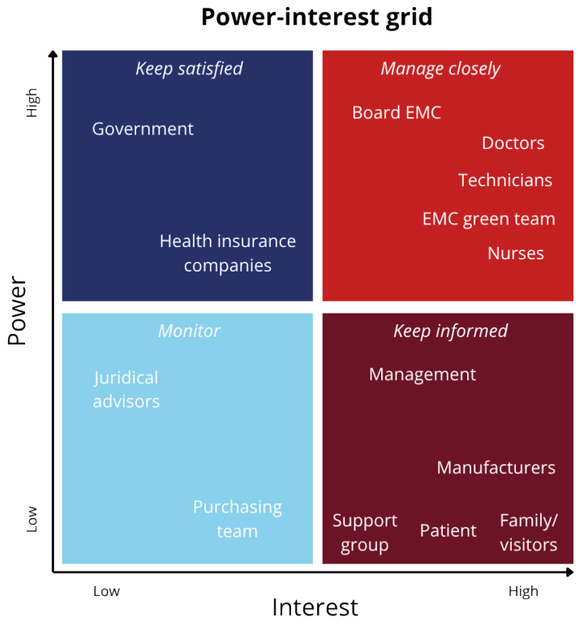


Figure 23: Stakeholders placed in a power-interest grid

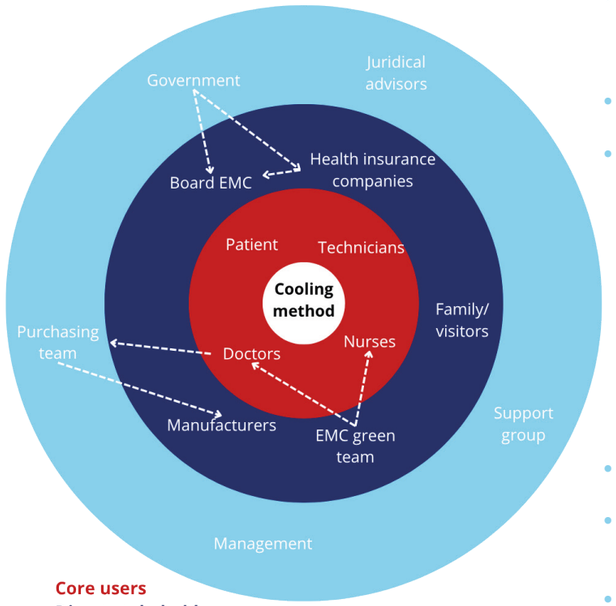


Figure 22: Stakeholdermap with their relations

- Purchasing team EMC: purchases products needed in the hospital. ICU-doctors can place orders with this team as long as the costs are lower than €150.000, which TTM products are.
- Technicians: oversee whether the method and machines are being used correctly.
- Health insurance companies (e.g. Zilveren Kruis): reimburse hospitals for services provided to insured patients, set payment rates and coverage rules. For patients, they offer health insurance plans and (partly) cover medical costs according to terms.
  - Family/visitors: want the patient to receive the best care possible, want to visit the patient.
  - EMC green team: wants to transition the care given in the hospital to (more) sustainable alternatives. As of late, if something is purchased or a protocol is changed in the ICU, it must first be reviewed by the Green Team.
- Government: regulations apply to the hospital and must be adhered.
- Juridical advisors: support the hospital by providing legal counsel, ensuring regulatory compliance, and managing legal risk.
- Support group: patients who are dismissed from the hospital might visit a support group, which wants to help the patient with their experience.

2.4.10 Competitors of Arctic Sun & Thermogard

Both cooling methods have several competitors amongst their categories, Figure 24. However, companies offering exactly the same product are limited, for example, BD has no competitors offering adhesive pads. Furthermore, some companies offer cooling methods, but only for local areas on the human body, such as Merit Medical. Several companies are specialised in internal temperature monitoring, but do not offer any cooling treatment. The total revenue and number of employees of the identified competitors shown below can be found in Appendix 1. Medtronic, a company which has existed for over 75 years, is market leader by revenue amongst these companies. They offer many medical products, in all specialties and areas. Other companies, such as BrainCool, only offer products for TTM, therefore their revenue share is significantly less. BD has a higher revenue share than Zoll.

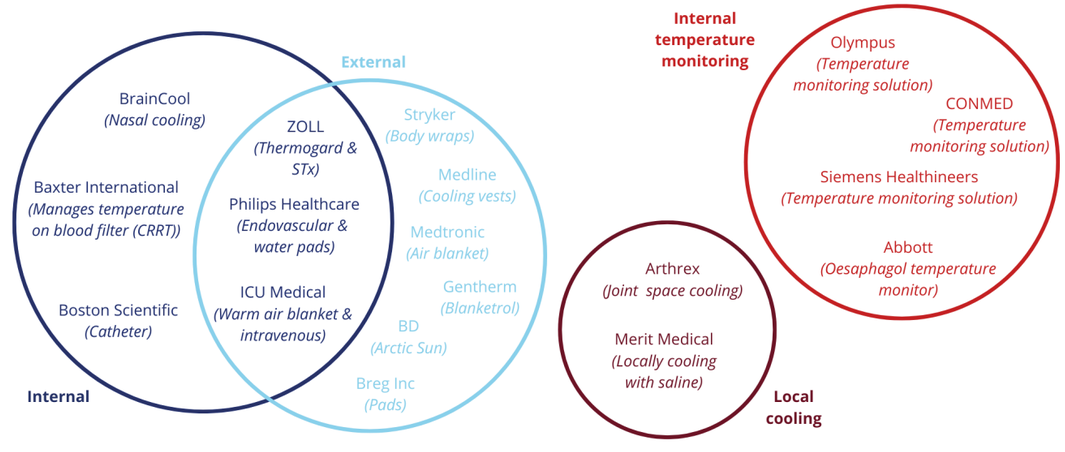


Figure 24: Overview of companies active in the cooling and internal temperature monitoring field

2.4.11 Hygiene vs. reusability

Sterility is a fundamental principle in hospitals and plays a critical role in preventing infections. Maintaining sterile and clean conditions helps eliminate or inactivate microorganisms that could otherwise cause serious infections, complications, or prolonged hospital stays. To ensure patient safety, hospitals implement strict sterilisation, cleaning and disinfection protocols for medical instruments, surfaces, and equipment. For example, the machines used to cool patients are wiped with alcohol after every use, to prevent spreading of microorganisms.

The department Infection Prevention would prefer every hospital product to be disposable to minimize chances of an infection spreading within the hospital. However, this is not sustainable due to high waste, so this department and the Green Team are looking into how products at EMC can be made more sustainable and remain safe to use for (multiple) patients. Risk occurs when products switch between patients, patients cannot infect themselves.

2.4.11.1 Infection prevention at EMC

There are three different classes of products in the hospital: high, medium and low risk of infection spreading. Products with a high risk are products entering the bloodstream, such as the catheter of the Thermogard. Products with a medium risk are products that come into contact with mucous membranes and non-intact skin. Products with a low risk only come into contact with intact skin, such as the Arctic Sun pads and STx Vest.

If products are to be reused, the high-risk products need to be sterilised. The medium-risk products need to be cleaned and then disinfected. The low-risk products only need to be cleaned. For cleaning, either a microfiber cloth with water is used to wipe the product, or the product is washed by an industrial washing machine on 60 degrees. If a product is of medium-risk, or if a product is impregnated by bodily fluids, or if the patient for which the product was used, is isolated, the product should be disinfected after it is cleaned. Disinfection occurs through thermal (an autoclave on 120 degrees) or chemical (chloride or alcohol) inactivation.

This results in the following design requirements for an external cooling product to be reusable, the product should be:

- Wipeable (so a smooth material with no texture, ridges, hairs or hooks etc.), or washable on 60 degrees
- It should be treatable with chlorine, alcohol, or on 120 degrees in an autoclave

2.4.12 Existing reusable products at EMC

Various products used at EMC are reusable, some of which are used in the ICU, see Figure 25. For example, EMC uses reusable blood cuffs. They are durable, easy to clean, made of polyethene, free of latex, silicone and PVC, soft with curved edges and washable and submersible for easy disinfecting (Non Invasive Blood Pressure Cuffs (NIBP) | Draeger, n.d.).

Tourniquets are also used for many different patients. Different versions exist, some are wipeable for disinfection (Tristel Solutions Limited, 2025; Reusable Tourniquet - NoJerm, 2025), others are made of polyester or elastomer and washable (Arnot, 2022). BD sells multi-usable tourniquets, made of PC, POM, polyester and lycra, these products can be cleaned in an autoclave on 120 degrees (367218 • BD® ProntoTM Reusable Tourniquet/Kimetec® CBC Classic Tourniquet, n.d.).

In the ICU, underpads are used for bodily fluids of patients during treatment. These used to be disposable, however, Nedlin has developed washable and therefore reusable underpads (Reusables | Nedlin, n.d.). EMC is currently running pilot tests on this product. Furthermore, this company sells other reusable products which are all washable such as passive warmth blankets and surgical gowns. The blankets are made of polyester, polar fleece and carbon threads.

2.4.13 Existing reusable external cooling products

Amongst external cooling methods, some are reusable options. The Blanketrol III system, produced by Gentherm, offers several blankets and kits to connect to the machine, both single use and reusable. The system uses water blankets manufactured in the US (Gentherm, 2025).

Gentherm offers two reusable waterblankets. The PlastiPad® is constructed of durable urethane and has a non-porous surface which makes the pads easy to clean, the pads are recommended to be cleaned with soap. Sterilisation is not recommended and the product cannot be autoclaved. Disinfection is recommended according to the protocol of the hospital (Gentherm, 2025).

The other water blanket, the Gelli-Roll®, cannot be cleaned with alcohol, since this causes pad deterioration. The pads are washable on 40°C, but cannot enter washing machines. This water blanket is encapsulated in soft, compressible Akton polymer gel for conforming to the patient's body and is latex free (Gentherm, 2025).

The Blanketrol system was used at EMC a couple of years ago, but the machine performed not as good as the machines of the Thermogard and the Arctic Sun, thus this machine is not used at EMC anymore.

Another cooling method which offers a reusable blanket is TrueCool, however, no further information on the materials of this blanket is available (EM-MED Sp. z o.o. Sp. K., 2021).

It should be noticed that these reusable cooling methods do not adhere to EMC's cleaning protocols.

Figure 25: Non Invasive Blood Pressure Cuffs (NIBP) | Draeger, n.d.; A reusable tourniquet (Tristel Solutions Limited, 2025); Reusable underpads and gowns (Nedlin, n.d.); PlastiPad (Gentherm, 2025); The Gelli-Roll (Gentherm, 2025)

2.5 PRODUCT AND PATIENT JOURNEYS

A patient of an OHCA is transferred with an ambulance to the hospital, where the patient can go to different places. Either the patient goes to the CATH-centre or the operation room, and thereafter to ICU-6. The patient can also go directly to ICU-6, if no intervention is directly needed or possible, i.e. in case of some genetic problems. If the Arctic Sun is used as a cooling method, this is applied in ICU-6. If the Thermogard is used, the catheter might be inserted in the CATH-centre, operation room or in the ICU-6 itself, this changes per situation, see Figure 26.

The Arctic Sun (Figure 27) is prepared and installed by the nurses. Two nurses are needed to attach the pads, if the patient weighs a lot, three nurses are needed. Applying the Arctic Sun pads generally takes around 15 minutes, however, if the patient is large and heavy, it may take up to 45 minutes. The Arctic Sun pads must be replaced after five days of use, or when the adhesive layer does not work anymore.

The catheter of the Thermogard (Figure 28) is inserted by the doctor, with assistance of a nurse, doctor or physician-assistant, the catheter is attached to the machine by a nurse. The Thermogard catheter must be changed after a maximum of 72 hours, due to infection risk.

The journey map of the STx Vest is similar to that of the Arctic Sun, since both are external cooling methods. The main difference is that installing and removing the STx Vest takes less time and elicits other emotions than the Arctic Sun, see Figure 29.

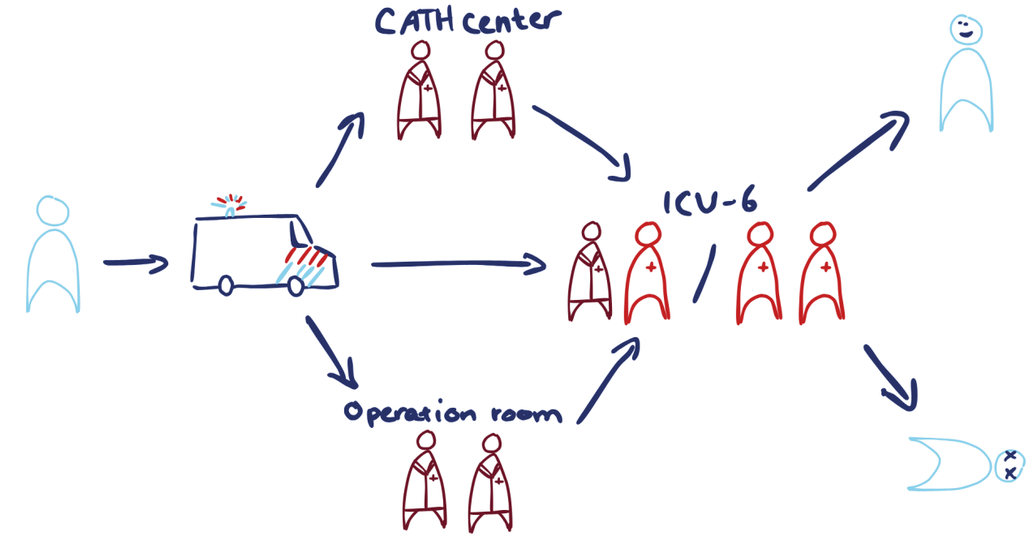


Figure 26: Overview of the possible patient journey

PREPARATION OF TREATMENT

Arrival in ICU in need of TTM
Patient box; -; patient [passive]; -; -

Find a nurse able to help
Corridor; 2 min; nurse; burdened; -

Go to storage
Corridor; 1 min; nurse; in control; -

Put on protective clothing
Patient box; 1 min; nurses; annoyed; 4 gloves

Grab correct size pads & machine
Storage room; 2 min; nurse; in control; -

Apply pads*
Patient box; 15-45 min; 2-3 nurses & patient [passive]; annoyed/ burdened; packaging of pads

Bring pads & machine to patient's room
Corridor; 1 min; nurse; determined; -

Start machine & treatment
Patient box; 5 min; nurse; determined; energy

TREATMENT

Treatment
Patient box; > 24 hours; patient [passive]; -; Energy

Walk with pads to patient's room
Corridor; 1 min; nurse; determined; -

4 times per 24 hours:

Put on protective clothing
Patient box; 1 min; nurses; annoyed; gloves

Find a nurse able to help
Corridor; 2 min; nurse; burdened; -

Check adhesitivity & patient's skin
Patient box; 3 min; nurse & patient [passive]; annoyed & sad; gloves & possibly new pads

Put on protective clothing
Patient box; 1 min; nurses; annoyed; 4 gloves

If pads are not adhesive anymore:

Go to storage & grab size pads
Corridor; 3 min; nurse; in control; -

Apply pads*
Patient box; 15-45 min; 2-3 nurses & patient [passive]; annoyed/burdened; packaging of pads

END-OF-LIFE

Empty pads & turn off machine
Patient box; 5 min; nurse; anxious; -

Clean machine for next use
Patient box; 5 min; nurse; relieved; cleaning materials

Find a nurse able to help
Corridor; 2 min; nurse; burdened; -

Return machine to storage
Corridor & storage room; 1 min; nurse; relaxed; -

Put on protective clothing
Patient box; 1 min; nurse; annoyed; 4 gloves

= patient

= nurse

Remove pads and dispose them as waste
Patient box; 20 min; nurse & patient [passive]; annoyed & unwell; disposable pads

Action
Location; time; people involved; emotion; ecological impact

***** See Figure 30 and 31 for how pads are applied

Figure 27: Arctic Sun product journey

PREPARATION OF TREATMENT

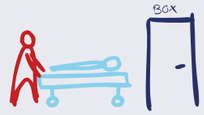
Arrival in ICU in need of TTM
Patient box; -; patient [passive]; -; -

Put on protective clothing
Patient box/OR/CATH; 15 min; doctor & nurse; annoyed; gloves & gown & cap

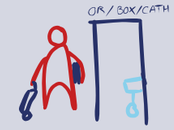
Walk to cupboard to collect start-up kit
Corridor; 1 min; nurse; in control; -

Insert catheter
Patient box/OR/CATH; 20 min; doctor & nurse & patient [passive]; donfident, excited; sterile materials, packaging

Walk to storage to collect machine
Corridor & storage room; 1 min; nurse; in control; -



Transport patient to box, if the patient is in OR/CATH
Corridor; 3 min; nurse & patient [passive]; determined; -



Bring start-up kit to OR/ patient box/CATH-centre
Corridor; 1 min; nurse; determined; -

Install start-up kit and machine & begin treatment
Patient box; 10 min; nurse; determined; energy, packaging, 500ml NaCl

TREATMENT

Treatment
Patient box; 24-72 hours; patient [passive]; -; energy

Insert catheter
Patient box; 20 min; doctor & nurse & patient [passive]; confident, excited; sterile materials, packaging

4 times per 24 hours:

Put on protective clothing
Patient box; 1 min; nurse; annoyed; 2 gloves

Check catheter insertion
Patient box; 5 min; nurse & patient [passive]; anxious; energy

If wound is infected or 72 hours is surpassed:

Put on protective clothing
Patient box; 15 min; doctor & nurse; annoyed; gloves & gown & cap

END-OF-LIFE

Turn off machine
Patient box; 1 min; nurse; relieved; -

Return machine to storage room
Corridor; 1 min; nurse; relaxed; -

Put on protective clothing
Patient box; 1 min; nurse; annoyed; gloves

Take out catheter, dispose of catheter and start-up kit
Patient box; 5 min; nurse; anxious; start-up kit & catheter

= nurse

= patient

= doctor

Clean machine
Patient box; 5 min; urse; relieved; cleaning materials

Action
Location; time; people involved; emotion; ecological impact

Figure 28: Thermogard product journey

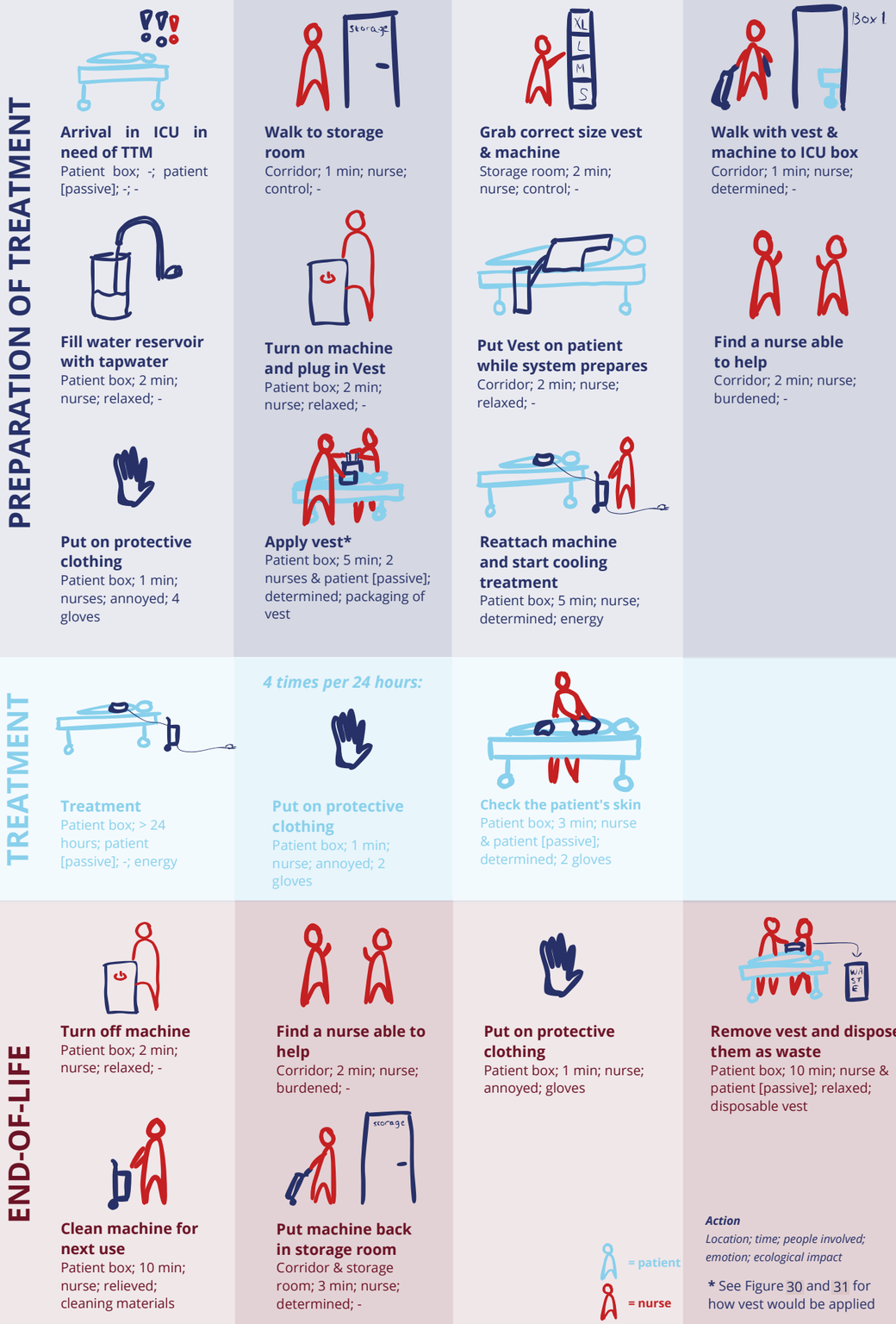


Figure 29: STx Vest product journey

2.5.1 Treatment of the patient and impact on product

If a patient needs to be laid down on something,for example new sheets, nurses have one common way to do this, shown in Figure 30. Another, lesser used, method for placing something under a patient, is lifting their upper body from the bed, into a seating position. Patients are often placed in a ICU-bed using for example bed sheets.

This prevents the placement of the cooling vest before the patient is placed in bed: the sheet would be in between the cooling vest and the patient, prohibitting the vest from direct contact with the patient's skin.

Turning patients is the most physically heavy task for nurses, thus should be avoided if possible.

How pads on the backside of a patient would be attached is shown in the simplified figure below (Figure 31).

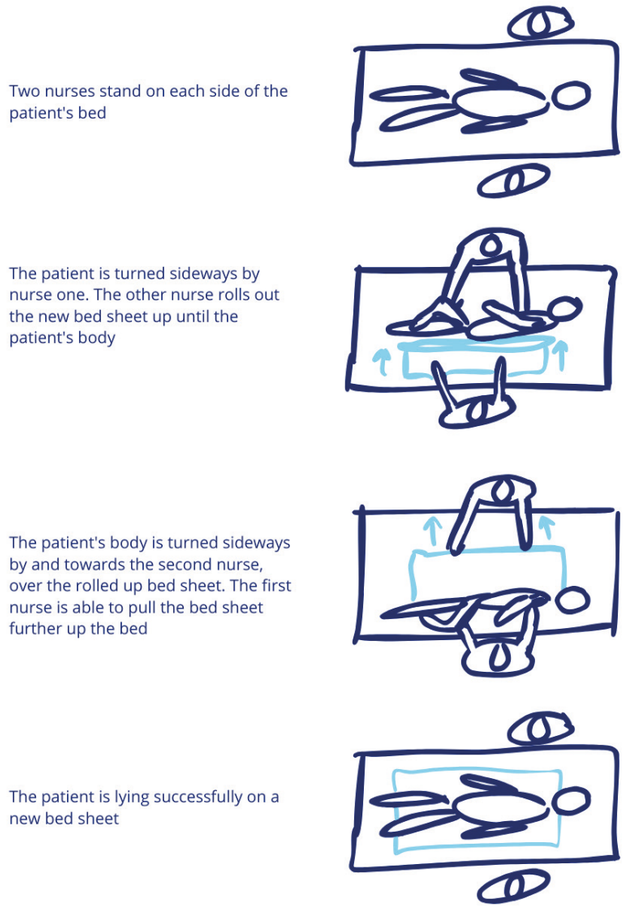


Figure 30: How something is put under a comatose patient

Figure 31: How the Arctic Sun pads are applied to the back of the patient

2.6 COMPARING THE ARCTIC SUN, THERMOGARD, AND STX VEST

There are four important pillars for healthcare: workload, cost, sustainability, and experience. To compare the three cooling methods explored in this thesis, these pillars will be examined per method. This chapter is based on the product journeys in Chapter 2.5. A treatment time of 24 hours is used to calculate impact, since this is the minimal time of treatment for now at EMC.

2.6.1 Workload

For an indication of the costs of salary, treatment of 24 hours with no replacing of products is assumed. For an indication of the time spent with the patient or on the method, the product journeys were used as a source. The Thermogard can be placed by different people, in different places, therefore two scenarios are included.

Only the time spent on starting the cooling treatment, checking the treatment and removing the treatment is calculated, see Figure 32. Second-level time spent on the patient due to cooling is not included, for lack of data.

2.6.2 Costs

The costs of the methods per treatment are related to the purchasing costs and the salary of the medical staff. The costs mentioned in this chapter are fictive for an indication.

2.6.2.1 Salary

According to the CAO of UMC's, an intensivist earns a gross income of €9,726 - €13,959, for 55 hours per week (UMCNL voor medewerkers, 2023). The mean gross income per hour therefore is €215.32. An ICU-nurse earns a gross income of €4,034 - €4,313, for a workweek of 36 hours (UMCNL voor medewerkers, 2023). This amounts to a mean gross income of €129.82 per hour. For an indication of the costs of medical staff directly involved, the time calculated in 2.6.1 is used, see Figure 32.

2.6.2.2 Price of disposables used

The Thermogard with Quattro catheter, used at EMC, costs around €1300 per patient, of which around €330 is the start-up kit. Additional costs will be made for the extra materials needed to insert the catheter. The Quattro catheter is the largest and most expensive catheter offered by Zoll. A slightly smaller catheter offered by Zoll is Icy, this catheter is €100 cheaper than the Quattro. So, by using this catheter for patients who do not need the largest catheter, EMC could save costs.

By using a catheter inserted in the groin, such as the Quattro or Icy, a high central line, which is preferred for medical tests is not possible. Zoll offers another catheter for high insertion, the Solex. This catheter differs only a couple of euros from the Quattro. However, this high line results in easier medical testing, so less time spent on the patient by medical staff, thus choosing this catheter will result in less secondary salary costs (Catheter Family - Netherlands, n.d.).

The STx Vest manufactured by Zoll costs around €520, of which the vest costs only around €180, the rest of the price is for the start-up kit. The only additional costs needed are for non-sterile gloves, which are negligible due to low impact.

The Arctic Sun costs €570 for the cooling kit for torso and thighs, with an additional €170-€200 for the use of an universal pad. Other additional costs are needed for non-surgical gloves, no further costs are made.

This results in the following overview (Figure 32) of costs related to the use of the products.

	Time (minutes)	Salary	Purchase costs disposables
Arctic Sun	150 - nurse	€325	€570 - €700
Thermogard	25 - doctor & 90 - nurse 50 - doctor & 65 - nurse	€285 - €320	€1300
STx Vest	67 - nurse	€145	€520

Figure 32: Overview of costs and time per treatment, costs are indicative

2.6.2.3 Products purchased

Based on the amount of products purchased by EMC from the first of January 2024 until the 3d of December 2025, the yearly costs per method can be estimated on around €67,500 for the Arctic Sun and €69,300 for the Thermogard.

2.6.2.4 Costs of machines

At EMC, there are three Thermogard systems in use, and seven Arctic Sun machines. The Thermogard machines are stationed in ICU-6. Three of the Arctic Sun machines are stationed in ICU-4, two at the IC-neo, and two at the IC-kids.

The Thermogard machines were purchased in 2016. The Arctic Sun machines were purchased in 2023. According to a medical electronicus at EMC, the machines are expected to last for a period of 10 years. Per year, around €2,000 for each machine is spent on maintenance. The Thermogard systems are more expensive than the Arctic Sun machines, with a difference of more than €8000 per machine.

The Arctic Sun system is cheaper and bought more recently. Furthermore, this system is used in surrounding hospitals. Therefore, it would be wise to introduce a reusable pad which fits this system. This would mean more Arctic Sun machines need to be purchased by EMC to accommodate more patients in ICU-6 using this cooling system.

Figure 33: A cut open AS pad to investigate the layers

2.6.3 Sustainability

A product's sustainability is determined by several factors across the entire life cycle. Amongst these factors are the materials used in the machine, the lifespan of the machine, the manufacturing of the products, the energy use of the machine during treatment, the disposable materials required for each treatment, and the transportation of the products. For each factor, the manufacturers provided some information, but not detailed enough for a quantitative assessment. In this chapter, the factors will be assessed in a descriptive manner. The manufacturing processes of the disposable products are unknown and thus will not be described. Gaining insight into this overall picture is essential to compare each cooling method on sustainability.

2.6.3.1 Materials in the products

The catheter of the Thermogard is made of all biocompatible polyurethanes. The contact surfaces of the catheter are coated with Duraflo Treatment, a heparin coating (Alsius Coorporation, 2003). This heparin coating is a thin biocompatible layer applied to devices which have contact with blood. It prevents blood from clotting through introducing antithrombin, which binds with thrombin, resulting in no clotting able to take place (Gore Medical Products Division, n.d.).

The pads of the Arctic Sun system (Figure 33) consist of a patented layer construction. An adhesive layer connects to the skin, a layer of thin film allows water to flow through the pads and an insulation layer on top minimizes thermal loss to the environment (BARD medical, n.d.). The disposable product is made of different materials, the insulation layer is PE closed cell foam. Furthermore, polyester fabric, acrylic PSA, velcro, PE/PP blend and PVC are part of the disposable product as well.

The STx Vest exists of around ten different materials, most of which are thermoplastics. The skin-friendly inner lining is durable and biocompatible. The vest is connected with stretchable Velcro, which allows for differently sized patients (ZOLL, n.d.).

Both the Thermogard and the STx Vest also make use of the start-up kit, existing of a stainless steel coil and thermoplastic tubing.

The disposable products are currently not recycled. The materials used for the products do not allow for easy recycling due to many different thermoplastics being used. Mixed materials are hard to separate to then recycle. Designing external cooling with separation of materials in mind, or using only one material if possible will result in easier recycling of the materials. A more sustainable product should aim for this. Each product can be improved with regards to the end-of-life and closing the loop of materials.

2.6.3.2 Packaging

Since the current products used for cooling are all disposable, their packaging has a high impact on sustainability as well; each treatment involves a new package.

The Thermogard is stored inside a cardboard box, inside is a tray which stores necessary parts to insert the catheter. As this internal cooling method is sterile, the products are sterilised and sterily packaged. Sterile packages are for example made of paper and foil pouches.

The Arctic Sun pads come in a silver pouch (Figure 34). These pouches are packed per two in a cardboard box for shipment. The pouches itself are large and seem inefficient in material use, they are large and the pads are not tightly stored inside. Furthermore, the material of the packaging is another blend of different materials instead of using one single plastic which can then be recycled.

The STx Vest is very efficiently stored, the vest becomes very small when rolled up. The packaging consists of cardboard and a soft-plastic film.

The start-up kit of the Thermogard and STx Vest comes in an efficiently packed box made of carton, inside is a hard-plastic to store the parts of the start-up kit. The parts are tightly placed inside the box, see Figure 34.

Packaging of cooling products could be improved on their recyclability by using only one type of material which is recycleable, for example in the PD (hard plastics and drink cartons) waste stream. A more sustainable product should aim for this. External cooling does not need to be sterile, only clean. This lowers the specifications and requirements of packaging significantly, which makes designing for recycling easier.

Figure 34: The packaging of Arctic Sun pads (right) and the start-up kit for the STx Vest (left)

2.6.3.3 The materials needed per treatment

For gaining insight into the amount of materials needed per treatment, once again, a treatment time of 24 hours is assumed. Protocols of EMC were used to gain insight into all the materials involved in placing and removing a catheter (*Protocol Thermogard: Post Cardiac Arrest Zorg Op De ICV/Hartbewaking*, n.d.). For listing the materials needed for the Arctic Sun and STx Vest method, nurses were involved.

Since the catheter of the Thermogard must be placed sterile and is an invasive procedure, a lot of materials are needed for this procedure, most of which are disposable in order to preserve the sterility of the procedure. Since the placement of the Arctic Sun and the STx Vest is non-sterile and non-invasive, a lot less material is needed. An illustrative representation of the materials needed per treatment is shown in Figure 35. The amount of materials and the weight of all materials involved are included, excluding packaging. The amount of materials for the Thermogard is estimated on around 70, it depends per patient. The amount of materials for the Arctic Sun is 15 and for the STx Vest is 11. The weight of Arctic Sun is estimated on 1.3 kg, based on a used set which was weighed. A used Thermogard was also weighed and resulted, in combination with weights of products seen in waste audits, on 1.5 kg. The weight of the STx Vest is 1.5 kg, based on weight measurements of the product.

Listing all materials needed for the different TTM methods, it is clear that Thermogard uses most materials, many disposables are needed since the treatment is sterile and internal. However, total weight per method is quite similar. All disposables are discarded in the main waste stream, for which is paid per kilo, thus costs for the disposables as waste is also quite similar.

Figure 35: Disposables needed per treatment for 24 hours, illustrative visualisation not to scale

2.6.4 Experience

The fourth pillar of our healthcare system is experience. To gain insight into the emotions of the medical staff, the journey maps were used. The following graph was made to summarize the findings, see Figure 36.

According to the product journeys, the Arctic Sun results in the most negative emotions, STx Vest in the least. The STx Vest results in the most positive emotional impact, the Arctic Sun in the least. Some quotes from medical staff are included below to show the difference in emotional impact of the different methods.

"I always use Thermogard if I can, I think this method is more efficient and we already have access [to the bloodstream] in the OR" – cardiologist.

"I would always pick Thermogard over Arctic Sun. Applying the pads to a person is a horrid task, they are awkwardly hard and big. I feel like I am destroying more of the patient, than helping when using the Arctic Sun. It feels terrible, to do that to people, I get emotionally affected by it as well." – nurse on ICU-6.

"They can keep the Arctic Sun at ICU-4, we don't like it here" – nurse on ICU-6.

2.6.5 Pros and cons of cooling methods

Overall, Thermogard is the preferred method currently used at ICU-6. The Arctic Sun is described as a 'clumsy monstrosity', and is experienced as emotionally heavy on the nurses. The STx Vest is not yet used.

To summarise the main findings on the current methods, an overview of pros and cons is made. The third cooling method, STx vest, is included. Its pros and cons are hypothetical, but based on opinions of medical staff. See Figure 37 for a comparison of the three methods.

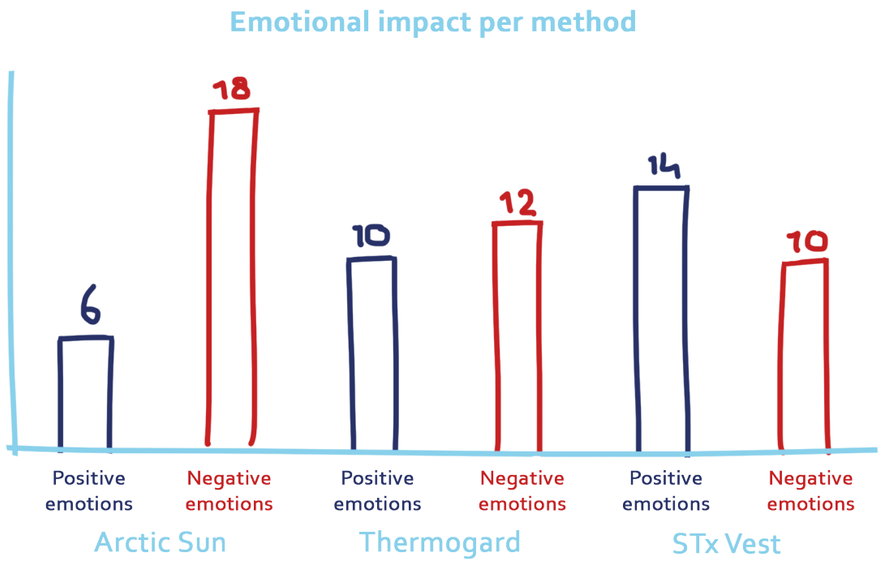
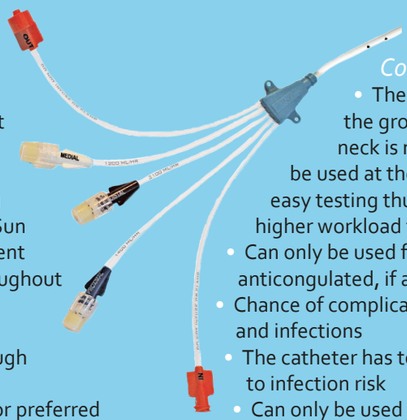


Figure 36: Emotional impact per cooling method, based on product journeys

Pros Thermogard

- Cooling through the bloodstream results in a more stable and consistent temperature, the machine is less needed to change the temperature of the patient, so the machine is turning on and off during use than the Arctic Sun
- This method results in a more consistent cooling, because the blood flows throughout the whole body and therefore allows gradual cooling with less variations
- Medication can be administered through the catheter, very convenient
- Has been around longer and is therefor preferred
- Cooling/warming rates of 1-2 degrees per hour
- 'Cools closer to the target, so more efficient'



Cons Thermogard

- The catheter used at EMC is placed in the groin, therefor an extra catheter in the neck is not possible, only one catheter can be used at the time. A neck-catheter allows for easy testing thus the current catheter results in higher workload for doctors and nurses
- Can only be used for thorax patients since they are anticongulated, if a patient is not, clots will form
- Chance of complications such as clotting, thrombosis and infections
- The catheter has to be removed within 72 hours, due to infection risk
- Can only be used at EMC, due to a lack of machines in the surrounding hospitals
- A doctor is needed for insertion: busy schedules and expensive salary costs
- Takes longer to start treatment than Arctic Sun
- High costs of the disposables

Pros Arctic Sun

- Can be used for patients which are transported to other hospitals
- Can be started quicker than Thermogard, by only nurses
- No chance of thrombosis or infections
- Non-invasive method
- Easy to use

Cons Arctic Sun

- Not fit for thorax patients, instant access to the chest is needed. Due to the adhesive gel, the pads cannot be instantly removed
- Chance of burns/wounds due to the pads, especially when removing
- The adhesive pads are bad for skin. Cooling the skin results in less blood in the skin, which results in more easily damaged skin
- The idea that the temperature treatment is less precise, mainly because it depends on the blood flow in the patient's skin
- Less direct feedback mechanism: more variations in temperature, however, the main temperature is as good as external cooling
- Emotionally not pleasant to apply the pads to the patient, very inhuman 'feels like I am destroying more than helping'.
- High workload, 3 nurses for heavy patients
- Have to check whether the pads are still adhesive, time-consuming task
- The pads are large and stiff, thus difficult to apply
- Slower cooling or warming than Thermogard

Pros STx Vest

- Less emotional strain on nurses than Arctic Sun, due to higher patient comfort
- Instant access to the chest of the patient
- Takes less time to start and remove
- Can be installed by nurses only
- No risks of burns or infections
- Easy to use

Cons STx Vest

- Not usable for patients who are transferred to other hospitals due to needing the Thermogard system
- Soft layer has risk of fluids entering
- Disposable material

Figure 37: Overview of existing methods and the newly introduced STx Vest and their pros and cons (images: Arctic SunTM 5000-temperatuurmanagement Systeem | BD Nederland, n.d., Quatro Catheter, n.d. STx Vest, n.d)

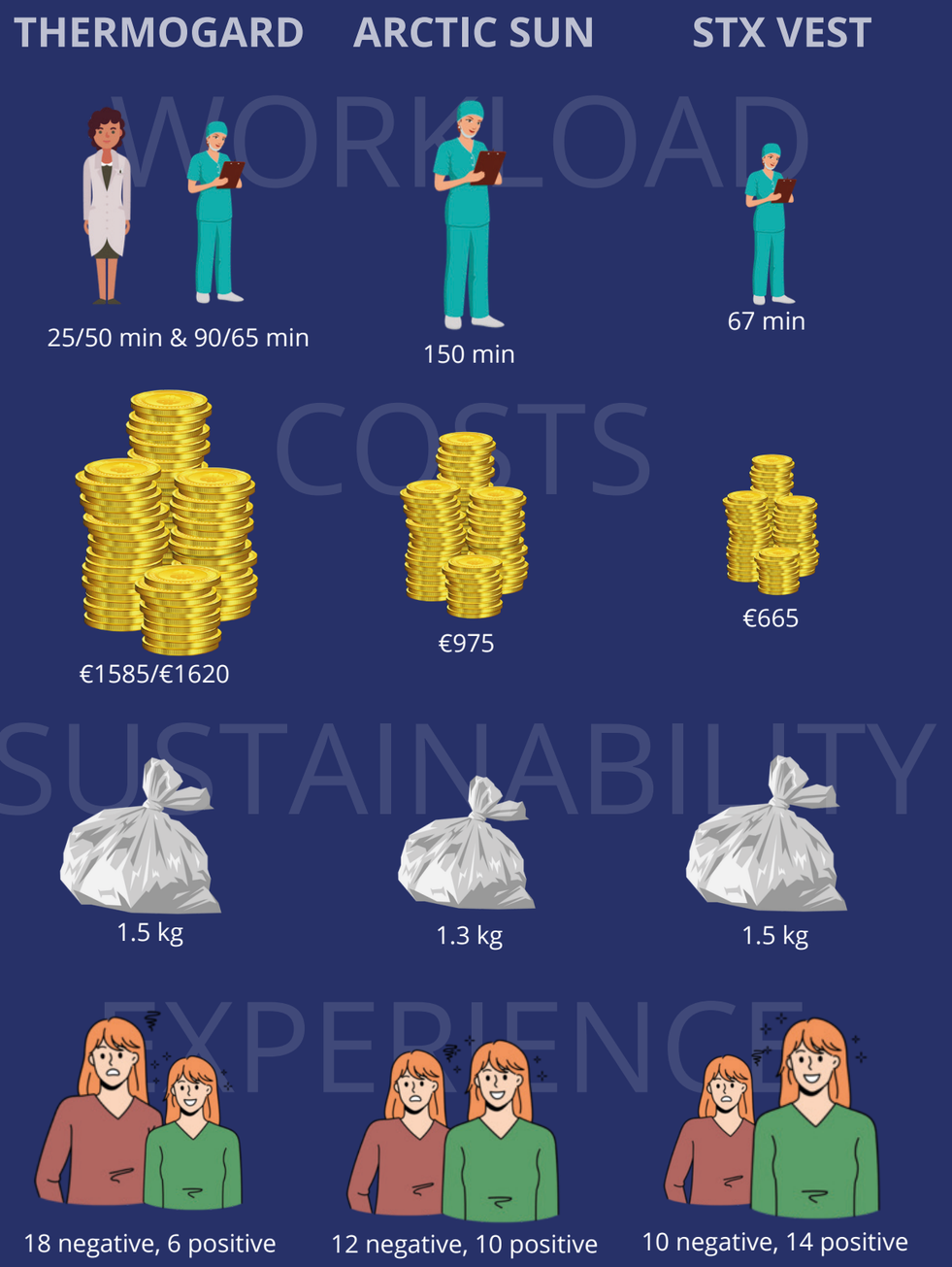


Figure 38: Global overview of all three cooling methods

2.6.6 Overview of comparison

When comparing the pillars of healthcare for all three cooling methods, the following overview can be found, see Figure 38. Thermogard is the most expensive method, but Arctic Sun asks more of the healthcare staff and their time. Waste is measured in kilograms since these products go into the general waste stream, for which the hospital pays per kilogram.

The STx Vest seems the best scoring cooling method, it takes the shortest time, costs the least amount of money and evokes the most positive emotions and the least negative emotions. Only with regards to sustainability does the vest not score the best.

2.7 CONCLUSION DISCOVER PHASE

Given that all cooling methods provide the same secure target temperature, all methods are valid options to use. However, per method, pain points exist, see Figure 39. A 46pain point is identified as a specific problem, frustration or ineffeciency experienced by a user. Take notice of many pain points of the Arctic Sun being negative emotional impacts, which are not an issue in the STx vest, mainly due to the lack of adhesive gel, which is the main cause for all emotional strain amongst nurses.

In the following chapter, design directions will be presented for these pain points, as well as design requirements, based on which certain design solutions will be further explored.

Figure 39: Overview of pain points per method

3 DEFINE

Based on the Discover-phase, an ideal future scenario is presented. This Chapter the possible design spaces are evaluated and feasible design areas are identified. Following, the design goal is identified and the list of requirements to which the design should adhere is presented.

3.1 IDEAL FUTURE SCENARIO

Summarising the wishes of the different stakeholders at EMC found in the Discover stage, the following future scenario can be thought of, see Figure 40. Only one method and machine would be used at EMC, which is also used in hospitals nearby. This solves the problem of transferring patients with a cooling method which is not compatible with other hospitals and therefore wrongly installing the method. The method is usable for all patients: not depending on whether they use anticoagulations and also allows for instant chest access, so this method can be used throughout ICU-4 and ICU-6 without any trouble.

This cooling method is non-invasive with no risk of wounds or burns; for optimum recovery of the patient's body without any risk of injury. The method should not evoke strong emotional responses in nurses and doctors. The method is reusable, to reduce costs and ecological impact. Furthermore, this new product does not increase the workload, and is easy to use.

In order for this future scenario to become a reality, the medical staff in ICU-6 needs to get acquainted with and used to external cooling. In order to be successful, this external cooling method should not result in any disliking or distrust and the medical results should be the same as with the current methods.

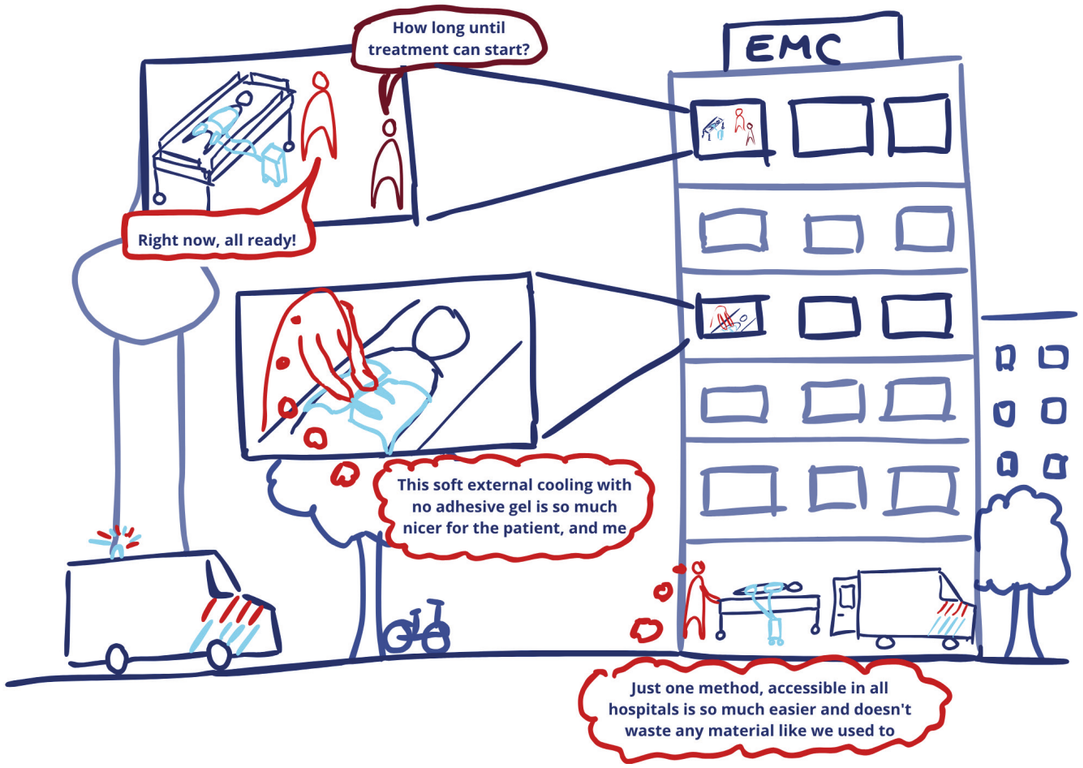


Figure 40: Ideal future scenario

3.2 POSSIBLE DESIGN SPACES TO PROBLEM DEFINITION

The conclusion of the Discover phase resulted in a summary of pain points found amongst the three cooling methods. In order to find feasible design spaces, these pain points will be tested and examined in this chapter.

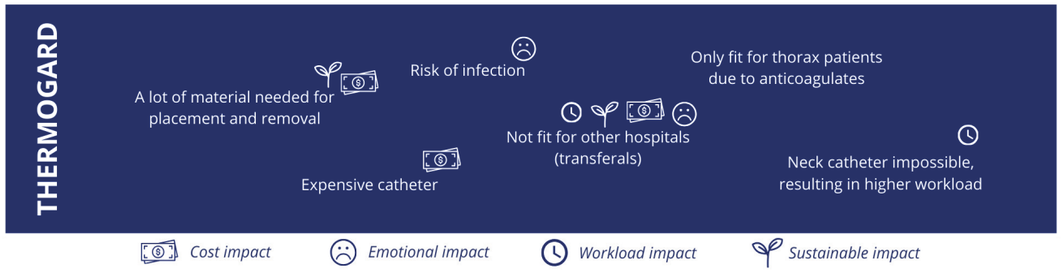


Figure 41: Overview of pain points

3.2.1 Thermogard

The Thermogard has some pain points which cannot be changed and some pain points which can be changed to create an improved and more sustainable procedure. See Figure 41 for an overview of the pain points.

3.2.1.1 Unalterable pain points

- The materials of the Thermogard itself seem to be minimal and optimized, however, much material is needed for insertion and removal of the catheter. These materials for insertion and removal are integrated in hospital protocols and needed for the sterile procedure, therefore cannot be changed

- The Thermogard is only fit for patients with anticoagulation medicine. Patients in ICU-4 cannot take this medication, so the Thermogard cannot be used throughout the whole of EMC.

- Using the Thermogard comes with the risk of infections, because this method is invasive and enters the body.

3.2.1.2 Pain points with possible solutions

- The Thermogard cannot be used for patients who are being transferred to other hospitals, since they do not have the Thermogard XP System.

In order to overcome this obstacle, either other hospitals need to invest in this system, which is outside the scope of this project, or EMC needs to refrain from using this system. Another possible solution might be an adaptor of some sort, however, since two different manufacturers would need to work together this might be difficult to achieve.

- The treatment with Thermogard is more expensive than Arctic Sun or STx Vest; the catheter costs more and does not last as long (72 hours versus 5 days). Additionally, more material is needed for insertion and removal which also amounts to higher costs.

Zoll offers catheters which are €100 cheaper.

- While using the Thermogard, insertion of a high central line near the clavicula or neck of the patient is impossible, since two catheters in the blood stream are not an option, and the current catheter used is inserted in the groin. This lack of high central line results in higher workload during medical check-ups, they are more time consuming with no central line in place.

Zoll offers high central line catheters which can be inserted near the neck and below the clavicula.

The Thermogard is a more stable cooling method than the Arctic Sun, however there is no difference in outcomes between the methods. The Thermogard is only fit for thorax patients, the target group is small. Furthermore, the placing of this catheter comes with disadvantages which cannot be changed: materials needed for insertion and removal, lack of high central line, and infection risk. Although the method is preferred by many people in ICU-6, there are several disadvantages which cannot be changed and will remain.

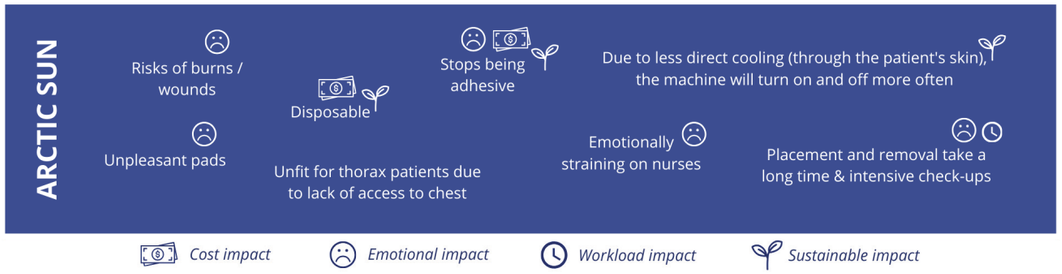


Figure 42: Overview of pain points

3.2.2 Arctic Sun

The Arctic Sun has many pain points which can be altered to improve this cooling method. Since this treatment is non-invasive, changes can be made more easily. The pain points of the Arctic Sun cooling method, see Figure 42, provide several problem areas with possible design solutions.

3.2.2.1 Pain points with possible solutions

- The adhesive layer results in several pain points: 1) risk of burns or wounds; 2) stops being adhesive; 3) no instant access to the chest; 4) placing and removal takes a long time and many check-ups are needed for adhesiveness.

Removing the adhesive layer will solve these pain points. Furthermore, the method will become less emotionally straining on nurses if the adhesive layer is removed and the pads will be made smaller, softer and more manageable.

- The pads are disposable.

Making the pads fully or partly reusable will decrease material waste, this will likely also result in less costs.

- Less direct cooling, because of the patient's soft tissue, which results in less direct feedback. The machine turns off and on more often, the cooling is less stable.

Improving the cooling or feedback to be more direct, for example with a better algorithm will result in more stable cooling with less input of the machine.

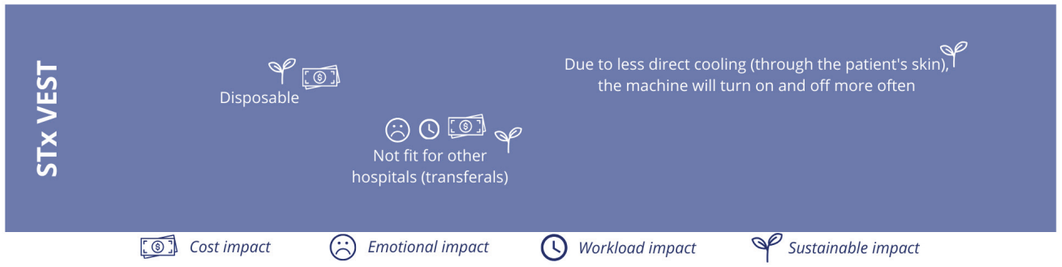


Figure 43: Overview of pain points

3.2.3 STx vest

It should be noted that both Arctic Sun and STx Vest are external cooling methods and most of the pain points of Arctic Sun are not a problem for STx Vest, mainly because this method does not use an adhesive coating. The remaining pain points of the STx cooling method, see Figure 43, provide several problem areas with possible design solutions. The identified pain points are hypothetical, based on opinions of medical staff.

3.2.3.1 Pain points with possible solutions

- The STx Vest cannot be used for patients who are being transferred to other hospitals, since they do not have the Thermogard XP System.

In order to overcome this obstacle, either other hospitals need to invest in this system, which is outside the scope of this project, or EMC needs to refrain from using this system. Another possible solution might be an adaptor of some sort, however, since two different manufacturers would need to work together this might be difficult to achieve.

- The vest is disposable.

Making the pads fully or partly reusable will decrease material waste. Changing to reusable will likely also result in less costs.

- Less direct cooling, because of the patient's soft tissue, which results in less direct feedback. The machine turns off and on more often, the cooling is less stable.

Improving the cooling or feedback to be more direct, for example with a better algorithm will result in more stable cooling with less input of the machine.

3.2.4 Feasible design areas

Given the ideal future scenario of using only one device within EMC, and the limited possibilities to overcome the disadvantages of the Thermogard, combined with the fact that this cooling method is not suitable for all patients or for transfers to surrounding hospitals, the feasible design focus is directed towards the Arctic Sun and the STx Vest.

Design areas contributing to this future scenario include:

- Making the Arctic Sun pads and STx Vest reusable
- Removing the adhesive layer of the Arctic Sun pads
- Integrating a more direct temperature feedback system in the Arctic Sun and STx Vest
- Creating an adapter for using Arctic Sun pads and Thermogard with both systems

3.3 DESIGN GOAL

Several improvements in external cooling were identified throughout this project: higher comfort for patients, reusability to increase sustainability and higher user friendliness for medical staff. A value proposition was presented to the Green Team at EMC, which is a multidisciplinary team of ICU-nurses and ICU-managers, to involve the stakeholders. The pros and cons of the identified design areas were presented in order to gain insight into which design area would have the most impact and support within the hospital. A small brainstorm for some ideas was done and shown as well in this meeting. The design space with the greatest impact was identified as making external cooling disposables reusable.

Keeping the feasible design areas in mind, the design goal of this thesis is:

"Creating a ***reusable external*** cooling method, with ***no adhesive layer*** which is available for ***all patients*** at EMC and whose patients can be ***transferred*** to surrounding hospitals."

3.4 LIST OF REQUIREMENTS

The Discover phase of the project amounted to the following list of requirements. The requirements have been divided per pillar, an extra list was made for other requirements. During the project, this list has been expanded. This list was first used as a basis for ideation. During ideation, the list was used to evaluate the ideas and finally the list was used during finalising of the concept.

Legend
- Observations / EMC staff
    - 1: Cardiologist-intensivist
    - 2: Perfusionist (supports the surgeon during operations by temporarily taking over the function of the heart and lungs using a heart-lung machine& responsible for the ECMO as a treatment)
    - 3: Neurologist-intensivist
    - 4: Trainee infection prevention
    - 5: ICU-nurse
- Own interpretations
- Literature / protocol

3.4.1 Requirements

3.4.1.1 Cost requirements
- Does not cost a lot more than current methods

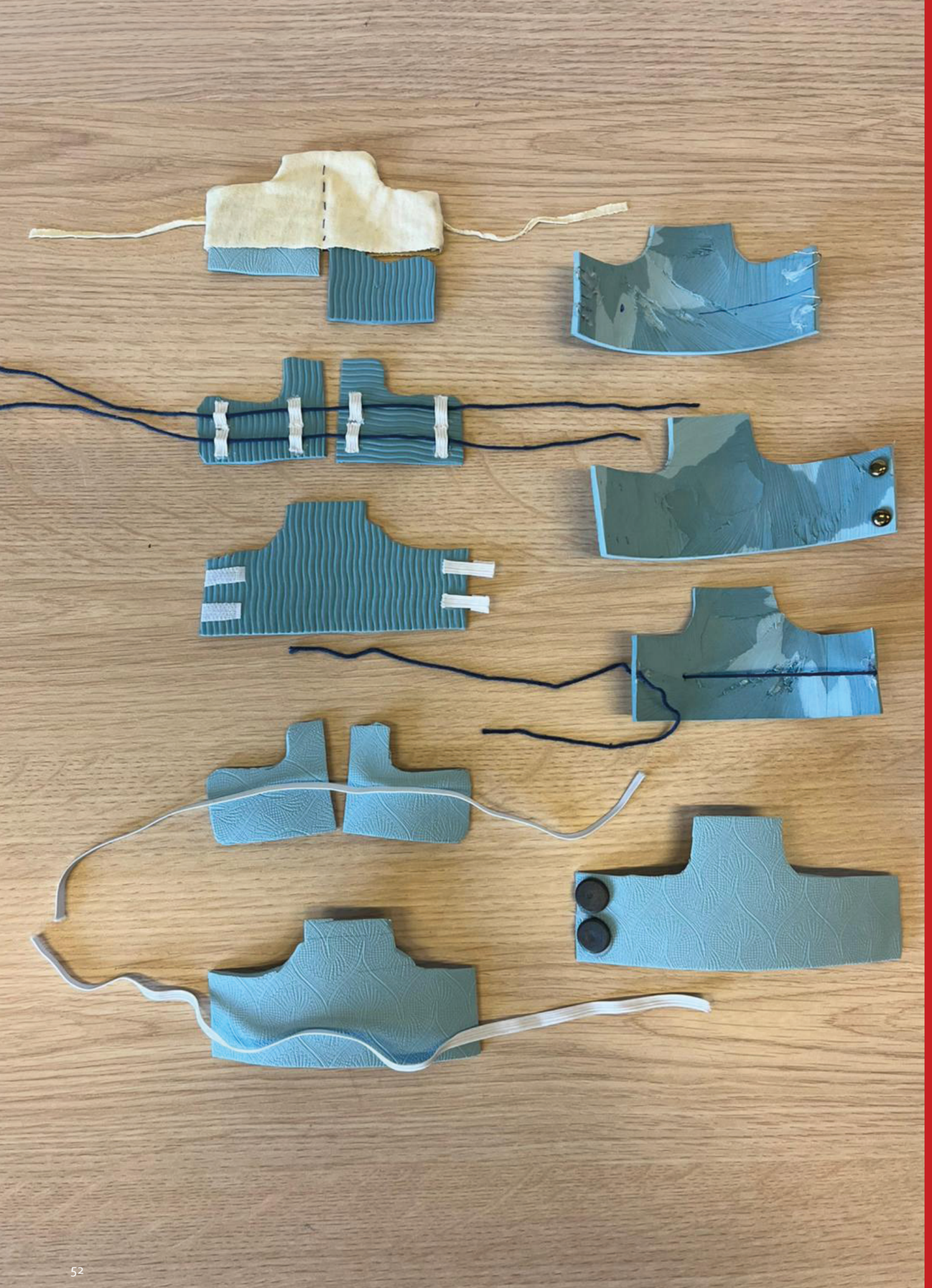
3.4.1.2 Sustainability requirements
- Material should be cleanable in order to be reusable: either industrially washable on 60°C or wipeable with a microfiber cloth[4]
- Product should be designed for at least X cleaning cycles (e.g., ≥50 industrial washes)
- Materials must withstand hospital disinfectants (alcohol, chlorine, peroxide)
- Design should aim for compact storage and reduced logistics waste
- End-of-life materials should be recyclable as much as possible

3.4.1.3 Workload requirements (time, pressure)
- Starting up the treatment does not take longer than 15 minutes (current)
- Does not interfere with medical treatment and tests (e.g. CT-safe & staff needs access to bodily sites).
- Maximum of two nurses needed for administration
- TTM treatment must start within 8 hours of return of ROSC[1]
- Cooling method should be available to differently sized patients
- Should allow skin monitoring during treatment (e.g., easily taken off, clear patches in material, easily openable areas)

3.4.1.4 Wellbeing requirements
- Does not emotionally strain or physically harm the medical staff
- Does not emotionally strain or physically harm the patient
- Should be hypoallergenic, dermatologically safe materials; e.g. latex-free[5]
- Breath of the patient needs to be 37°C (for risk of bronchitis/breathing issues)[1]
- Product should not be wet on the patient's skin, risk of maceration (the softening and breaking down of skin caused by prolonged exposure to moisture)[2]
- Method needs to cool the patient, without risk of frosting[2]
- No hard pressure points on the patient's skin, for risk of bedsores[5]
- Edges must be soft to prevent skin shear

3.4.1.5 Other requirements
- Chest must be instantly accessible or after one action[3]
- Must be able to provide targeted temperature of 33-37.5°C, with steps of 0.5°C
- Should be feasible for all patients in the hospital, in both ICU-4 and ICU-6; e.g. not depending on anti-coagulation medicine
- Any medium used for cooling needs to be cleaned/ refreshed after 48 hours[2]
- Does not involve any open fluids or damp because of the electronics in the ICU[2]
- Method needs to work on Arctic Sun machine, for transferrals to other hospitals
- The peripherical parts of the body should not be cooled[3]
- Needs to be possible to turn patient sideways, both ways[5]
- Automated feedback mechanism should be implemented; the temperature can be changed if needed
- Should be capable of warming (for controlled rewarming)
- Temperature distribution should be even and eliminate risk of thermal burns
- Must operate quietly and without vibration to avoid disturbing sedation levels
- The material should be less than 5cm in height when rolled up, or folded, in order to lay the patient on it

3.4.2 Wishes
- Not conspicuously visible for visitors
- Cooling should aim at cooling the blood, since this is most effective way to cool the brain[3]
- Low risk of bedsores
- Should be intuitive to use
- Clear instructions should be available on device for help
- Minimal cables to prevent cluttering in patient box
- Must not interfere with current work situation of medical staff
- Intuitive design



4 DEVELOP

In this chapter, the final concept is delivered. A double diamond structure is used for iterating. First, ideation of multiple ideas is done. Evenutally, through feedback from stakeholders, three concepts are developed. A final evaluation amongst stakeholders resulted in the choice of one concept to develop further and deliver.

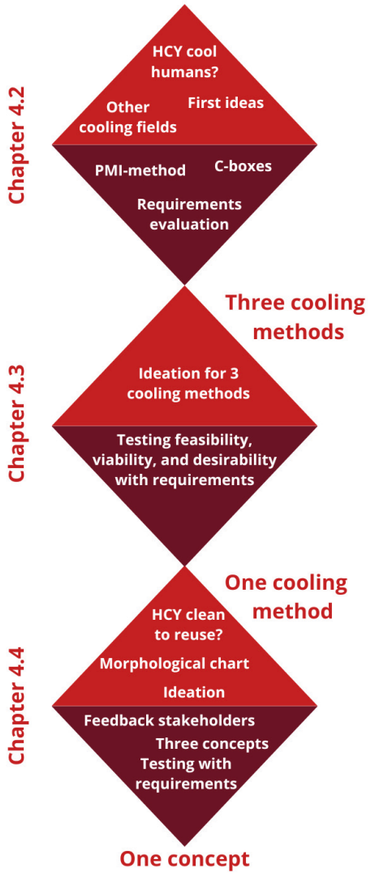


Figure 44: Structure of the Development phase

4.1 THE DEVELOPMENT PHASE

In order to develop a sustainable cooling method for patients at EMC, multiple methods were used, see Figure 44. The topic of cooling humans was explored through a brainstorm and researching other fields in which humans are cooled, both visible in Appendix 2. The main takeaways are described in Chapter 4.2.

Three cooling methods were explored in depth, which were filtered to one: cooling pads, see Appendix 3. The main takeaways are shown in Chapter 4.3.

Within the topic of cooling pads, different ideas were created, with the help of a morphological chart, which is included in Appendix 4. These were then evaluated amongst stakeholders and tested on the list of requirements, which resulted in three concepts. These were prototyped for another round of feedback from stakeholders, after which one concept was chosen to continue further development and continue with in Chapter 5. The final diamond can be found in Chapter 4.4.

4.2 THE FIRST DIAMOND

In order to find applicable cooling methods for patients, the identified methods were evaluated against the list of requirements. Five requirements were identified as most important by stakeholders, having medical repercussions if not adhered to. These five requirements were (listed in order of importance):

1. The method should cool actively (x: passive; ?: both possible; √: active cooling)
2. The cooling focuses on cooling the patient's core (x: full body; ?: both possible; √: core cooling, o: other)
3. The method should cool externally (x: not possible; √: possible)
4. The method should bring no risk of maceration or frosting to the patient (x: risk; √: no risk)
5. The method should not change the work environment drastically for medical staff (x: changes; √: no changes)

The results are shown in Figure 45. Three cooling methods scored affirmative and possible (light red) on all requirements, without any negative scores (dark red): cooling pads, water blankets/beds and air blankets. These methods will be further iterated on in the next diamond.

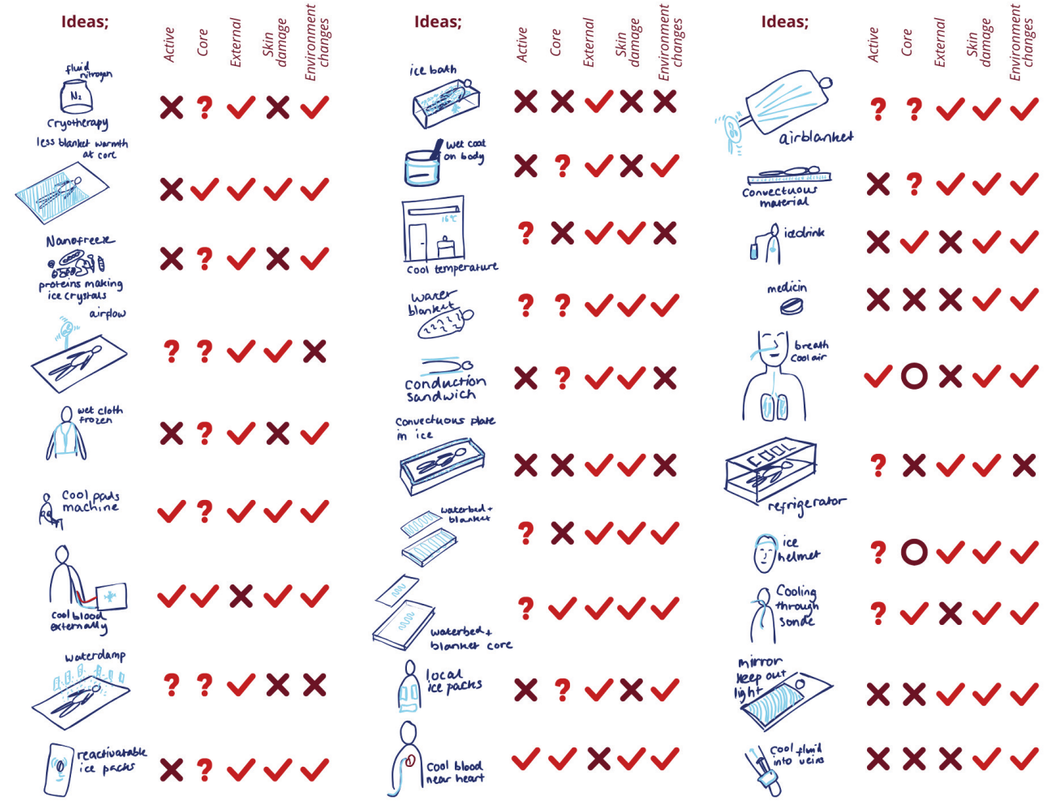


Figure 45: Evaluation of cooling methods based on medical requirements

4.3 THE SECOND DIAMOND

Several ideas were made as iteration on the cooling pads, water blankets/beds and air blankets, see Appendix 3.

According to the literature in Chapter 2.3, cooling pads and water- and air-circulating blankets have the same neurological outcomes. However, cooling pads provide quicker induction, higher efficiency, faster cooling rates and better temperature maintenance than water-circulating blankets.

Moreover, based on the list of requirements, pads are the most viable, feasible and desirable cooling method to continue with, due to allowing peripheral counter warming and providing better contact between the body and the cooling product than air- or water blankets.

4.4 THE THIRD DIAMOND

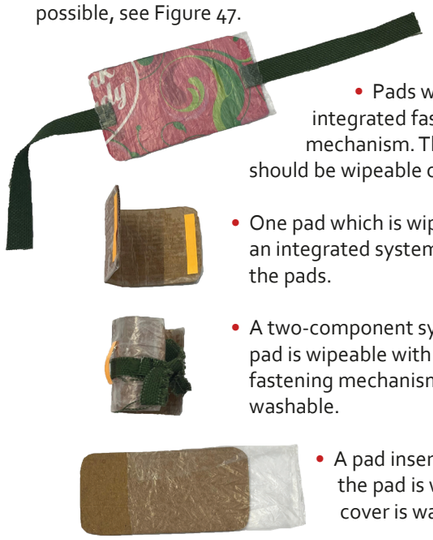
At the start of the third diamond, a brainstorm with other design students was conducted. Design options based on cleanability and place of attachment were made, which were included in a morphological chart. This resulted in several concepts, of which small prototypes were made for Barbara, a Barbie doll used for working on a smaller scale. These were then evaluated with the help of someone from the department of infection prevention and several nurses. Finally, three concepts were further developed and once again evaluated by stakeholders.

4.4.1 Brainstorm

A brainstorm was conducted with other design students, see Figure 46, in order to fully assess the problem area and possible solutions. As a result, more options of keeping cooling pads near a body were found and more closing mechanisms were identified. Most results of the brainstorm were confirming the design process thus far.

4.4.2 Cleanability of pads

In order to clean the pads, four different product types are possible, see Figure 47.



- Pads with a fully integrated fastening mechanism. The assembly should be wipeable or washable.
- One pad which is wipeable, with an integrated system for fastening the pads.
- A two-component system; the pad is wipeable with a separate fastening mechanism which is washable.
- A pad inserted in a cover; the pad is wipeable, the cover is washable.

Figure 47: Possible options keeping cleanability in mind

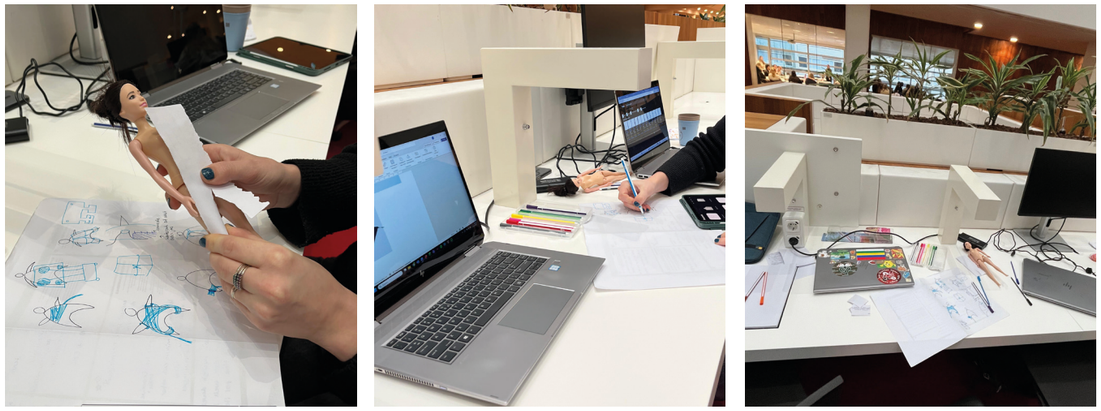


Figure 46: Brainstorm with IDE students, with Barbara

4.4.3 Placement of attachment

Possible places of the closing mechanism on the product were studied and evaluated by medical staff. Hypothetically speaking, the closing mechanism could be on the back, the front, or the sides of the patient, see Figure 48. The product could also be fitted around the patient with no closings, like a large sock or sleeping bag.

Pressure points are prone to bedsores. Bedsores are wounds caused by prolonged pressure and friction. The pressure compresses small blood vessels, reducing oxygen and nutrients to the skin and underlying tissue, which leads to cell death and wound formation (Umcu, n.d.). Given the risk of bedsores, the placement on the front of the patient's body or an insertion sleeve is preferred. Comatose patients are on a turning-schedule where they lie on their back and sides in shifts of three hours. For testing and care, the patient can also be turned to their sides. For medical staff, the insertion sleeve is a hassle to put on since the patient is comatose and for quick body checkups this closing system is not preferred. Thus, the closing mechanism should be located on the front of the patient. This allows rapid access to the chest if necessary and prevents edges on the patient's back that could contribute to pressure injuries.

Figure 48: Possible placement of attachment (red) on a human body

4.4.4 Morphological chart

Further ideation of cooling pads was started based on a morphological chart, see Appendix 4. The main subfunctions identified and included in the graph were:

- The pads should be cleanable
- The pads should be adjustable to body size
- The pads should be kept in contact with the body
- The pads should cover the body
- The locations of closure systems of the pads
- The amount of pads

This resulted in several ideas, which were then evaluated on their feasibility, viability and desirability. For example, a cooling mechanism based on vacuum is not desirable for the medical care the patient needs; their body needs to be easily accessible. Furthermore, the combination of the low temperature of the cooling bag and the medical coma will likely result in damage to the blood vessels in the skin due to the vacuum.

In the end, three different categories of concepts were identified as possibilities, see Figure 49.

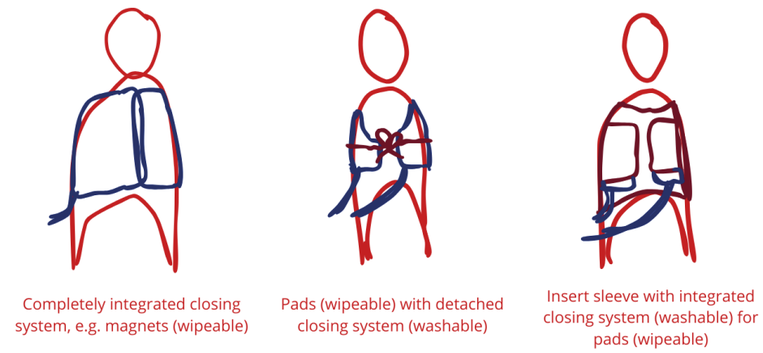


Figure 49: Three feasible product categories to continue with

4.4.5 Shape of the pad

When determining the basic shape of the cooling pad, several factors must be taken into account. First, the patient's body must remain accessible at specific locations during treatment, thus the shape of the pad must accommodate this accessibility (see Figure 50). Furthermore, one pad is preferred over several pads to avoid displacement of the pads during treatment, according to medical staff.

Clinical experience at EMC has shown that cooling the torso alone provides sufficient cooling capacity for TTM, according to medical staff. From a sustainability perspective, limiting the cooling area to the torso also reduces the amount of material required. Additionally, the buttocks contain a relatively high proportion of fat tissue, which has lower blood circulation compared to other tissues. Cooling this area would therefore be less effective. To maximize cooling efficiency, the pad can end above the buttocks. Faeces tend to start flowing as well, which is another reason the pad is preferred to stop above the buttocks, in order to avoid contamination with the pad. Moreover, the human tailbone and hips are sensitive areas for bedsores, these areas must be avoided.

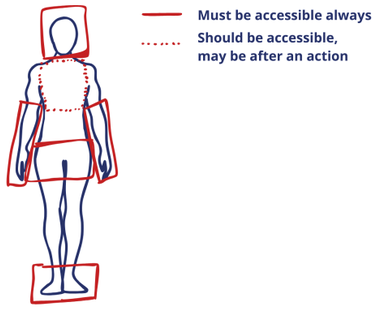


FIgure 50: Unavailable body parts

Multiple versions of shapes of the cooling mechanism were created and evaluated by nurses, see Figure 51. The breast area should be avoided for comfort of the patient, furthermore, some patients have a sub-clavicula catheter, thus the area at the collarbones and neck needs to be free. Furthermore, to avoid bedsores, no ridges should be on pressure areas, thus the edges should be above the patient's tailbone and hips.

Finally, the cooling mechanism should extend as high as possible on the back in order to maximize the effective cooling surface area while still respecting the anatomical and clinical constraints described above.

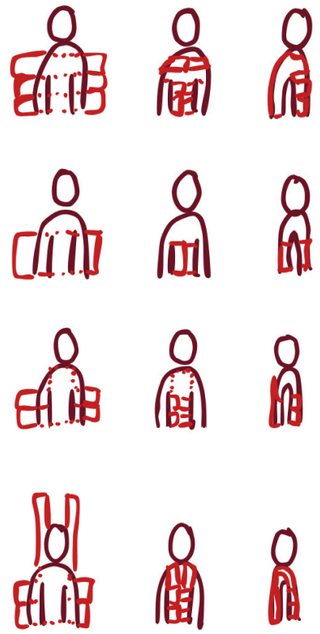


Figure 51: Possible shapes of pads around a human torso

4.4.6 Brainstorm for the three feasible product categories

4.4.6.1 Insert sleeve

The first category found is an insert sleeve, Figure 52. This would be possible for 1 or 2 pads. A stretchable area would be integrated for the pads to fit closely around the body. The closing mechanism would, for example, be Velcro, which is washable. The insert sleeve, including stretch features and closing mechanism, needs to be washable on 60 degrees in a machine.

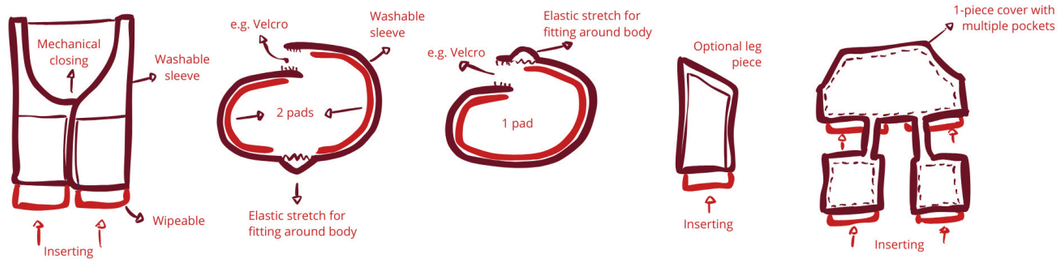


Figure 52: Insert sleeve ideas

4.4.6.2 Completely integrated closing mechanism

The second category identified is a fully integrated closing mechanism, for example magnets, see Figure 53. These would be integrated inside the pad, so the exterior is completely wipeable. This could also be done with press studs on the pads, if the press studs are wipeable. Another version of this would be a hybrid version where the pads would be completely wipeable, with holes in each end. One side would only have one gap, the other side would have multiple gaps for sizing. Through these holes, a fastening system would be placed, such as split pins or a bolt and nut. These are cleanable if they are made of metal, or the closing mechanism itself might be disposable.

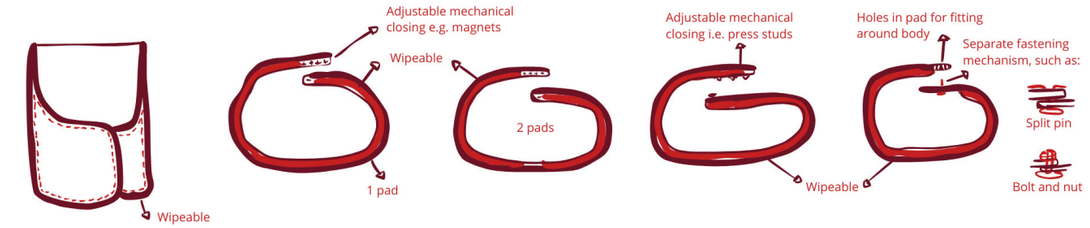


Figure 53: Integrated closing mechanism ideas

4.4.6.3 Wipeable pads with separate closing

The final category includes a completely wipeable pad, with a separate closing mechanism which is washable, see Figure 54. In order for the closing mechanism to remain in place, multiple options are possible, either the pad or mechanism itself should provide enough friction, or the pads should have belt loops on the back, or there should be ridges in the pads to function as canals. Different possible closing mechanisms were created. For inspiration, existing products with a closing mechanism for patients were included, see Figure 55.

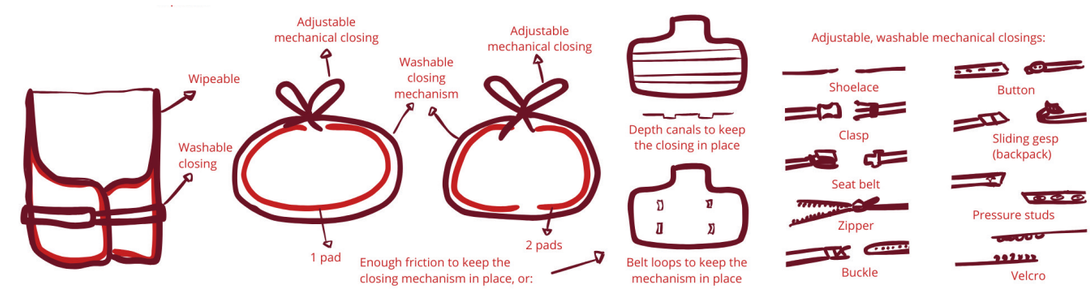


Figure 54: Separate closing mechanism ideas

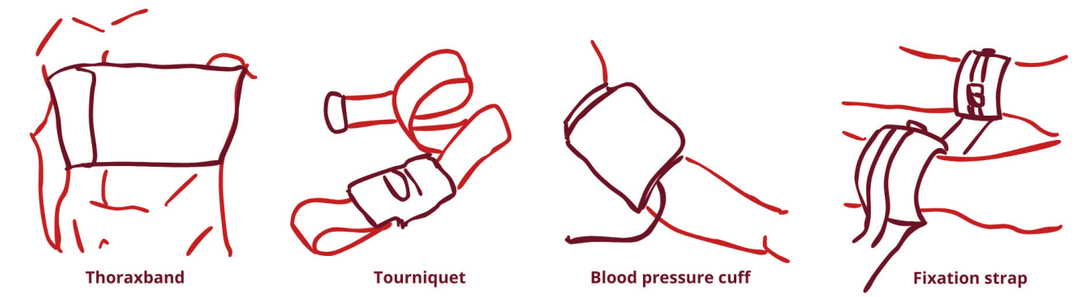


Figure 55: Known closing mechanisms in the hospital

4.4.7 Prototypes on Barbara

In order to communicate these categories and to create more ideas, prototypes were made, see Figure 56. A few new ideas were created, such as a hook system on the edge of one pad, and one based on a wrap dress.

Moreover, one hybrid concept was created: a wipeable pad with a disposable closing. This idea was generated to keep the workflow low and to create an easy-to-use product. These were then shown to medical staff at the ICU and someone from infection prevention to gather feedback and insights.

Hook system, adjustable like a regular bra closing

Separate closing mechanism put through the pads, adjustable due to multiple holes in the pad

A wrap-around closing, attached to the pad or separate

Wipeable pads with a washable insert sleeve

Pads with giding hoops and a separate washable closing

Pads with a separate washable closing

One wipeable pad with a disposable/washable attachment

Integrated magnets inside pads

Figure 56: Prototyping concepts on Barbara

4.4.7.1 Conclusions prototypes Barbara

The figure below shows feedback from nurses, doctors and people from infection prevention per prototype.

Generic feedback was gathered as well:

- One pad is preferred, due to less risk of displacement.
- The cooling method should be as simple as possible; one pad, one closing, which is preferably familiar for staff.
- Different sizes should be available for differently sized patients.

Three ideas were identified as feasible by infection prevention, doctors and nurses:

- 1 wipeable pad with separate disposable closing mechanism
- Washable insert sleeve, wipeable pads
- 1 wipeable pad with washable closing system

The evaluation of these prototypes resulted in the following design criteria: the design should be one pad covering the torso, it should use one closing mechanism, be easy to use, and familiar to staff.

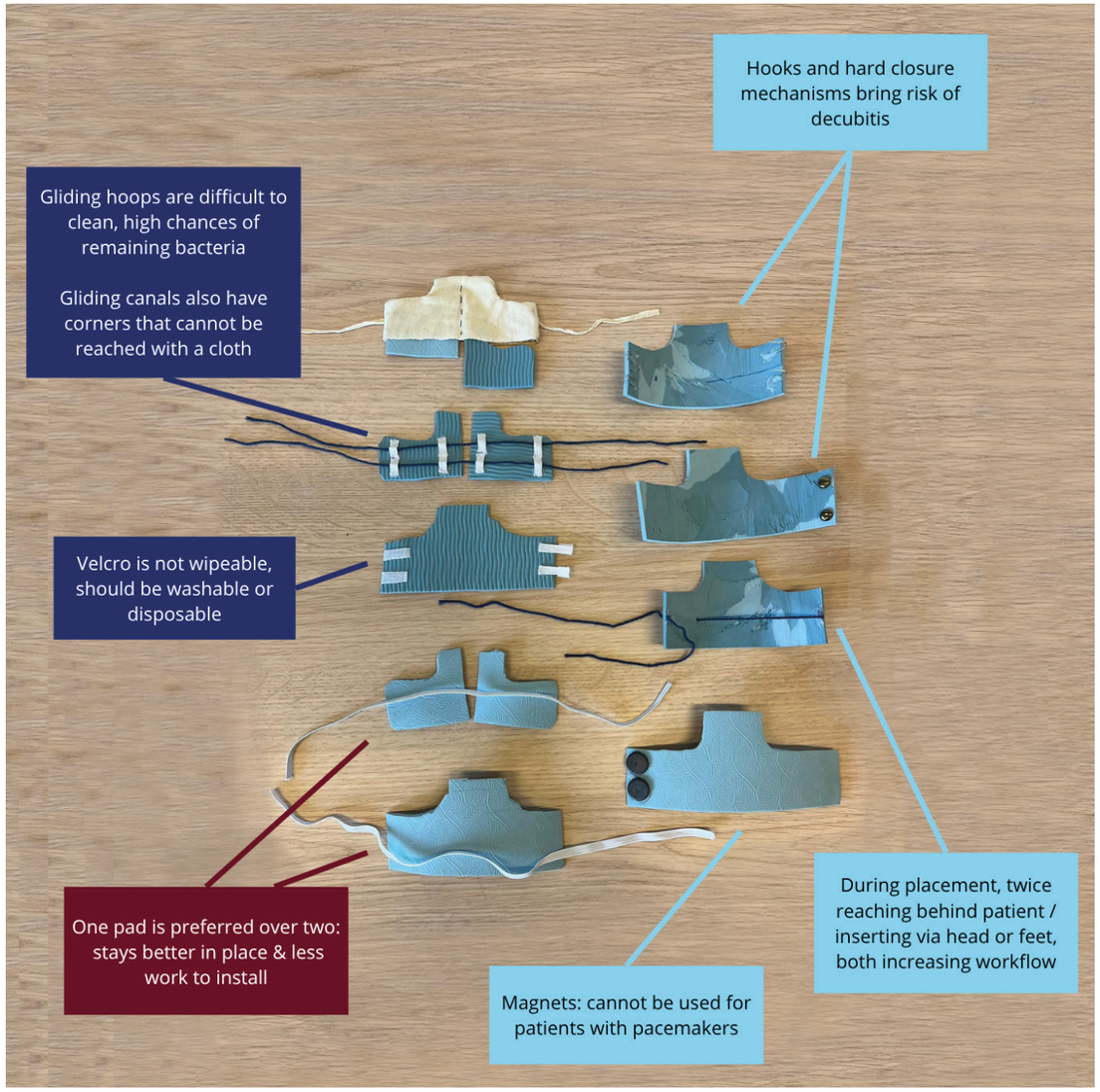


Figure 57: Prototypes with feedback recieved from medical staff, dark blue is feedback from infection prevention, light blue from nurses, dark red from doctors

4.5 CONCEPTS

To continue the Development phase, the three ideas identified as feasible were further iterated on. The workflow was created, iterations were made on the ideas to improve them and new prototypes were made to communicate the ideas to medical staff.

These three cooling mechanisms would all require two nurses to lay the patient on the pad and remove it once treatment is done.

4.5.1 Wipeable pad with disposable closing

The first concept is a hybrid solution with regard to reusability. It consists of a reusable cooling pad with disposable closures, made of standard medical tape (Figure 58). The pad itself is wipeable and therefore reusable. The closures, however, are attached to the pad using adhesives. As medical staff are accustomed to using stickers, tape, bandages, and similar products, this method is intuitive to use. This concept represents a trade-off between full reusability and ease of use.See Figures 59 and 60 for the workflow for the medical staff.

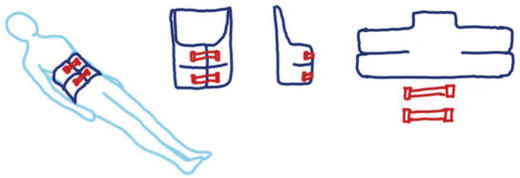


Figure 58: Concept one, wipeable pad with disposable closing

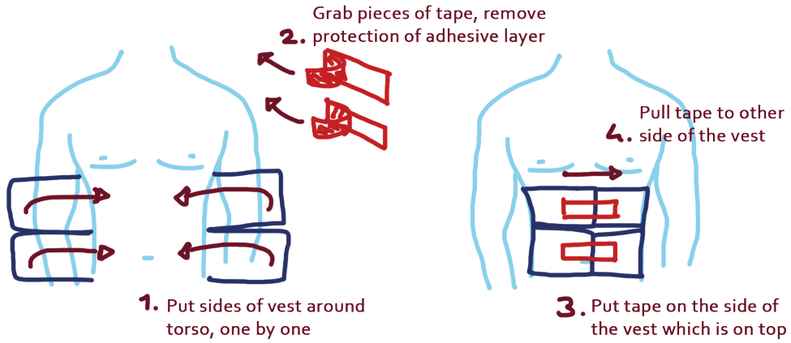


Figure 59: Starting the treatment, with the steps in numbers

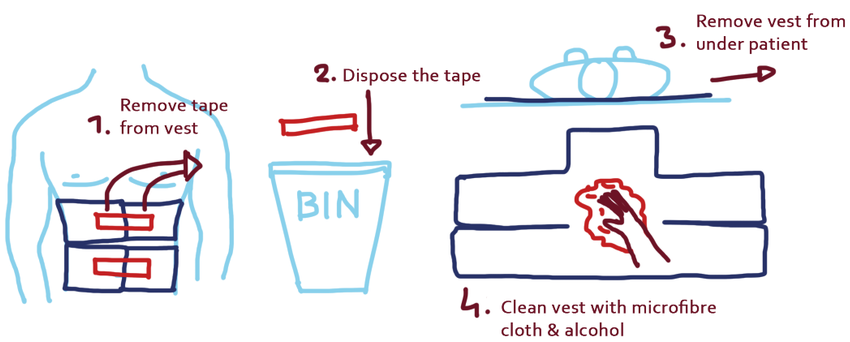


Figure 60: Ending the treatment, with the steps in numbers

4.5.2 Washable insert sleeve

The next concept is a washable insert sleeve, for example made of cotton, see Figure 61. The sleeve itself can be washed on 60 degrees. The pads need to be cleanable due to risk of cross-contamination, thus they are cleanable with a microfibre cloth.

Straps for closing the pad are integrated in the sleeve, placed in such a way that they can accomodate differently sized bodies. Furthermore, two straps are included to keep the pad in place. Figures 62 and 63 show the workflow.

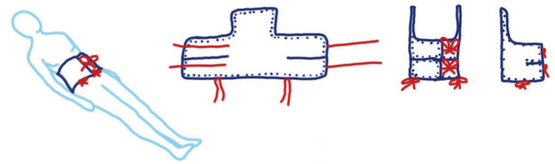


Figure 61: Concept two, washable insert sleeve

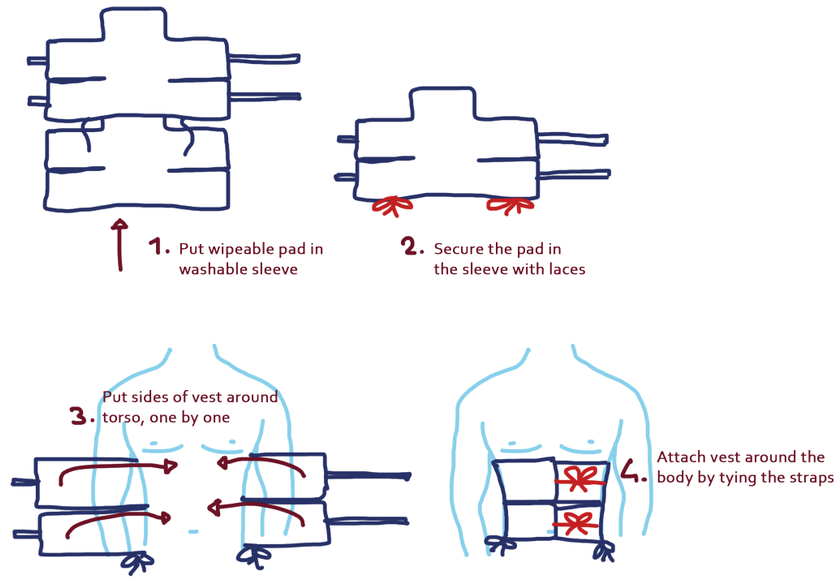


Figure 62: Starting the treatment, with the steps in numbers

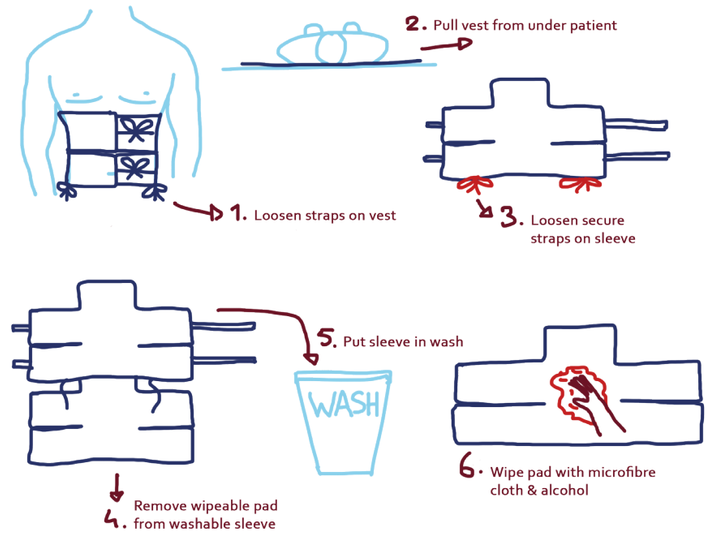


Figure 63: Ending the treatment, with the steps in numbers

4.5.3 Wipeable pad with washable closing

The final concept is quite similar to the first. Instead of using a disposable closing mechanism, a washable closing mechanism is used, e.g. made of fabric, see Figure 64.

The separate closing mechanism would have to provide friction with the pad to remain in place. According to nurses, a mechanical closing system such as a buckle is not expected to risk creating pressure points if the buckle is on top of the pad, as this protects the skin enough from the pressure.

Figures 65 and 66 show the workfllow of this concept.

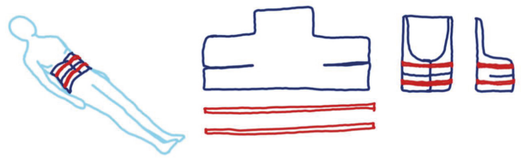


Figure 64: Concept three, separate closing mechanism on wipeable pad

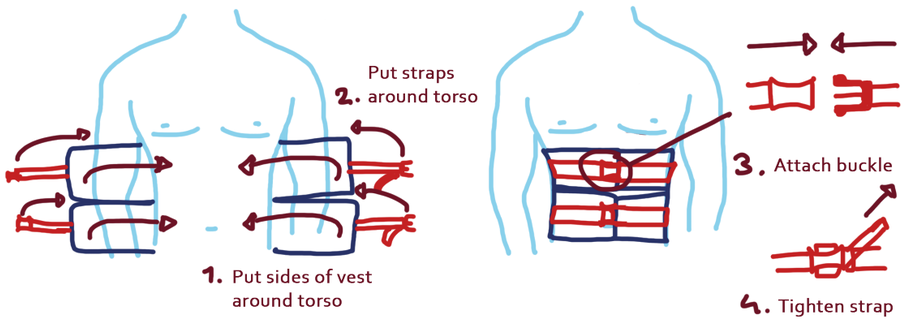


Figure 65: Starting the treatment, with the steps in numbers

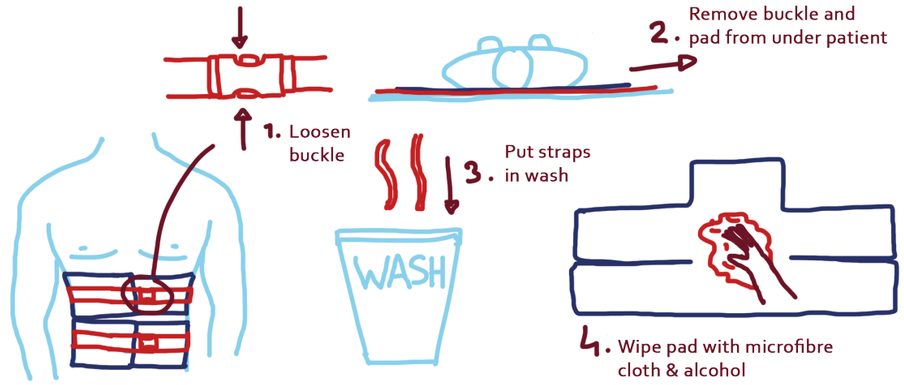


Figure 66: Ending the treatment, with the steps in numbers

4.5.4 Evaluation of three concepts

The three concepts (Figure 67) were evaluated with the help of nurses at the ICU. The concepts were tested against the requirements to continue with the best concept in the Deliver phase.

4.5.4.1 Nurses

The three concepts were shown to ICU-nurses, including the visuals of the workflow of starting and ending the treatment and small prototypes. After explaining the concepts, feedback was gathered for improvements and inefficiences were identified. Furthermore, insights were gathered into the workflow of how to place the pad under patients and the flexibility required of the pad to allow this. As for the presented concepts, concept one is preferred by nurses for several reasons:

- Oftentimes, pads need to be refreshed or cleaned during treatments, due to bodily fluids that leak. Using a washable part (concepts two and three) slows down the cleaning process. Only needing to wipe down the pad (concept one) is preferred over needing to get a clean subsitute for the washable part in the concept. This is less of a hassle and takes less time.
- Less is more, and the first concept is experienced as most intuitive and simple. Therefore, nurses are most enthusiastic about this option. The attachment straps allow for easy fitting around the patient, no extra steps are needed to adjust the pads to the body, this happens intuitively whilst attaching the straps. The attachment straps need to be packaged separately so a new one could be grabbed if needed and no entire package would have to be opened.
- The third concept brings the risk of displacement of the closing mechanism relative to the pad, as well as during treatment and during placement. Furthermore, this closing mechanism requires more cognitve load and attention than the other concepts, according to nurses. It brings the risk of having to turn the patient multiple times if the placing of the closing mechanism goes wrong. Turning patients is one of the most labour-intensive tasks for medical staff thus should be avoided if possible.
- The strings in concept two are undesirable for risk of knots or products getting stuck in the strings during treatment, or them being in the way of treatment. A cord lock would be a better alternative. Furthermore, the mechanisms securing the pad inside the sleeve would have to be placed elsewhere. Patients are on a lying-schedule of three hours to prevent bedsores, including on their sides. Thus, there can be no strings, knots or cord lock placed on the side because of the risk of pressure points.

4.5.4.2 Design

All three concepts adhere to the design goal of this project: "Creating a reusable external cooling method, with no adhesive layer which is available for all patients at EMC and whose patients can be transferred to surrounding hospitals." The three concepts also fit the requirements. To gain insight into which concept adheres best to the design requirements, the weighted objectives method is used, see Table 1. This is an evaluation method for comparing concepts based on their overall value, by including the importance (also known as weight) of criteria. In this case, five requirements are included in the evaluation. Ease of use is considered the most important and has therefore received a weight of 30 out of 100. The amount of materials used per product, the time spent per product and the cleanability are considered with a weight of 20 out of 100 each. Finally, interference with medical treatment is included as a criteria with a weight of 10 out of 100. The concepts then received a score of 1-5 per criteria. Each score is multiplied by the weight, to gain insight into the total value of the three concepts. Concept 1 scores the best, followed by concept 3. Concept 2 has the lowest score.

Table 1*: Weighted objectives method*

Criteria [weight]	Concept 1	Concept 2	Concept 3
Ease of use [30]	(5); 150	(3); 90	(2); 60
Material used [20]	(3); 60	(3); 60	(5); 100
Time spent [20]	(5); 100	(1); 20	(3); 60
Cleanability [20]	(5); 100	(1); 20	(3); 60
Interference with treatment [10]	(5); 50	(1); 10	(4); 40
Score [100]	***460***	***190***	***320***

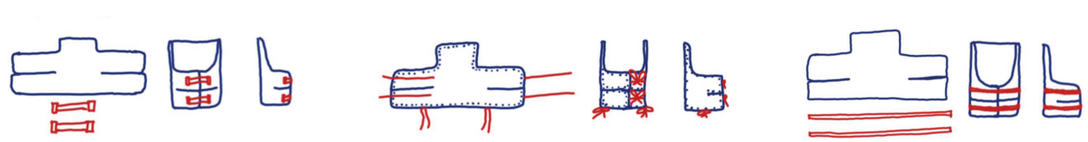


Figure 67: Overview of concepts, from left to right: concept 1, concept 2, concept 3

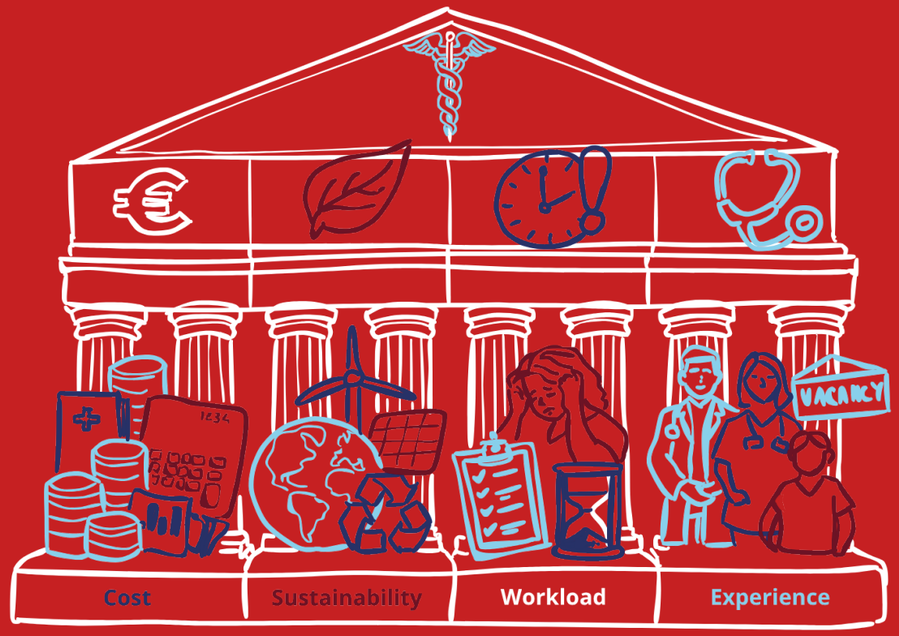


Table 2: *Overview of concepts and their details related to the pillars of healthcare*

Concept 1	Simplest concept, simplest production costs, however the closing is disposable thus these costs will increase with amount of uses.	Not fully reusable.	Most simple. Easy to clean due to the pad being wipeable.	Most intuitive.
Concept 2	Production costs would probably be highest, since this concept uses the most material.	Consists of twice as much material, without any medical reason, it does not relieve the pads of needing to be cleaned. The extra material does not gain any profits in the workflow.	Placement takes more time due to the sleeve.	Washable material is easily contaminated by bodily fluids which is not preferrable to work with.
Concept 3	Friction between the pad and closing will result in damage. The reusable pads will probably need to be refreshed more often.	The friction introduced in the closing mechanism may result in damage on the pad prematurely in comparison to other concepts.	Placement takes more time than concept 1, less time than concept 2. Easy to clean, but the washable closing takes more time than a disposable one.	Most difficult to place under patient, because of separate closing.

To evaluate the concepts in more detail, they are evaluated to the four pillars, Table 2. Analysing the three concepts evaluated with the four pillars in mind, the table can be abstracted to value the details, see Table 3. The scores of the three concepts per pillar are compared and evaluated with a 0, 1, or 2. A score of 0 means the concept scores the lowest in regard to the pillar, whilst a score of 2 is the highest. The pillar of sustainability has equal scores as all three concepts have some negative issues and it is unclear which scores highest and which scores lowest, this would have to be tested.

Table 3: *Summary of concepts' scores on four pillars (0: low, 2: high)*

	Concept 1	*Concept 2*	*Concept 3*
Costs	*2*	*0*	*1*
Sustainability	*1*	*1*	*1*
Workload	*2*	*0*	*1*
Emotional wellbeing	*2*	*1*	*0*

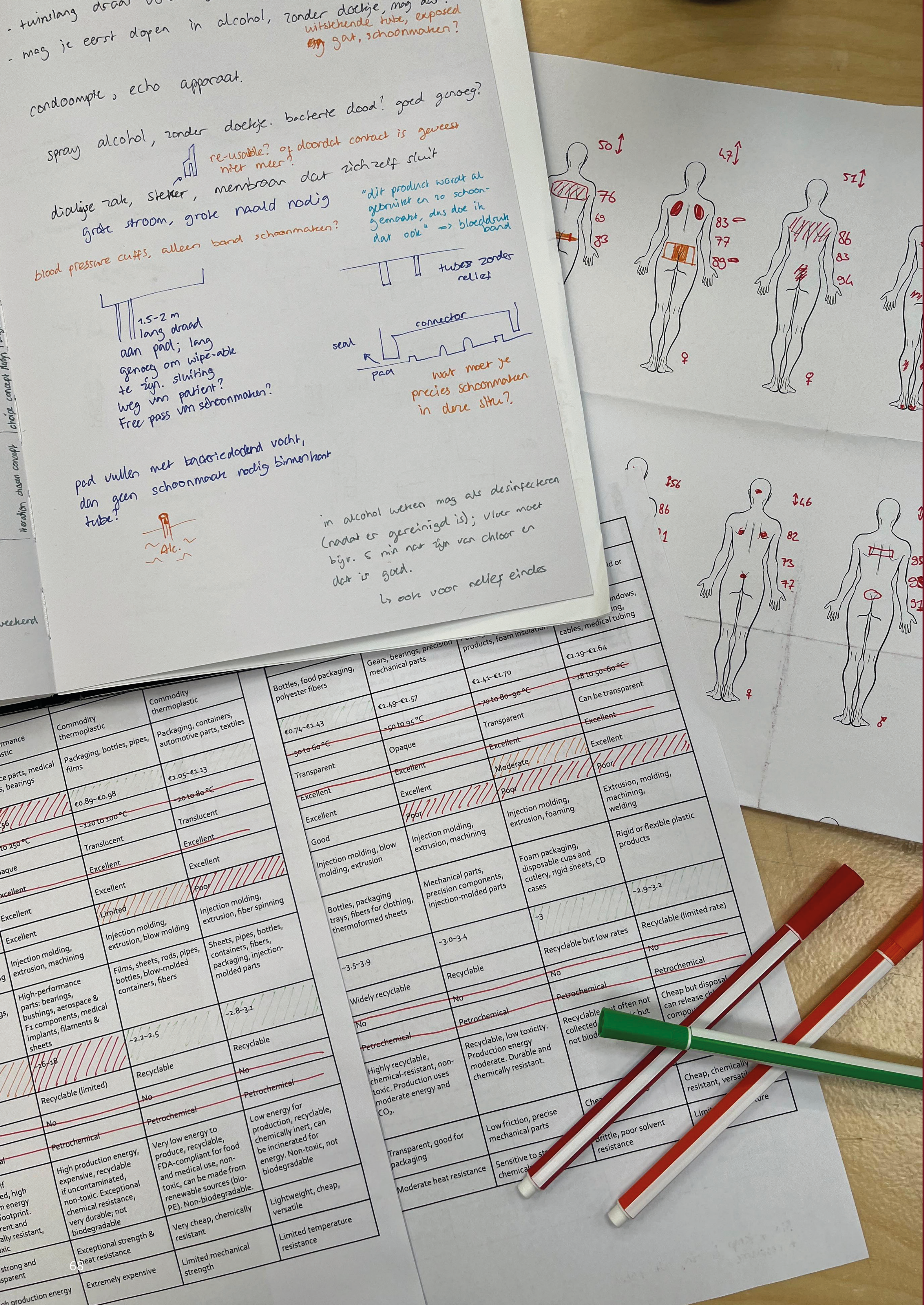
As a final evaluation method, several stakeholders were asked to rank the three concepts on preference. The awarded scores are 3 for their preference and 1 for the concept with the lowest score, see Table 4.

Table 4: *Overview preference of concepts per stakeholder, scored 1 (low preference) - 3 (high preference)*

	Concept 1	*Concept 2*	*Concept 3*
Infection prevention	*2*	*3*	*1*
Nurse	*3*	*2*	*1*
Nurse	*3*	*1*	*2*
Cardiologist	*3*	*1*	*2*
Nurse	*3*	*1*	*2*
Nurse	*3*	*1*	*2*
Score	*14*	*8*	*8*

4.5.4.3 Conclusion evaluation three concepts

Different methods were used to evaluate the concepts, to ensure a valid and thorough chosen concept to continue with. In all evaluations, concept 1 was determined to be the best concept. Thus, this concept will be further iterated on in the next step of this project, see Chapter 5.



5

DELIVER

This chapter finalises the concept. The shape, size, material, connections are investigated and determined. Workflows, visualisations and manuals are included. Prototypes were made. The design concept is evaluated.

5.1 CONCEPT FINALISATION

Whilst the final concept has been chosen, several issues still require iterations for the concept to become realistic. This chapter will discover the remaining issues and uncertainties of the design.

5.1.1 Final pad

The basic shape of te pad has been determined in Chapter 4.4.5. The specifics of the shape and the size of the pad still need to be determined.

5.1.1.1 Size of pad

Stakeholders expressed the wish for the cooling pad to be available in multiple sizes, to accommodate different body shapes. In order to explore the right sizes, several databases were used: DINED, NASA (1978) and Gorden et al. (1989). The conversion theory presented by Dekker and Molenbroek (1999) was used to translate these measurements into modern data. A small test was done as well, where people were measured to gain insights into which measurements are valuable. See Appendix 5 for the gathered data from the databases and test.

The measurements used to determine the sizing for the pad are: hip circumference, waist circumference, shoulder breadth, circumference under breast and height between shoulders and waist. Hip circumference is used to determine the breadth of the pad at the underside; shoulder breadth is used to determine the breadth of the pad at the top; circumference under the breast is used to determine the breadth of the pad under the breast.

Based on the gathered data, the following sizes were determined, see Figure 68. All ranges of measurements are in centimetres, dark blue from the DINED database, light blue from Gordon et al. (1989) and red from the measurements of the ergonomic test. First, both male and female sizes were made, after which the biggest length of the two options was chosen as the final size. These sizes were tested on people and dolls, see Figure 69. One obese doll was used, with a torso circumference of 114 cm. Amongst these dolls and people, the shoulder width of 40 cm was broad enough for all sizes. The length of 70 cm seems to be too large, however, as the dolls ended just below the belly button, this is uncertain. The width of the sidepieces for the torso were broad enough. During testing, the length of the shoulderpiece was determined. Once more, it became clear that different body types benefit from different shapes. See Figure 70 for the final sizes of the pads.

5.1.1.2 Final shape of pad

The cooling pad is most effective when contact between skin and pad is as high as possible. An ergonomical study was done to find where to place the pad on the body. Prototypes were made to investigate how to achieve the highest contact. Several options were made out of a yoga mat to test their fit around human bodies.

Data of 15 participants were gathered, they were asked to determine their pressure points on their backside whilst lying down. The opacity of these fifteen sketches was turned down to 15% and these fifteen sketches were then combined into one sketch to gather insights into pressure points, see Figure 71. Confirming, in accordance with the theory on pressure points, the pad should end above the

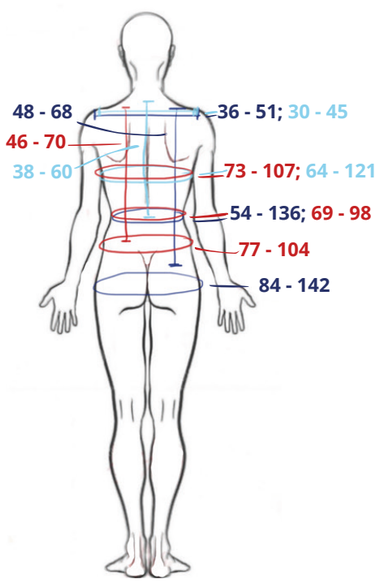


Figure 68: All ranges of measurements in centimetres, dark blue from the DINED database, light blue from Gordon et al. (1989) and red from the measurements of the ergonomic test.

Figure 69: Prototyping the size and shape of the vest

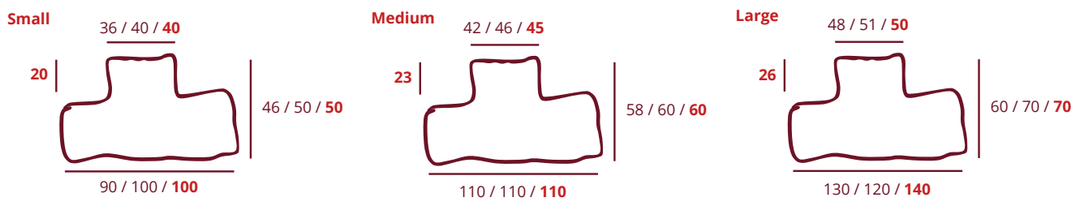


Figure 70: Sizes based on databases and measurements

tailbone and buttocks. The pad should end beside and above the shoulders, to avoid any ridges and to maximise the available amount of cooling area.

Multiple pads were tested to determine the most effective contact area and the ideal shape to fit around different body types, see Figure 72. First, the basic shape was tested. It was quickly established that there was a lot of space between the pad and the patient's side, especially for women. Thus, a split was introduced in the side, at the place where the waist is located. During testing, the place of the waist in the pad was determined. Next, a prototype with two splits was tested, and a version with three splits. However, one single split was found to be effective enough whilst keeping the workflow impact low.

The fourth shape did not yet fit the people perfectly during the test, see Figure 73. The shape of the pad was iterated, tested and fitted until a shape was found which fit these body types, see Figure 74. For people with broad shoulders and a skinny torso, the left shape is preferred, whilst for people with a broad torso or round shape, the right shape is preferred. Testing the skinny-shape with cushions and a wintercoat, to make the body rounder, resulted in the lack of advantage of this shape, see Figure 75. Thus, this skinny-shape only works for certain people. Eventually, this reusable pad might be further developed and different shapes for different body types might be valuable to create. However, for now, one standard shape which accommodates different body types is preferred.

In the end, the most ideal shape for different body types was found to be with one single split, to make it a unisex shape, and to accommodate people with thin waists, thick waists, obese people and thin people.

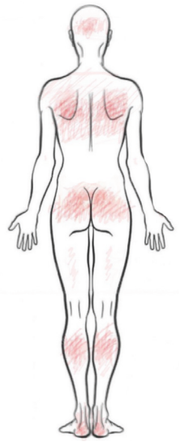


Figure 71: Combined pressure points from 15 participants in ergonomic test

Figure 73: Space between ribcage and pad in the fourth shape tested

Figure 74: Skinny shape (left sketch) with better contact to body

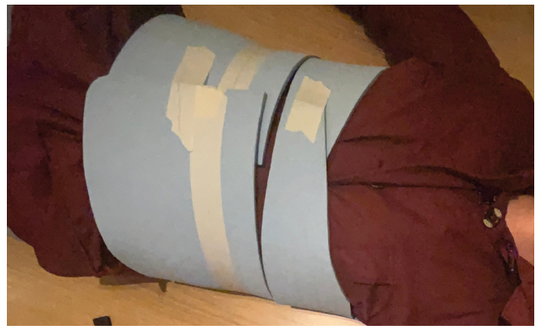
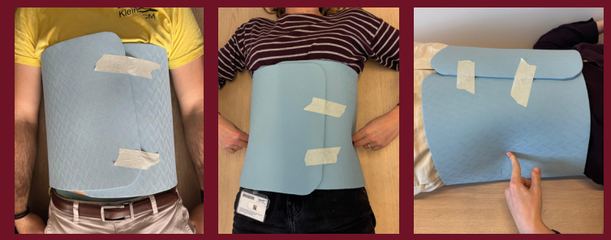


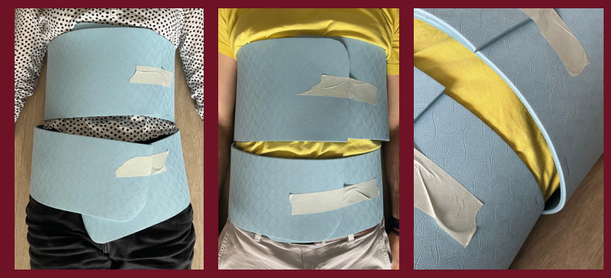
Figure 75: Testing the skinny-shape with a winter coat and cushions

- Rounded corners were added for a softer look-and-feel, as well as a better fit at the shoulders.
- This first prototype was a medium size, for the next iteration the pad was resized to small. This resulted in a more straight fit, due to less impact of the shape of female hips.

- For the next iteration, a shape fit for different waists was made by implementing a split, after participants showed where their waste was located.



- Due to the added split at waist height, there was more contact area between skin and pad. However, there was still space in many places. Plkacement of the split was tested near the end of the ribcage.



- This higher placed split near the ribcage followed the shape of the body better, contact between pad and body was higher.

Figure 72:Transformation of shape through prototyping

- Furthermore, the corner at the armpit was made at an acute angle instead of a right angle, since this allowed for better fitting without reducing contact area at the shoulders.
- During testing it was found that the split should run to where the patient's back lies on the surface, for maximum fitting around the body. If the split is shorter, the material is not able to shape along the body.

5.1.2 Connecting tubes of cooling pad

The development of a reusable cooling pad system requires careful consideration of hygiene, cleanability, and infection prevention, not only for the pads themselves but for the entire system. Both the external surfaces and the internal fluid pathways must be designed in a way that minimises bacterial growth and allows for effective cleaning and disinfection. Chilled fluid circulates through the pads to provide the cooling effect, requiring inlet and outlet tubing that connects the pad to the cooling system. A critical design challenge lies in creating a fluid connection between the pad, the tubing and the system that maintains a smooth, cleanable exterior surface whilst remaining reliable, leak-proof, and easy to (dis)connect. These design challenges were discussed with the department of infection prevention and the ideas were the result from a brainstorm session.

The cleaning process itself consists of two steps: cleaning followed by disinfection. Mechanical cleaning removes visible contamination and organic material from the surface with a microfiber cloth. After this step, chemical disinfection can be applied using alcohol or chlorine. Soaking or spraying with these disinfectants is sufficient. For example, hospital floors must remain wet with chlorine for approximately five minutes to achieve effective disinfection. The same principle can be applied to components with surface texture.

For external cleaning, it is important that the connections and surrounding surfaces do not contain ridges, grooves, or textured features where dirt or bacteria could accumulate. Smooth geometries with rounded edges are necessary. A simple tube opening with a smooth diameter of approximately 1 cm is sufficient, similar to the tubes used on the Arctic Sun system.

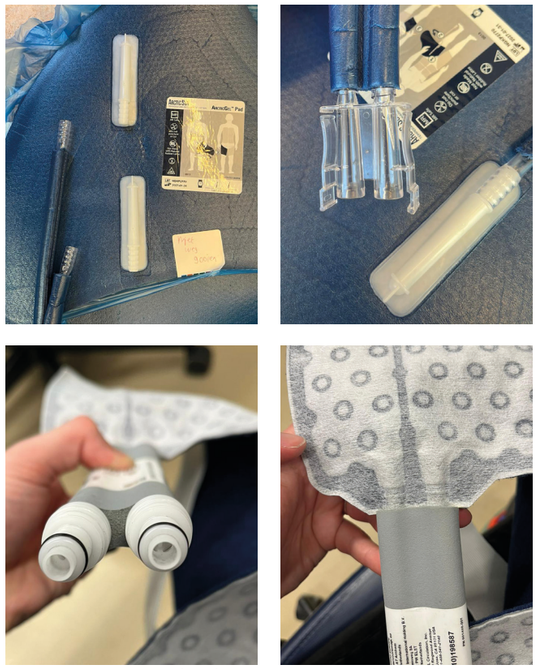


Figure 76:Connection details in existing external methods

The outputs and tubing of the current external cooling methods are not cleanable due to many ridges and complex geometries in the products, see Figure 76.

5.1.2.1 Connection concepts

Various types of fluid connectors were investigated to identify solutions that allow for reliable water transport while remaining easy to clean, such as the spike connection in medical fluid bags, see Figure 77. This connection pierces a sealed membrane to establish fluid flow. Inspired by this concept, the integration of a similar membrane was considered. The membrane would be smooth enough to be wiped clean, after which the tubes could be inserted for each use. While this solution could provide a hygienic external surface, repeated puncturing may weaken the membrane over time, potentially leading to leakage.

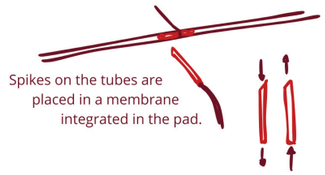


Figure 77: Connection inspired by membranes in IV-bags

Another potential solution is to place a protective connector housing over the pad connection, see Figure 78. In this configuration, only the exterior surface of the housing would need to be wiped clean. The internal edges and ridges of the connection would be enclosed within the housing and would not require direct cleaning, as bacteria cannot reach these areas during use. When a new hose set with fresh water is used for each treatment session, this approach may provide a hygienic solution.

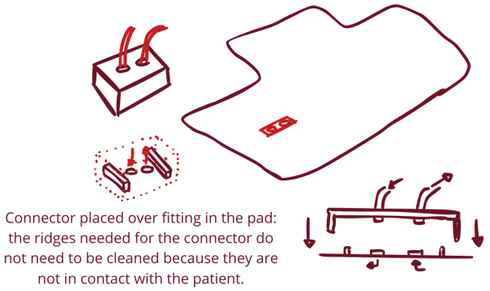


Figure 78: Connection with external housing

Another concept is the use of an intermediate coupling piece that separates the pads from the machine, see Figure 79. In this design, the pads and their hoses could be cleaned independently from the machine and its hoses.

A connector between the two systems would serve as the separation of the two. This connector can be made from disposable but recylable plastic, or from reusable metal, which is to be cleaned using the same hospital procedures that are used for other metal medical instruments.

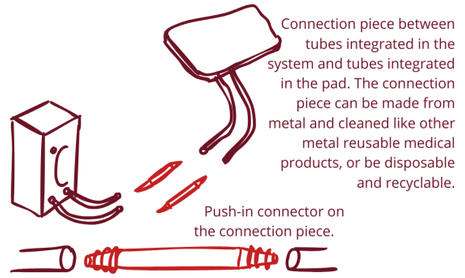


Figure 79: Connection with separate connector

A final connector option involves the use of longer tubing, see Figure 80. Bacteria do not migrate along tubing systems on their own. Therefore, if the pad were connected to a hose approximately two meters in length, only the end connected to the machine would be difficult to clean with a microfiber cloth. Because this section does not come into contact with the patient, it may still meet hygienic requirements. However, attention must be paid to avoid possible cross-contamination by medical staff during treatment and cleaning.

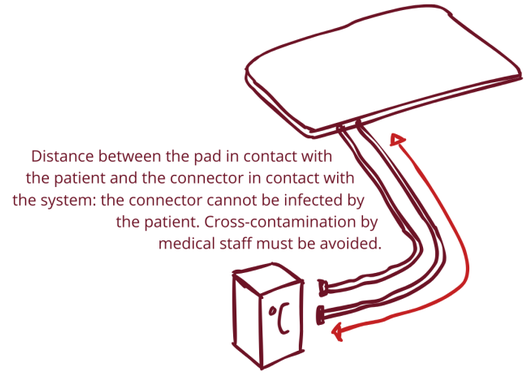


Figure 80: Connector with longer tubes to increase distance

5.1.2.2 Internal hygiene

In addition to external cleaning, the internal environment of the cooling system must also be considered. Water can act as a medium for bacterial growth, particularly when it remains stagnant. Even after draining the system, small droplets of water may remain inside the tubing and pads, which can still support microbial growth. This may explain why the start-up kit of the STx Vest and the tubing used in the Arctic Sun system are currently disposable.

In theory, the tubes could be dried internally using compressed air. Although this would not make the interior sterile, removing residual moisture could significantly reduce the risk of bacterial or fungal growth. Since the internal tubing does not come into direct contact with the patient, complete sterility is not be required. The effectiveness of this drying approach could be tested experimentally by drying the tubes with compressed air and then cutting them open to inspect for microbial growth. However, due to limited availability of the start-up kit during the final phase of this project, this test was not be performed.

Other approaches to reduce microbial growth in the system include maintaining continuous water circulation when the system is not in use or storing the pads in a freezer. Filling the system with alternative liquids such as distilled water or alcohol is not a reliable solution, as bacteria may adapt to distilled water over time and alcohol does not eliminate all bacteria responsible for hospital-acquired infections.

To reduce internal contamination risks, the following cleaning procedure is proposed: 1) drain the system completely after each use; 2) flush the tubing and pads with clean water; 3) circulate a disinfectant, such as alcohol, through the system; 4) rinse with sterile or filtered water; 5) dry the tubing using compressed air to remove residual moisture; 6) store the system in a dry environment.

An ATP (adenosine triphosphate) test can be used to monitor contamination of the inside. This test measures biological activity and is commonly used to verify cleaning effectiveness. During the procedure, ATP is applied to the product, after which the product is cleaned and disinfected. A measurement is then taken to determine whether ATP is still present. Such testing could be used to establish guidelines for evaluating whether the internal surfaces of the pads and the fluid pathways remain safe for continued use.

5.1.2.3 Conclusion

Further testing is required to determine which connector concept provides the best balance between hygiene, usability, and reliability. Stakeholders such as medical staff, engineers, and infection prevention specialists should be involved in this process to ensure that all requirements and cleaning procedures are considered.

The preferred direction is a reusable connection system, provided that an effective cleaning and drying protocol can be implemented. However, if disposable components are required, they should be designed from a recyclable mono-material to minimize environmental impact. A key design consideration is the trade-off between single-use connectors and reusable connectors with a cleaning protocol. Disposable components reduce infection risks but increase medical waste and environmental impact. Reusable connectors reduce waste and may lower long-term costs, but require a reliable cleaning and disinfection protocol.

5.1.3 Material of pad

The material selected must comply with several requirements, as identified in the list of requirements in Chapter 3, to create a sustainable and reusable cooling pad. The material in the product should:

- Be pliable, to shape around the patient's body
- Have no hard edges, to avoid bedsores
- Have a smooth surface, in order to be cleanable
- Be resistant to cleaning with chlorine and alcohol, in order to be disinfectable
- Be water resistant, to allow a flow of cooling liquid through the system

Simplifying the build-up of a cooling pad, the following layers were identified by taking the existing product of the Arctic Sun apart, see Figure 81.

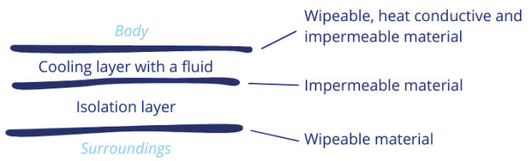


Figure 81: Visualisation of the different layers in the AS pad

5.1.3.1 Materials to avoid

Several materials are avoided in hospital settings, to guarantee patient safety. Natural latex and natural rubber (made from natural latex) are avoided in hospital settings because of high risk of irritations and allergies. Synthetic latex and synthetic rubber do not contain the proteins triggering allergic reactions in the natural versions of the materials and can therefore be safely used.

PVC, also known as vinyl, is one of the most used types of plastics in the healthcare system, and has been for the last decades. It is cheap and very adaptable into countless forms, shapes and sizes. It has been added to the restriction roadmap published by the EU in 2022. PVC is a hazard to human health. During production PFAS, known as "forever chemicals" are used and nearby populations are exposed to water and air pollution. Many chemical additives are used in PVC, of which some are toxic and harmful. The problem of toxic and harmful additives needed for PVC is structural, since these make the material as flexible as is needed for products (PVC's Time Is up – Also in The Medical Sector | Health Care Without Harm - Europe, 2025).

5.1.3.2 End of life

Whilst the goal of this project is to design a reusable cooling pad, it is unrealistic to assume this product will remain in use forever, since every product degrades over time after multiple uses. Therefore, the design will keep end-of-life in mind as well, to optimise the sustainability value.

Currently, the disposables of the three cooling methods are disposed in the residual waste. This waste stream in the ICU is incinerated after which the ash is disposed in landfills, which means the materials are not retrieved for recycling.

Designing for end-of-life increases sustainability value of products by maximizing resource recovery and minimising environmental impact. This can be done through several strategies:

- Design for disassembly; designing products in such a way that different parts with different materials can be easily detached by using fasteners instead of adhesives
- Using mono-material, this makes for easier recycling
- Designing modular designs, in which parts of the product can be replaced when needed, instead of disposing the whole product

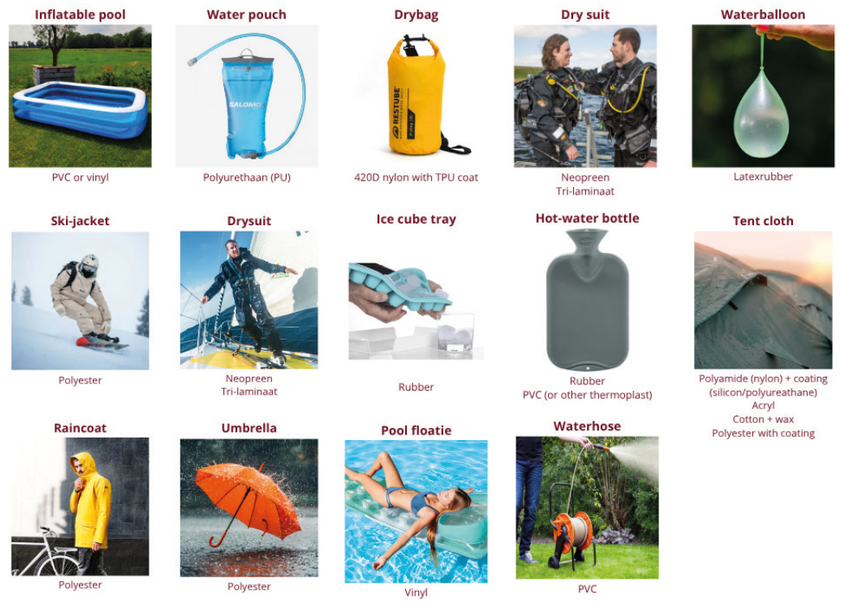


Figure 82: Benchmarking possible materials

5.1.3.3 Benchmarking

Existing products which contain fluids or keep fluids out were investigated as inspiration, see Figure 82. Properties of these materials are shown in Appendix 6. All materials have poor resistance to chlorine. Neoprene, natural rubber and PVC have excellent resistance to alcohol. Nylon and PVC are the only recyclable materials. Neoprene is not weldable. PU involves toxic chemicals during production. Looking at the properties, PVC is the only suitable material for this design project.

5.1.3.4 Possible materials

The Granta EduPack 2025 R2 database was used to investigate potential materials for the design. The software organises materials into different levels of detail to support material selection. Level 2 of the database was selected for this study because it provides a broader range of materials and more detailed information than Level 1, while remaining easier to navigate than Level 3. Level 3 contains more comprehensive data but includes a significantly larger dataset, making it more complex to use for an initial material screening. Based on this level of detail, several selection criteria were applied:

- Since the material should be pliable, the material databases searched are elastomers, polymers, natural materials, foams and polymer composites.
- The material's durability for water should be excellent
- The material's durability for alcohol (ethanol and methanol) or chlorine should be acceptable or excellent
- The material should be recyclable

Possible materials based on these search criteria are: ceramic foam, PC, PEEK, PE, PET, POM, PP, PS, PVC.

In order for the material to be cleanable and wipeable, the surface of the material should have a smooth finish. Below is a clear list on surface smoothness and suitability for the materials.

- Ceramic foam is highly porous and rough. Even after manufacturing, the pores of the material remain open, so it cannot achieve the smooth wipeable surface required for microfiber cleaning.
- PP can easily be produced with smooth surfaces via injection molding or extrusion.
- PET can be manufactured to be smooth and glossy, it is often used for food and drink packaging.
- POM has a smooth and low-friction surface, it is often used in medical products and is easy to clean.
- PS can be finished smoothly but is brittle and therefore less durable for mechanical stress or water pressure.
- PE is possible to finish with a smooth surface, but the material is slightly waxy which may hold oils. The material is often used in hygenic applications.
- PEEK can be manufactured into a very smooth surface.
- PC can be finished smoothly but is sensitive to cleaners.
- PVC can be manufactured well with a smooth surface, often used in hospital products and easy to clean.

Appendix 6 shows the general properties of the identified materials to use in this design. Ceramic foam is not included since this material is not wipeable.
Based on these general properties, PEEK is eliminated as a possible material option, due to the high material price and high CO_2 footprint per kg of material. PS is eliminated as an option due to moderate and poor resistance to chlorine and alcohol, the material would degrade quickest during cleaning. PC is another material which is sensitive to cleaning solvents and which has a relatively high price and CO_2 footprint. The following materials remain as possibilities: PET, POM, PVC, PE and PP.

In 2020, the Europian Commission published the Restrictions Roadmap under the Chemicals Strategy for Sustainability towards a toxic-free environment as part of the European Green Deal (European Commission, 2022). Of the five possible materials, PVC is included in the list of planned restrictions, thus PVC should be avoided.

The remaining four possible materials were plotted on their thermal conductivity, see Figure 83. High thermal

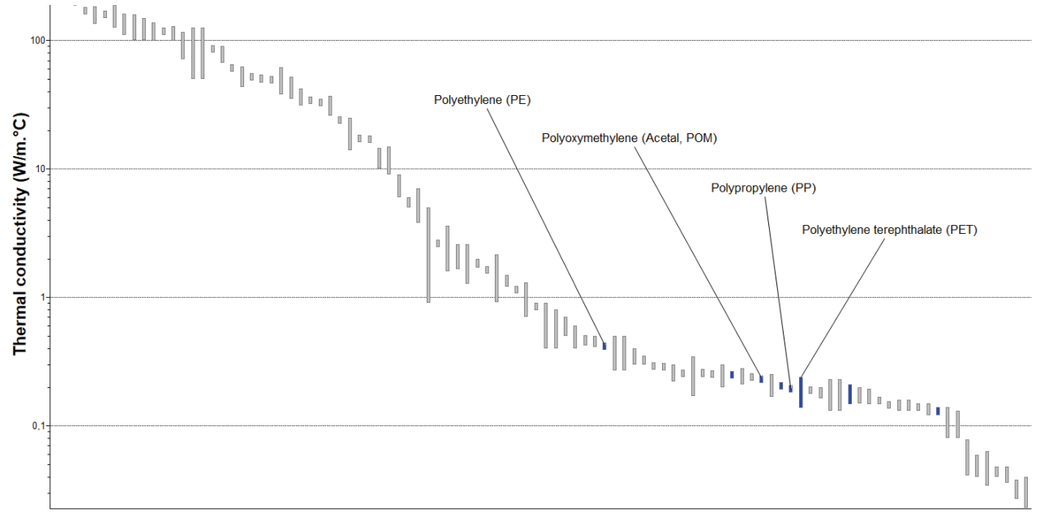


Figure 83: Thermal condictivity of possible materials

conductivity means the material transfers heat easily, a low thermal conductivity means the material isolates. Based on this graph, PE is the material which transfers heat the easiest, which means less energy is needed for heat transfer. However, the four possible materials are very close to each other; the difference in thermal coefficiency is presumably not that impactful.

POM is a material which is known for its stiffness and engineering applications, this material cannot easily be made pliable or soft. For the purpose of this project, this material is not the right choice and therefore eliminated.

5.1.3.5 Conclusion of possible materials

PE, especially low-density polyethylene (LDPE), is flexible, chemically resistant, and can be heat sealed, making it a potential material. PP has excellent chemical resistance but is generally too stiff for applications requiring a soft and compliant structure. PET is relatively stiff and difficult to heat seal, making it unsuitable for flexible airtight products.

In applications where resistance to cleaning agents such as alcohol and chlorine is required, material selection becomes more critical. PE shows very good resistance to both alcohol and chlorine-based cleaners and is therefore a strong candidate.

Additives or elastomers are needed to make soft and pliable materials of PP, PE and PET. All three materials can be manipulated to achieve this structure needed for cooling pads around a human body.

Which material is used in the final product should be tested in prototypes and is dependent on many factors such as the abilities and knowledge of the manufacturer. PE is recommended to be prototyped first since this material has the lowest CO_2 footprint per kg, the lowest price per kg and is likely the most flexible out of the three potential materials. This material is known for a slightly waxy surface which might prove difficult to clean, this would have to be tested.

5.1.4 Common manufacturing methods in plastics

The following manufacturing processes can be used to achieve a smooth surface:

- Injection molding; very smooth, mold-polished surfaces
- Extrusion (sheet or plate); smooth surfaces
- Thermoforming; smooth molded surfaces
- Machining + polishing; smooth surfaces for engineering plastics

All identified possible materials are thermoplastics, which are the most commonly used type of plastic. They are able to go through several melt and solidification cycles without degrading; the process is completely reversible, which makes recycling thermoplastics feasible.

The cooling pad consists of different parts, the main pad is made of flexible material, whilst the connection to the tube, the valve, is solid material. The main pad would be manufactured by creating a sheet of material by extrusion, which is cut into shape. Then the two layers of sheetmaterial are sealed by welding them together. In the process of welding, plastic sheets are heated locally and pressed together to form strong and water- and airtight seams.

Several manufacturing processes exist for creating rigid products of thermoplastics, each with their own advantages, limitations, and typical applications. For the valve in this product, injection moulding is preferred. Injection moulding is a widely used manufacturing process for thermoplastics. Molten plastic is injected into a mold under high pressure and then cooled to solidify. This process is highly suitable for mass production due to its repeatability, high production speed, and ability to produce complex geometries with tight tolerances. Other existing manufacturing methods for rigid parts are 3D-printing, which is not an option due to the layered nature and the resulting ridges for dirt to accumulate, or CNC-machining, which results in material waste and which is more expensive for batches of products (Guide to Manufacturing Processes for Plastics, n.d.).

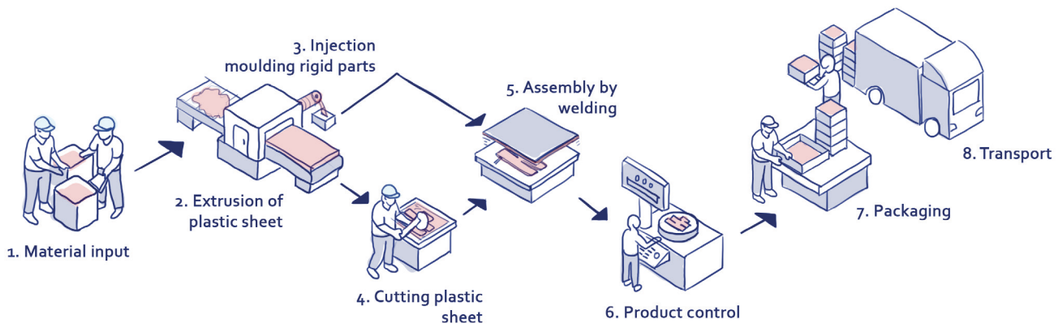


Figure 84: Manufacturing process

5.1.5 Tape as a fastening method

Tape was selected as the fastening method because it is perceived as a simple solution with a high ease of use. To maintain this usability, it is important that the tape can be applied easily. The cooling pad is not required to provide compression, it only needs to fit closely around the body. This means that the tape does not need to be applied under tension, allowing flexibility in its placement. Contact with the patient's skin is preferably avoided; however, it is not considered problematic if it does occur. Different implementations of tape as a fastening method are possible: standard medical tape or reusable nano tape.

5.1.5.1 Standard medical tape

Standard medical tape is the tape commonly used for wound dressing. This ensures a familiar and intuitive application for nurses. Using a roll allows the required amount of tape to be determined per patient and enables individual preferences to be accommodated. Furthermore, a roll results in less packaging waste than separately packaged pieces of tape, which was expressed as a wish by nurses. Options such as pre-cut pieces of tape or a strap with adhesive only at the ends, were considered. However, these were not selected due to limited flexibility in use.

This standard medical tape inherently introduces the risk of adhesive residue remaining on surfaces. This should be avoided, as such residues can trap dirt and contaminants. If present, adhesive residues can be easily removed using 70% alcohol (*Sticker Residue Won't Budge? Try These 8 Fixes Blog*, n.d.). The alcohol commonly used in hospitals for surface disinfection is ethanol with a concentration between 70% and 80% (RIVM, n.d.). This implies that the pad should be wiped with alcohol at the locations where adhesive residues are present, after which it can be cleaned and disinfected according to standard procedures. No additional cleaning agents are required to remove these residues.

5.1.5.2 Reusable nano tape

Nano tape is a reusable, transparant tape, made from soft nano-PU gel, or an acrylic-based gel. Its strong adhesive properties are due to a micro-suction-like structure that enables bonding to smooth surfaces. Once the tape is contaminated with dirt or dust, it can be rinsed with water. After drying, the tape has the same adhesive strength as before washing. Another advantage of nano tape is the lack of adhesive residue on the pad, which allows for easier cleaning of the pads at the end of treatment. Nano tape can be used up to 600 times according to manufacturers (*Nanotape Bestellen - Nanotape*, n.d.).

5.1.5.3 Conclusion on the type of tape

To ensure that tape is always available, a supply will be stored near the cooling unit. Nurses do not typically carry tape with them, so this approach ensures that tape is always within reach when a patient requires cooling.

The main disadvantage of using standard medical tape is its single-use, disposable nature, whereas its main advantage is its widespread familiarity. The nano tape is reusable for the same patient. Each nursing shift, the skin needs to be checked at least once, which requires removal and installment of tape on the pad. Using nano tape would result in less waste of tape by reusing the same piece of tape throughout the cooling treatment. The disadvantage of nano tape is its newness in the hospital, as well as the need to wash the tape if its adherence decreases during use, which adds to the workload.

Keeping sustainability in mind, this reusable cooling pad is proposed with nano tape. During trials, the use of nano tape should be reviewed, standard medical tape can always be used as an alternative.

5.1.6 Flow in pad

Since the pad consists of two sheets of PE welded together, with a flow of fluid inside, a pattern of welding is valuable, see Figure 85. Without any pattern, the vest will extend in width due to the volume of the fluid (1). With a pattern, this extending in width can be decreased, the material allows for less deforming (2). An optimal pattern to keep the two layers together is a pattern with many different contact points between the two layers (3). A combination of both (4) - a welded pathway to introduce a flow pattern, and small contact points along this pattern - will likely result in the most optimal flow in the pad without extending and therefore being in the way of the patient. The best pattern will have to be modelled and tested.

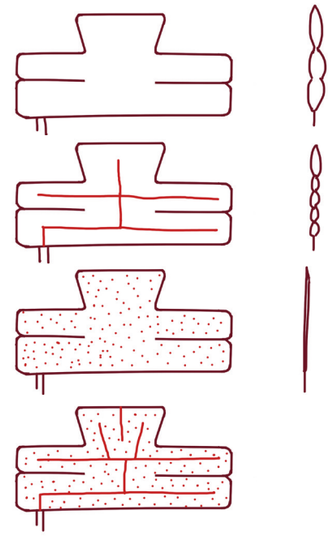


Figure 85: Possible welding patterns in sheets, with side views

5.2 FINAL CONCEPT: THE CLINICHILL

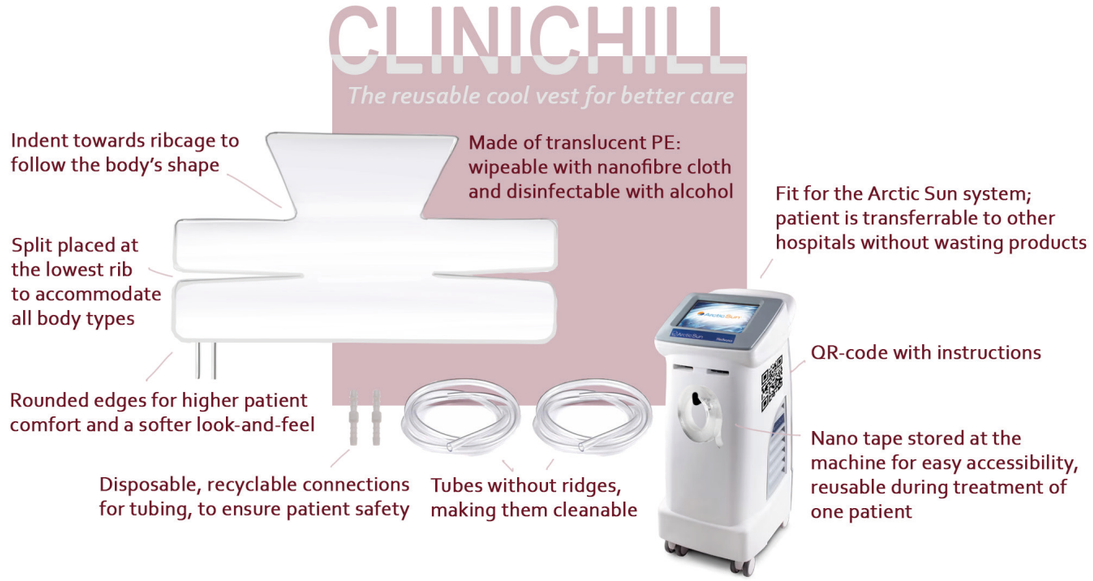


Figure 86: Concept presentation of the Clinichill

Figure 87: Visualisation of the Clinichill in use, underlaying image created by AI

The final design concept, the Clinichill, is visualised in Figure 86. Figure 87 shows a visualisation of the product on a patient.

The material choice of PE allows for cleaning and disinfecting and therefore makes this vest reusable for different patients. The nano tape allows for quick access to the chest. The lack of adhesive layer to the patient's skin keeps the skin protected and makes this vest easy to work with. It is intuitive and simple. It is available in three different sizes. The vest fits to the Arctic Sun machine, as the hospitals in the surrounding area have this system. Thus, patients can be transferred to other hospitals if needed, without having to worry about removing the cooling vest, or wasting any material. If this product will be brought to market, a tracking system will be valuable to track where the vests go and make sure each hospital has enough to provide treatment for patients. Thus, if EMC transfers multiple people to other hospitals, their cooling vests will be tracked and a service will bring them back them so EMC has enough in storage.

Currently, EMC has three cooling systems at ICU-6 and four at ICU-4. Four other cooling systems are placed in specific ICUs, such as neo-ICU. Assuming this amount of cooling devices is sufficient, EMC should have seven reusable cooling vests per size in storage. If this reusable vest will be the standard at EMC, more Arctic Sun systems will need to be bought for ICU-6.

5.2.1 Final workflow

Treatment with the Clinichill can be started by nurses, doctors are not needed. See Figure 88 for a visualisation of the final workflow of installing the cooling vest. Figure 89 shows the final workflow for removing the vest. The cleaning of products in the ICU is done by nurses, or care assistants if nurses are busy.

On the machine of the Arctic Sun, a QR-code is added, this QR-code links to a user manual of the cooling vest, which is shown below.

User manual Clinichill

1. Required equipment
   - Cooling machine (Arctic Sun)
   - Cooling vest in correct size
   - Nano tape (on front of this machine)

2. Setup
   - Install the machine according to hospital protocol and switch it on.
   - Connect the vest tubing to the machine ports.

3. Preparing the patient
   - Call a nurse to assist with positioning.
   - Disconnect the vest from the machine for placement.
   - Turn the patient gently to the side.
   - Install the cooling vest under patient as you change the bedsheets. Lay the patient back onto the vest in a comfortable and safe position.

4. Securing the vest
   - Reconnect the tubing to the machine.
   - Take the nano tape supplied with the machine.
   - Put the vest around the patient. It should not compress, but make sure the vest is in contact with the body all around the torso. Use nano tape to secure the vest.

5. Routine checks during each shift
   - Remove the nano tape, wash it according to protocol.
   - Check the patient's skin.
   - Reuse the nano tape.
   - Verify that the vest tubing is still securely connected and that cooling flow is normal.

6. End of treatment
   - Drain the vest.
   - Turn off the machine.
   - Disconnect the tubing, remove the connection pieces and dispose of them.
   - Remove the nano tape and dispose it in the waste bin.
   - Clean the vest surface, wipe the product down with a microfibre cloth. If the vest is contaminated by bodily fluids, the vest should be disinfected with 70% alcohol.
   - Wipe and clean the tubes and machine.
   - Return both the machine and the vest to the storage area.

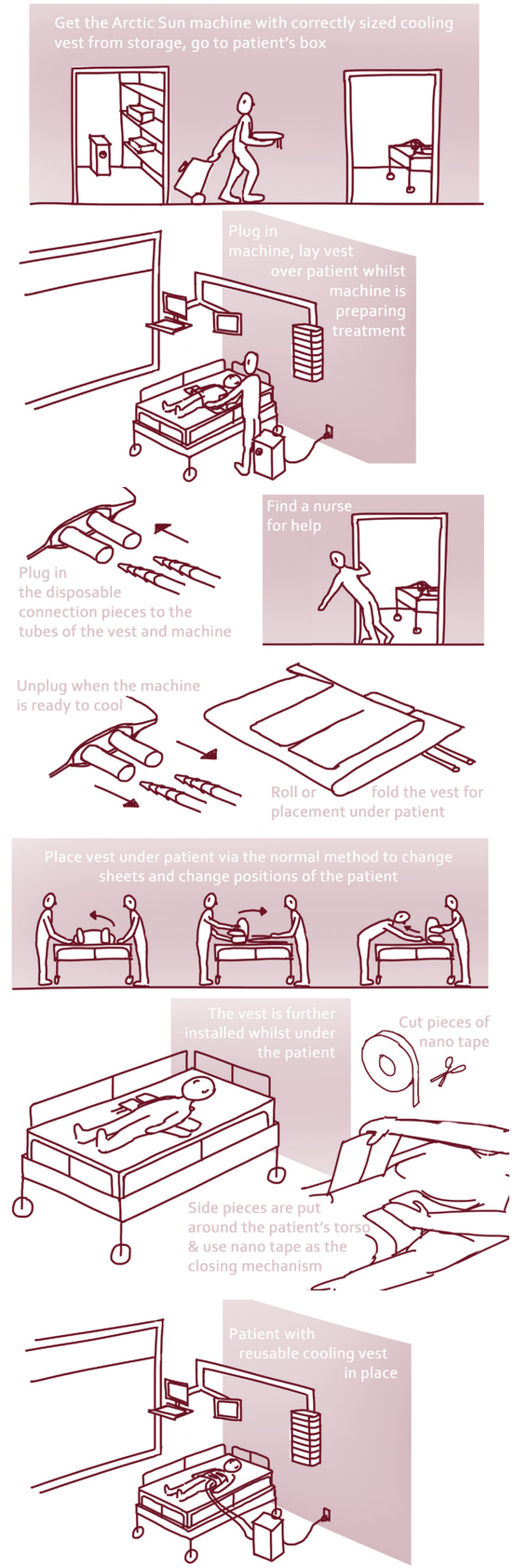


Figure 88: Workflow for installing the Clinichill

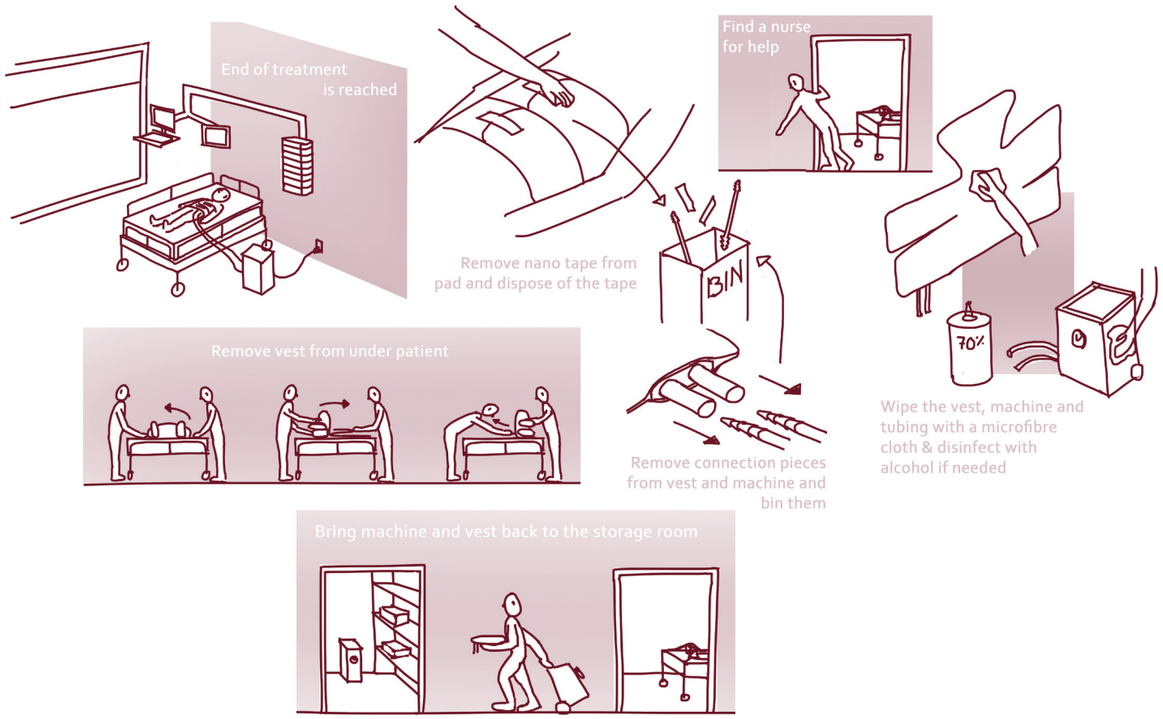


Figure 89: Workflow for ending treatment with the Clinichill

5.2.2 Cost estimation

For an estimation of the costs of the product, the material needed is calculated. For this calculation, the following details are needed: PE has a price of 0.89 - 0.98 €/kg and a density of 0.92 g/cm³.

The sheets of material of the vest are assumed to be 0.5 mm thick, however, this would have to be tested during manufacturing. This means that for the small-sized vest, a PE sheet of 2000 mm x 500 mm x 0.5 mm is needed, which is then cut in half to create two layers. These dimensions result in an estimated weight of 460 grams per vest.

The tubes would be approximately 2 m in length, to allow for enough space between patient and machine for the machine to be out of the way. The current tubes used in the Arctic Sun are 8 mm in diameter with a wall thickness of 1 mm. Calculating the weight of the tubes results in an estimated weight of 40 grams per tube.

An additional 30 grams is estimated for the material holding and guiding the tubes in the vest. In total, the amount of PE used for one vest would thus be 460 + 2 x 40 + 30 = 570 grams.

The sheet of PE and the tubes are assumed to be manufactured through extrusion. The connection between the tubes and the vest is assumed to be made with injection molding. The vest is assembled by welding. Estimating the price of these manufacturing processes is difficult, as the prices depend on a many factors. For injection molding, a simple mold costs around €1.000 for small parts (MakerVerse, 2025). Extrusion of a PE sheet is €1.83 per kg on average (*Polyethylene Cost Guide: Price for Resin, Film, and More 2026 – Design Transition Studio*, 2026). Extrusion of PE pipes is estimated on €2 per kg (Ecplastics et al., 2024).

The price of the product will also include labour and production time. The costs for labour depend heavily on where the product is made. In the Netherlands, factory workers earn around €15.40 - €17.50 per hour, whereas minumum wage in the United States is around €6.31. In countries such as Mexico, wages are even lower. How much of the manufacturing process will be done automatically and how much will be done by workers is to be determined and greatly impacts the price of labour. Where production takes place also impacts the price through transport costs.

Apart from the vest, the tube connectors and nano tape also need to be manufactured and thus impact the cost estimation. However, as the tube connectors are simple parts made from plastic, and nano tape already exists on the market for a few euros per roll, these costs will not greatly impact the total cost estimation.

As EMC cools approximately 300 patients per year, the production volume would be relatively low. In general, this increases cost, the costs of molds will be divided by a lower volume and therefore the total cost will be higher.

The currently used external cooling methods at EMC cost more than €500 euros for the disposables. This first investigation of a cost estimation for a reusable cooling vest does not provide reason to increase the product cost significantly. Thus, a reusable cooling vest is expected to be possible in the same price range.

5.2.3 Prototypes

Several prototypes where made for this final concept. A yoga mat (Figure 90) was used for the final shape and ergonomic test, shown in Chapter 5.1.1. A prototype to show the look and feel was made out of a translucent showercurtain to show at the ICU (Figure 92). This material was also used for a larger size for an obese doll, see Figure 94. The showercurtain is expected to be less rigid than the final material of the product, thus the large amount of creases will not happen in the final product. The connection to the tubes was also prototyped for clear communication and visualisation, see Figure 93. Finally, a small piece of material was welded to test the tactility, pliability, and look of the final concept (Figure 91). This was done using transparant plastic which has similar properties to PE, therefore it is a valuable substitute. This similar material was used to create a small vest for Barbara (Figure 95).

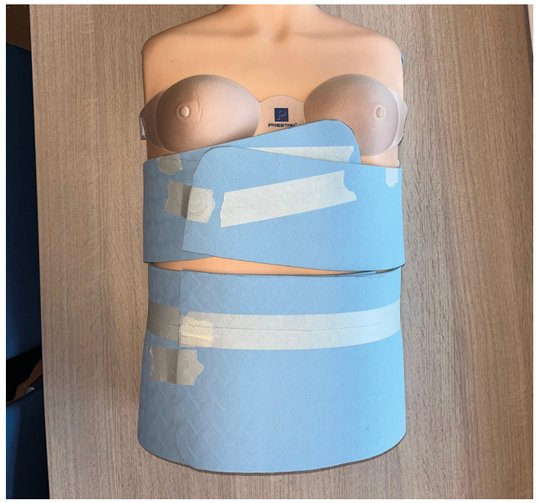


Figure 90: Yoga mat for ergonomics

Figure 91: Prototype with similar material & flow pattern integrated

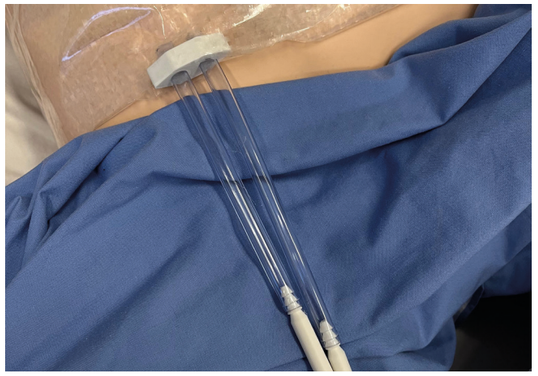


Figure 93: Prototype details

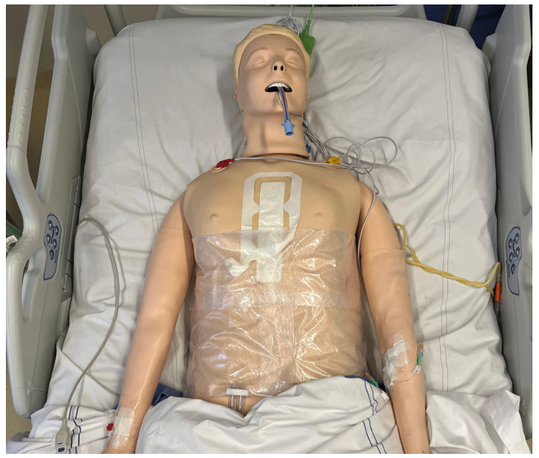


Figure 92: Prototype at ICU for the look & feel of concept

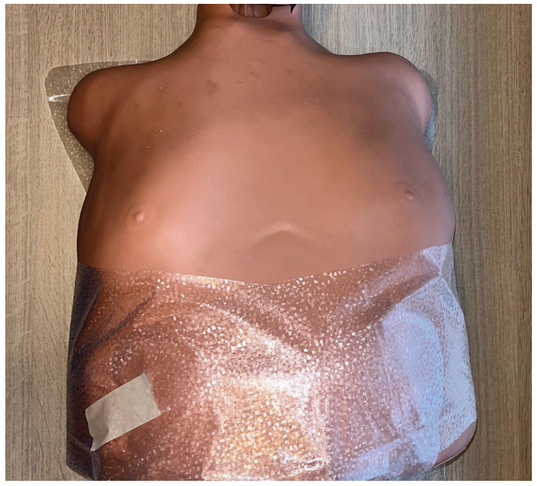


Figure 94: Prototype of shower curtain for size check on obese Fred

Figure 95: Scale prototype for Barbara

5.2.4 Evaluation

The Clinichill is evaluated on desirability, feasibility, viability and sustainability.

5.2.4.1 Desirability

The strength of this concept is its simplicity and ease of use. This reusable cooling vest was designed with the help and input of different stakeholders. The design requirements were based on their insights, which resulted in several important design decisions. As a result, the final design is in line with the wishes and needs of stakeholders such as nurses, doctors and infection preventionists. Moreover, the design is ergonomically tested for optimal comfort, there will be no impact on the patient's body by any ridges or pressure points. The shape is made to accommodate different body types.

This new design influences the workflow by introducing cleaning steps instead of disposing of the products. Whilst this takes more time, the cleaning is easy due to the simple shape and large areas of the product. Furthermore, the cleaning steps are the same as for other products in the hospital. This familiarity increases ease of use. Clear instructions on the workflow enhance the chances of successful implementation.

5.2.4.2 Feasibility

The suggested material of PE is widely available, recyclable, cheap and easy to manufacture. Moreover, the material is resistant to the cleaning chemicals used in the hospital and is water resistant, it can be manufactured as a pliable sheet, to allow for easy forming around different body shapes. The suggested manufacturing processes are also widely used and standard, making for a simple production process. PE can be finished with a smooth surface, which is needed for cleaning. Furthermore, rounded corners and lack of crevices are integrated for easy cleaning.

5.2.4.3 Viability

The estimated cost of this cooling vest is not significantly higher than the existing disposable products. The manufacturing processes and parts are relatively simple and can be done with a high level of automation. Since this cooling vest is compatible with the Arctic Sun system, the machine is already familiar at EMC. Three more Arctic Sun machines would be needed at ICU-6. As for operational viability, a minimum of seven vests per size are needed to accommodate the maximum amount of patients which can be cooled at the same time. If a patient is transferred to another hospital, a tracking system will keep track of the vests. An automatic inventory update will be of value for easy tracking and storage notices. While the amount of cooling treatments at EMC is relatively low per year, the impact of changing the cooling methods to reusable vests will decrease waste by more than 400kg per year. This significant decrease in waste results in less costs for waste disposal.

5.2.4.4 Sustainability

Since this design is reusable, the amount of disposables per treatment is significantly reduced. The three existing cooling methods amount to 1.3-1.5 kg of waste per treatment, whereas this reusable cooling vest only disposes of the nano tape and the tube connectors. The nano tape is not suitable for cleaning and disinfecting due to the embossment of suction cups in the material; the surface is not smoothly finished. More research can be done on making the tube connecters reusable, to include them in the cleaning process of the hospital.

The tube connectors and vest are made from a mono-material. This allows for recyclability. The two sheets of material are welded together. Adhesives are added between the tube in- and outlet to the vest, but this amount is minimal enough to be acceptable. According to the Green Team, 10% of a recyclable plastic product can be contaminated by adhesives.

Focusing on cooling only the torso decreases the amount of material used in the product, without compromising on the effectiveness of the care.

5.3 IMPLEMENTATION

Before implementation is possible, further verification is needed. Durability and hygiene should be validated, usability should be confirmed. The technical details, protocols, materials used and thermal and hygienic performances should be evaluated. Tests on life-time and amount of uses should be done to preserve the safe use of the product. Once the product is tested and found to be safe to use, a pilot at the ICU should be done, to finalise the design and its workflow.

For a successful implementation of this reusable cooling vest, several steps must be done. First of all, a manufacturer should invest in the concept. This is an opportunity for manufacturers to start or expand their portfolio of sustainable products. Offering reusable products will improve the manufacturer's name with regard to sustainability, which will secure their market position and brand. By investing in and offering reusable products, the profit model of the manufacturer will change significantly.

Furthermore, the clinical field should be accepting of reusable materials and be convinced of the product and patient safety. When transitioning from single-use to reusable medical products, hospitals must comply with established protocols to ensure patient safety and hygiene. After every use, the product should be severely cleaned to be safely reused for another patient without compromising their safety. Implementation of a validated reuse workflow is needed, including tracking of number of uses to ensure consistent performance throughout the product's lifespan. The product should adhere to the hospital's protocols of reusing products to ensure successful introduction.

6 CONCLUSION

This chapter concludes the project, answers the research question posed in the introduction and reflects on the project.

6.1 DISCUSSION

When companies are willing to set aside their profit model based on disposables, it certainly becomes possible to develop a reusable cooling vest that meets all hygiene requirements, such as the Clinichill.

The power of this reusable cooling vest is its simplicity. The design was made with the mindset 'less is more', since the need for, and value of, simplicity and familiarity was often mentioned by different stakeholders for a high chance of easy implementation.

Because of the simplicity of the design, the cooling vest is easy to use. It takes less time to install than the Arctic Sun and around the same amount of time as the STx Vest, but the important advantage of the Clinichill over the STx Vest is its reusability. This results in a significant decrease in material waste compared to the other methods in this thesis. Furthermore, removing the need to buy the disposables results in lower costs. Finally, the user experience of this vest is higher than both the Arctic Sun, due to removal of the adhesive layer, and the Thermogard due to lack of infection risk and easier installation. Since this reusable cooling vest is a type of external cooling, fluctuations in the target temperature remain. The amount of body tissue of the patient impacts this greatly.

The material of the vest is recyclable, which enhances the end-of-life value. For this to work, the vest should enter the plastic waste-stream in the hospital.

Reflecting back on the R-strategies, this design concept fits the strategies of reuse and recycle. By manufacturing the cooling vest from one thermoplastic material, several other materials are refused, which results in the product being recyclable. The change in TTM protocol, from a target temperature of maximum 36 degrees to preventing fever, allows refusal of starting treatment and rethinking the treatment. Only once the patient's temperature is rising does the patient need to be cooled. A possible future scenario of the Clinichill is two patients arriving after an OHCA, their temperatures are monitored. One patient remains 37 degrees and does not get a fever; no cooling vest is used. The other patient does eventually have a rising temperature, thus the Clinichill is installed to prevent fever. Currently, this scenario would involve two disposable sets of cooling methods. The future scenario includes only the use of one reusable cooling method; energy and materials are conserved.

While this project has shown that it is possible to create a reusable cooling vest, this remains a relatively small area of impact. The hospital industry remains dominated by disposable materials, most of which do not need to be disposable. It is time to challenge the norm of disposable products to create a more sustainable hospital environment and decrease our negative impact on climate change. Manufacturers must be woken up and rethink their defaults. However, pushing this mindset in motion is very difficult, mainly because disposables bring along convenient properties such as profit. This thesis shows that sustainable change is possible, and often more within reach than we think.

6.2 LIMITATIONS

The current ergonomic test was done on a relatively fit group of people containing only Dutch people. The databases used also contained relatively fit people, although the NASA databases are partly international, they are done on soldiers, which is one of the fittest segments of society. Oftentimes, patients in the ICU are less fit. Fred, the obese doll at EMC, was used to check the large size created, but this was the only plus-size which was tested. Thus, the shape and size of the pad would improve if more different body types were included.

Whilst several stakeholders were directly involved throughout this project, many other nurses, intensivists and people in the hospital were not directly involved. Gaining their insights throughout further iterations would be very valuable.

6.3 RECOMMENDATIONS

With Clinichill as a solution, around 300 disposable cooling products could be saved each year at Erasmus MC. However, to bring this product to market, much more research is still needed.

How long the vest can be used before end-of-life should be researched. For example, the durability of the seams after repeated use and cleaning should be tested. The safety of the patients should be protected at all times, thus extensive knowledge of the degradation of the product should be available. A digital passport of each vest might be valuable to add. Linking this to the inventory system, a warning can be programmed to let the purchasing department know when a new vest should be bought. The connection between the machine and the vest should be researched more; how long does it remain leak-free, how many times can it be used? Reusable tube connectors and disposable tube connectors should be assessed.

More testing on the best materials to use should be done. How durable is PE really, is it pliable enough to form nicely around the body, is it still recyclable after manufacturing? Is a mixture of different materials more valuable? Multilayer materials can be combined to achieve desirable properties. If a different material is introduced, the recyclability of the product will likely decrease. The trade-off between the product's function and end-of-life through recycling of material needs to be kept in mind. The current proposal is to make the material of the vest translucent, the preferred look of the vest needs to be investigated. A colour might make the vest look more kind, because of a higher sense of privacy, while a translucent or even transparant vest might make medical check-ups easier for staff.

The Clinichill does not have an isolating layer on the exterior preventing coldness from spreading to the air around the patient. Research will have to be done to check whether a thicker layer of material on the exterior side will prevent energy from spilling. A loose blanket could be placed around the patient's torso to keep the cold from escaping to the surroundings. The potential benefits of such an addition should be thoroughly investigated, as well as whether it is worth investing in an extra layer of insulation compared to simply cooling the surrounding air.

More user tests should be done in the future. Does the nano tape work sufficiently enough? Or is standard medical tape preferred? Several tests with regard to hygiene should be done as well. Both for the exterior of the pad, as well as the interior of the system. Does the vest allow for sufficient cleaning, preserving the hygiene and safety? Does the inside of the system get infected by the patient or medical staff? At which intervals does the fluid in the system need to be refreshed, can the insides be cleaned and disinfected?

Testing will have to be done on the inner structure of the vest. Currently, the design is two flat sheets pressed together, the fluid inside will create its own pathway by pushing the two sheets apart. Another possible design is creating solid structures in the pad, by implementing a material such as PE foam, through which the fluid can flow. Tests will have to show if there is a significant change in cooling abilities.

The Clinichill is proposed in three different sizes, for adults. Disposable cooling pads exist for neonatals, infants and children. If the reusable pad proves successful, the next step would be to introduce sizes tailored to these patient groups as well. Additionally, it would be valuable to explore different body shapes to ensure the best possible fit; triangle-shaped bodies and pear-shaped bodies require differently shaped vests for optimal connection between vest and body. While the Clinichill aims to fit all, it might be valuable to investigate the different shapes for different body types possible.

6.4 PERSONAL REFLECTION

The difference between previous coursework in Industrial Design Engineering and this thesis project was the place in the organisation I took. Transitioning from mostly theoretical coursework with weekly guidance meetings from a coach, to a real hospital environment of which I became a part and where I had to stand on my own, was both challenging and very fulfilling.

Working in a hospital environment meant navigating diverse opinions of different stakeholders in a high-pressure environment. Shadowing medical staff was very insightful for me, to get familiar with the context and learn all the stakes involved in a design project for the ICU.

During the project, several personal circumstances were of influence on me and my project, but with clear communication with my supervisory team, this was handled well in my opinion. Clear communication was one of my goals of this project. Especially since this project involved a lot of stakeholder management, communication was very important. I think I succeeded, I got to talk to many different people and communication was clear, including expectations and time indications. Other goals I had for myself throughout this project were learning about co-creation and improving my visual communication skills. I had two sessions on co-creation to get familiar with the topic, one was an explanatory session and one was hosted by a graduate colleague. While the concept of co-creation in terms of a group of different stakeholders together at the same time, seems very valuable, I quickly decided that I wanted to speak to stakeholders directly. Due to high workload and lack of time in hospital workers, this seemed a way of working with less resistance and quicker contact. I did take insights from the first stakeholder, to the second, to the third etc. In that way, I represented all stakeholders to other stakeholders. During the project I worked a lot on visualisations and throughout the project I feel like I became better at communicating through visuals; which information was needed and which was not needed, where did I want attention to focus, etc.

At some moments in the project, I missed having group members working on the same project. When motivation is low in a project, usually, the energy of group members will help to continue with the project. My fellow graduation students were the next best thing and especially Anna en Leo were very involved in my project, so they were wonderful to talk to during these moments. I did realise that working solo on a project for several months can feel quite solitary, I would prefer working in a team.

Furthermore, during this project I once more came across my own pitfalls. However, I was-and am-aware of them so I can try to anticipate them. For example, I have trouble leaving the Discover phase of projects. I noticed this happened again and I communicated about this, after which my supervisory team encouraged me to continue to the next phase.

Overall, I enjoyed working on this thesis and at EMC. The experience pushed me to become a more adaptable, thoughtful, and responsible designer.

6.5 USE OF AI

During this thesis, ChatGPT and Copilot were mainly used for general writing assistance, by editing and improving English phrasing. Furthermore, for some pieces of text, AI was used to rewrite content for clarity, which was then used as an inspiration. Sometimes, AI was used as a brainstorming partner, but this was not experienced as positive or helpful. Finally, some images were created with the help of AI. For example, an image of a patient lying in a hospital bed was created by AI since there were no clear images available on the internet.

7 REFERENCES

The lst of references used throughout the project can be found below.

REFERENCES

367218 • BD® ProntoTM Reusable Tourniquet/Kimetec® CBC Classic Tourniquet, Latex-Free, NON-STERILE • 6pcs. (n.d.). Dalsup B.V. https://shop.dalsup.com/producten/bloedafname-en-toebehoren/367218-%E2%80%A2-bd-pronto-reusable-tourniquetkimetec-cbc-classic-tourniquet-latex-free-non-sterile-%E2%80%A2-6pcs-4591-/

AEDwinkel. (2024, February 23). Verschil tussen een ICD en een pacemaker | AEDwinkel.nl. *Medisol*. https://www.aedwinkel.nl/blog/post/wat-is-het-verschil-tussen-een-icd-en-een-pacemaker?srsltid=AfmBOorFGXtGZpTIhd7ijqiBIgz6ojiyrSVgB7P784IRFsK-TOohTb8X

Alsius Coorporation. (2003). *510(K) Summary: Alsius Corportation's ThermogardTM I Cool LineTM Catheter Thermal Regulation System.* Retrieved October 22, 2025, from https://www.accessdata.fda.gov/cdrh_docs/pdf/k014241.pdf

Arctic SunTM 5000 Temperature Management System | BD. (n.d.). Retrieved September 5, 2025, from https://www.bd.com/en-uk/products-and-solutions/products/product-families/arctic-sun-5000-temperature-management-system#overview

Arctic SunTM 5000-temperatuurmanagement systeem | BD Nederland. (n.d.). https://www.bd.com/nl-nl/products-and-solutions/products/product-families/arctic-sun-5000-temperature-management-system#arcticgelpads

Arnot, R. (2022, May 10). Medical Devices – Reusable vs Disposable Tourniquets. Westlab Health. https://health.westlab.com/news/reusable-vs-disposable-tourniquets

Aujla, G. S., Nattanmai, P., Premkumar, K., & Newey, C. R. (2016). Comparison of two surface cooling devices for temperature management in a neurocritical care unit. *Therapeutic Hypothermia and Temperature Management*, 7(3), 147–151. https://doi.org/10.1089/ther.2016.0031

BARD medical. (n.d.). *ArcticGel hydrogel coated pads*. Medicalexpo. Retrieved October 22, 2025, from https://pdf.medicalexpo.com/viewerCatalog/bard-medical/arcticgel/78646-133272.html#open

Bartlett, E. S., Valenzuela, T., Idris, A., Deye, N., Glover, G., Gillies, M. A., Taccone, F. S., Sunde, K., Flint, A. C., Thiele, H., Arrich, J., Hemphill, C., Holzer, M., Skrifvars, M. B., Pittl, U., Polderman, K. H., Ong, M. E., Kim, K. H., Oh, S. H., . . . Nichol, G. (2019). Systematic review and meta-analysis of intravascular temperature management vs. surface cooling in comatose patients resuscitated from cardiac arrest. *Resuscitation*, 146, 82–95. https://doi.org/10.1016/j.resuscitation.2019.10.035

Biocompatible Material. (n.d.). ScienceDirect. Retrieved October 28, 2025, from https://www.sciencedirect.com/topics/medicine-and-dentistry/biocompatible-material#:~:text=Biocompatible%20materials%20are%20defined%20as,upon%20interaction%20with%20surrounding%20tissues.

Bort medical ribbrace man. (n.d.). All4Fysio. https://www.all4fysio.nl/bort-medical-ribbrace-man

Catheter Family - Netherlands. (n.d.). https://www.zoll.com/nl-nl/producten/critical-care/temperature-management/catheter

CBS. (2022, September 9). *Hoe lang zijn Nederlanders? - Nederland in cijfers 2022*. Hoe Lang Zijn Nederlanders? - Nederland in Cijfers 2022 | CBS. https://longreads.cbs.nl/nederland-in-cijfers-2022/hoe-lang-zijn-nederlanders/

Cleveland Clinic Medical. (2025, September 30). *Hypothalamus*. Cleveland Clinic. Retrieved October 6, 2025, from https://my.clevelandclinic.org/health/body/22566-hypothalamus

Company Overview: About ZOLL Medical. (n.d.). https://www.zoll.com/en-us/about

Cooling techniques for targeted temperature management. (n.d.). https://www.ahajournals.org/doi/10.1161/JAHA.122.026539

De berekening van het effect van de Nederlandse zorg op het milieu. Methoderapport | RIVM. (2025, April 17). https://www.rivm.nl/publicaties/berekening-van-effect-van-nederlandse-zorg-op-milieu-methoderapport

De Fazio, C., Skrifvars, M. B., Søreide, E., Creteur, J., Grejs, A. M., Kjærgaard, J., Laitio, T., Nee, J., Kirkegaard, H., & Taccone, F. S. (2019). Intravascular versus surface cooling for targeted temperature management after out-of-hospital cardiac arrest: an analysis of the TTH48 trial. *Critical Care, 23*(1). https://doi.org/10.1186/s13054-019-2335-7

De Nederlandse Hartstichting. (n.d.-a). *Cijfers hart- en vaatziekten | Hartstichting*. Retrieved September 3, 2025, from https://www.hartstichting.nl/hart-en-vaatziekten/cijfers-hart-en-vaatziekten

De Nederlandse Hartstichting. (n.d.-b). *Dotter- en stentbehandeling | Hartstichting*. https://www.hartstichting.nl/hart-en-vaatziekten/behandelingen/dotter-en-stentbehandeling

Dekker, M. M. C., & Molenbroek, J. F. M. (1999). Collecting and Deriving Data for Human Modeling Software to use in Flight Simulator Design. *SAE Technical Papers on CD-ROM/SAE Technical Paper Series, 1*. https://doi.org/10.4271/1999-01-1887

Ecplastics, Ecplastics, & Ecplastics. (2024, July 18). *What are the True Costs of Plastic Extrusion?* EC Custom Plastics -. https://ecplastics.com/what-are-the-true-costs-of-plastic-extrusion/

EM-MED Sp. z o.o. Sp. K. (2021). *TARGETED TEMPERATURE MANAGEMENT*. https://www.centralmedical.co.uk/wp-content/uploads/2024/09/TrueCool_catalogue_en_version_2.0_triptych_spread.pdf

Endovascular catheter cooling via CoolGard 3000TM and Icy femoral cathether TM, Alsius Corp., Irvine, USA. (n.d.). https://www.researchgate.net/figure/Endovascular-catheter-cooling-via-CoolGard-3000TM-and-Icy-femoral-cathether-TM-Alsius_fig5_224830288

Erasmus MC. (n.d.). *Intensive Care (IC) Volwassenen: Over*. Retrieved September 16, 2025, from https://www.erasmusmc.nl/nl-nl/patientenzorg/klinieken/intensive-care-volwassenen#f7ca5365-5cda-47da-82c0-a58e1c336b48

European Commission. (2022). *Restrictions Roadmap under the Chemicals Strategy for Sustainability*.

Fukuda, T. (2016). Targeted temperature management for adult out-of-hospital cardiac arrest: current concepts and clinical applications. *Journal of Intensive Care*, 4(1), 30. https://doi.org/10.1186/s40560-016-0139-2

Gentherm. (2025, November 24). *Blanketrol® III System Hypo-Hyperthermia Device - Gentherm Medical*. https://gentherm.com/en/medical/blanketrol-3/

Glover, G. W., Thomas, R. M., Vamvakas, G., Al-Subaie, N., Cranshaw, J., Walden, A., Wise, M. P., Ostermann, M., Thomas-Jones, E., Cronberg, T., Erlinge, D., Gasche, Y., Hassager, C., Horn, J., Kjaergaard, J., Kuiper, M., Pellis, T., Stammet, P., Wanscher, M., . . . Nielsen, N. (2016). Intravascular versus surface cooling for targeted temperature management after out-of-hospital cardiac arrest – an analysis of the TTM trial data. *Critical Care*, 20(1). https://doi.org/10.1186/s13054-016-1552-6

Gore Medical Products Division. (n.d.). *CBAS® Heparin Surface Technology | Gore Medical EMEA*. https://www.goremedical.com/en-emea/cbas-material-technology

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., & Walker, R. A. (1989). *1988 anthropometric survey of U.S. Army personnel: Methods and summary statistics* (NATICK/TR-89/044). Anthropology Research Project, Inc.

Granta Edupack 2025 R2. (n.d.). [Dataset]. In Level 2. ANSYS.

Green Deal Zorg. (2025). *Achtergrond*. Green Deal Duurzame Zorg. Retrieved December 23, 2025, from https://www.greendealduurzamezorg.nl/green-deal/achtergrond/

Greif, R., Lauridsen, K. G., Djärv, T., Ek, J. E., Monnelly, V., Monsieurs, K. G., Nikolaou, N., Olasveengen, T. M., Semeraro, F., Spartinou, A., Yeung, J., Baldi, E., Biarent, D., Djakow, J., Van Gils, M., Van Goor, S., Gräsner, J., Hogeveen, M., Karageorgos, V., . . . Nolan, J. P. (2025). European Resuscitation Council Guidelines 2025 Executive Summary. *Resuscitation, 215*, 110770. https://doi.org/10.1016/j.resuscitation.2025.110770

Guide to manufacturing processes for Plastics. (n.d.). Formlabs. https://formlabs.com/blog/guide-to-manufacturing-processes-for-plastics/

Hartstichting. (2025a, February 11). *Hartstilstand*. https://www.hartstichting.nl/hart-en-vaatziekten/hartstilstand

Hartstichting. (2025b, April 14). *ICD*. https://www.hartstichting.nl/hart-en-vaatziekten/behandelingen/icd

Heard, K. J., Peberdy, M. A., Sayre, M. R., Sanders, A., Geocadin, R. G., Dixon, S. R., Larabee, T. M., Hiller, K., Fiorello, A., Paradis, N. A., & O'Neil, B. J. (2009). A randomized controlled trial comparing the Arctic Sun to standard cooling for induction of hypothermia after cardiac arrest. *Resuscitation, 81*(1), 9–14. https://doi.org/10.1016/j.resuscitation.2009.09.015

Het effect van de Nederlandse zorg op het milieu. Methode voor milieuvoetafdruk en voorbeelden voor een goede zorgomgeving | RIVM. (2022, October 3). Retrieved December 23, 2025, from https://www.rivm.nl/publicaties/effect-van-nederlandse-zorg-op-milieu-methode-voor-milieuvoetafdruk-en-voorbeelden-voor

Idemat 2017. (n.d.). [Dataset].

Islam, S., Hampton-Till, J., Watson, N., Mannakkara, N. N., Hamarneh, A., Webber, T., Magee, N., Abbey, L., Jagathesan, R., Kabir, A., Sayer, J., Robinson, N., Aggarwal, R., Clesham, G., Kelly, P., Gamma, R., Tang, K., Davies, J. R., & Keeble, T. R. (2015). Early targeted brain COOLing in the cardiac CATHeterisation laboratory following cardiac arrest (COOLCATH). *Resuscitation, 97*, 61–67. https://doi.org/10.1016/j.resuscitation.2015.09.386

Koop, L. K., & Tadi, P. (2023, July 17). *Physiology, heat loss.* StatPearls - NCBI Bookshelf. https://www.ncbi.nlm.nih.gov/books/NBK541107/#:~:text=Mechanism,100%20times%20that%20of%20air

Liao, X., Zhou, Z., Zhou, M., Tang, H., Feng, M., Kou, B., Zhu, N., Liao, F., & Wu, L. (2020). Effects of endovascular and surface cooling on resuscitation in patients with cardiac arrest and a comparison of effectiveness, stability, and safety: a systematic review and meta-analysis. *Critical Care, 24*(1). https://doi.org/10.1186/s13054-020-2731-z

Look, X., Li, H., Ng, M., Lim, E. T. S., Pothiawala, S., Tan, K. B. K., Sewa, D. W., Shahidah, N., Pek, P. P., & Ong, M. E. H. (2017). Randomized controlled trial of internal and external targeted temperature management methods in post- cardiac arrest patients. *The American Journal of Emergency Medicine*, 36(1), 66–72. https://doi.org/10.1016/j.ajem.2017.07.017 Luchtbed ENGHAVE B130xL190xH23 | JYSK. (2022, August 11).

MakerVerse. (2025, July 17). *How much injection molding costs*. MakerVerse. https://www.makerverse.com/resources/injection-molding/how-much-injection-molding-costs/#:~:text=services%20like%20MakerVerse.-,Cost%20of%20Injection%20Molds,compatible%20only%20with%20metal%20molds.

Mayer, S. A., Kowalski, R. G., Presciutti, M., Ostapkovich, N. D., McGann, E., Fitzsimmons, B., Yavagal, D. R., Du, Y. E., Naidech, A. M., Janjua, N. A., Claassen, J., Kreiter, K. T., Parra, A., & Commichau, C. (2004). Clinical trial of a novel surface cooling system for fever control in neurocritical care patients*. *Critical Care Medicine, 32*(12), 2508–2515. https://doi.org/10.1097/01.ccm.0000147441.39670.37

Medi Care System, S.L.U. (2022). QUICK RETENTION SYSTEM (Patent) [Patent]. In *SISTEMA DE RETENCIÓN RÁPIDA*. Patent ES1133355U. https://medicaresystem.es/wp-content/uploads/2025/08/Catalogo_SALVAFAST_ENG-ESP.pdf

Miao, B., Skaar, J. R., O'Hara, M., Post, A., Kelly, T., & Abella, B. S. (2023). A systematic literature review to assess fever management and the quality of targeted temperature management in critically ill patients. *Therapeutic Hypothermia and Temperature Management, 14*(2), 68–79. https://doi.org/10.1089/ther.2023.0015

Nanotape bestellen - Nanotape. (n.d.). https://www.nanotape.nl/

Nedlin. (n.d.). *Meer winst met Nedlin reusables.* https://www.nedlin.com/sites/default/files/2022-07/Nedlin%20reusables%20-%20brochure.pdf

Non invasive blood pressure cuffs (NIBP) | Draeger. (n.d.). https://www.draeger.com/en_aunz/Products/Non-invasive-blood-pressure-cuffs

NTR, Klokhuis (Director). (2024, July 4). *Lichaamstemperatuur*. Retrieved October 6, 2025, from https://hetklokhuis.nl/tv-uitzending/5478/lichaamstemperatuur

Our company | BD. (n.d.-a). Retrieved September 5, 2025, from https://www.bd.com/en-uk/about-bd/our-company#aboutbd

Our company | BD. (n.d.-b). Retrieved September 5, 2025, from https://www.bd.com/en-uk/about-bd/our-company#segments

Polyethylene Cost Guide: Price for resin, film, and more 2026 – Design Transition Studio. (2026, March 17). https://designtransitionstudio.com/polyethylene-cost-price-resin-film-more/

Post cardiac arrest zorg op de ICV/Hartbewaking (Versie 3). (n.d.). Zenya. Retrieved October 21, 2025, from https://erasmusmc.zenya.work/portal/#/document/8abof023-f10b-4e11-bcf8-odd4004ed6fo?portalId=231

Protocol CoolGard: Post cardiac arrest zorg op de ICV/hartbewaking. (n.d.). Zenya. Retrieved October 26, 2026, from https://erasmusmc.zenya.work/portal/#/document/8abof023-f10b-4e11-bcf8-odd4004ed6fo?portalId=231

PVC's time is up – also in the medical sector | Health Care Without Harm - Europe. (2025, June 30). https://europe.noharm.org/news/pvcs-time-also-medical-sector

Quatro catheter. (n.d.). https://paramedica.pl/products/zoll-thermogard-xp%C2%AE-ivtm%E2%84%A2

Ramadanov, N., Arrich, J., Klein, R., Herkner, H., & Behringer, W. (2022). Intravascular versus surface cooling in patients resuscitated from cardiac arrest: a systematic review and Network Meta-Analysis with focus on temperature feedback. *Critical Care Medicine, 50*(6), 999–1009. https://doi.org/10.1097/ccm.0000000000005463

Redactie. (2025, March 5). Arm moet omhoog bij bloeddrukmeting. *Gezondheidsnet*. https://www.gezondheidsnet.nl/bloeddruk/arm-moet-omhoog-bij-bloeddrukmeting

Reusable tourniquet - NoJerm. (2025, October 7). Nojerm. https://nojerm.com/reusable-tourniquet/

Reusables | Nedlin. (n.d.). Nedlin. https://www.nedlin.com/en/healthcare/reusables

RIVM. (n.d.). *Reiniging, desinfectie en sterilisatie in de openbare gezondheidszorg | LCI-richtlijn*. https://lci.rivm.nl/richtlijnen/reiniging-desinfectie-sterilisatie

Rosman, J., Hentzien, M., Dramé, M., Roussel, V., Just, B., Jolly, D., & Mateu, P. (2016). A comparison between intravascular and traditional cooling for inducing and maintaining temperature control in patients following cardiac arrest. *Anaesthesia Critical Care & Pain Medicine, 37*(2), 129–134. https://doi.org/10.1016/j.accpm.2016.08.009

R-Strategies for a Circular Economy. (n.d.). https://www.circularise.com/blogs/r-strategies-for-a-circular-economy

Shinada, T., Hata, N., Yokoyama, S., Kobayashi, N., Tomita, K., Shirakabe, A., Tsurumi, M., Okazaki, H., & Yamamoto, Y. (2013). Usefulness of a surface cooling device (Arctic Sun®) for therapeutic hypothermia following cardiac arrest. *Journal of Cardiology, 63*(1), 46–52. https://doi.org/10.1016/j.jjcc.2013.06.013

Staff of Anthropology Research Project. (1978). *Anthropometric source book: Vol. II. A handbook of anthropometric data* (NASA Reference Publication 1024). NASA.

Sticker Residue Won't Budge? Try These 8 Fixes blog. (n.d.). https://www.stickerit.co/en-us/blog/remove-sticker-residue

Stuwband kopen? | Merkala.nl. (n.d.). Merkala. https://www.merkala.nl/stuwband.html

Thermogard. (n.d.). Tri DM. https://tridm.com/en/producto/thermogard-xp-tgxp-temperature-management-en/

Thermogard temperature system. (n.d.). Medical Expo. https://www.medicalexpo.de/prod/zoll-medical-corporation/product-70628-520618.html

Thermogard-XP. (n.d.). https://www.zoll.com/de-de/products/critical-care/temperature-management/thermogard-xp

Tristel Solutions Limited. (2025, November 17). *daisygrip - The Reusable Tourniquet*. Tristel - United Kingdom - EN. https://tristel.com/product/daisygrip/

UMCNL voor medewerkers. (2023). [Salarisschalen bijlagen]. In *UMCNL*. https://www.umcmedewerkers.nl/app/uploads/sites/2/2025/10/Salarisschalen-cao-umcs-2024-2025.pdf?utm_

Umcu. (n.d.). Herkennen en voorkomen van Decubitus. UMC Utrecht. https://www.umcutrecht.nl/nl/voorlichting/herkennen-en-voorkomen-van-decubitus/folder

Vaity, C., Al-Subaie, N., & Cecconi, M. (2015). Cooling techniques for targeted temperature management post-cardiac arrest. *Critical Care, 19*(1). https://doi.org/10.1186/s13054-015-0804-1

Vargas, M., Sutherasan, Y., Servillo, G., & Pelosi, P. (2015). What is the proper target temperature for out-of-hospital cardiac arrest? *Best Practice & Research Clinical Anaesthesiology, 29*(4), 425–434. https://doi.org/10.1016/j.bpa.2015.09.003

Yartsev, A. (n.d.). *Mechanisms for heat transfer*. Deranged Physiology. https://derangedphysiology.com/main/cicm-primary-exam/thermoregulation/Chapter-111/mechanisms-heat-transfer

ZOLL. (n.d.). *InnerCool STx Surface Pad System*. Retrieved October 22, 2025, from https://pdf.medicalexpo.com/viewerCatalog/zoll-medical-corporation/stx/70628-161269.html#open1074566

ZOLL. (2015). *Total Temperature Management Solution*. Retrieved November 20, 2025, from https://pdf.medicalexpo.com/viewerCatalog/zoll-medical-corporation/tgxp-stx/70628-161271.html#open1074566

ZOLL Circulation, Inc. (2009). Operation Manual. In *ZOLL*.

8 APPENDICES

This chapter contains several supporting appendices for this thesis.

APPENDIX 1: REVENUE AND EMPLOYEES OF COMPETITORS

BD is second largest company in employees and in the top five with their revenue. Zoll is a smaller company. Zoll focusses mainly on cardiac products, whereas BD has a bigger product portfolio.

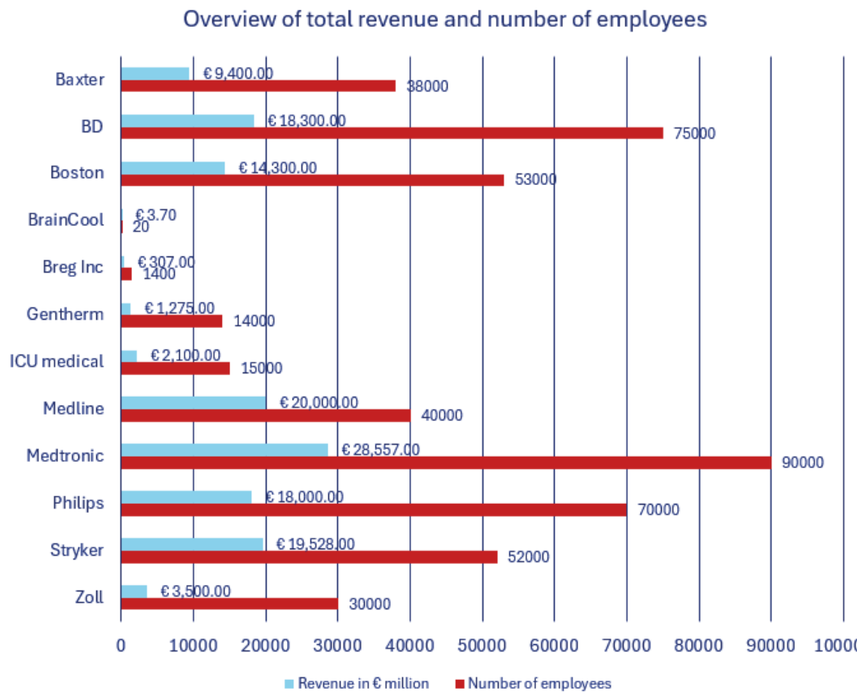


Figure 96: Revenue shares of companies active in internal and external TTM

APPENDIX 2: FIRST DIAMOND

HCY cool a human

To start the first ideation, inspiration was sought from the how-can-you method on the topic of cooling a human (Figure 97), and other fields of cooling humans (Figure 98).

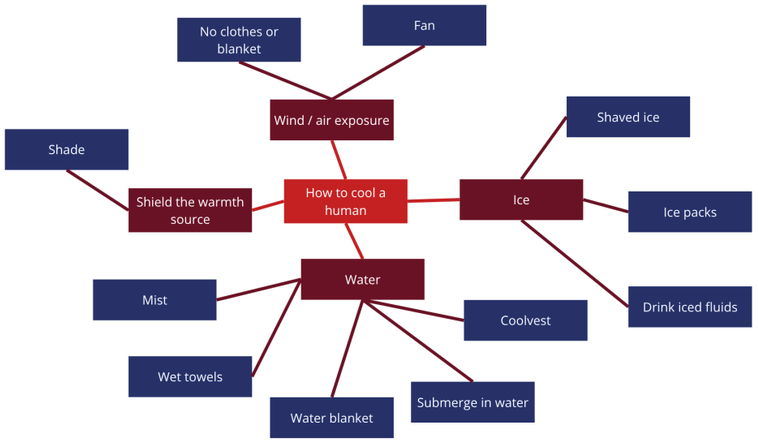


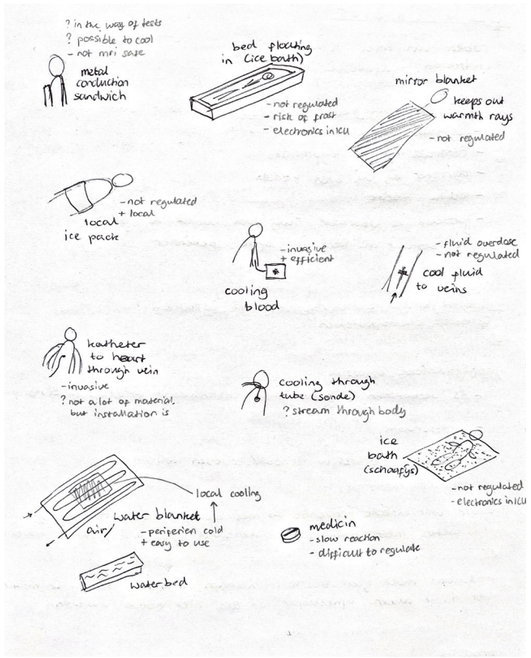
Figure 97: How can you cool a human

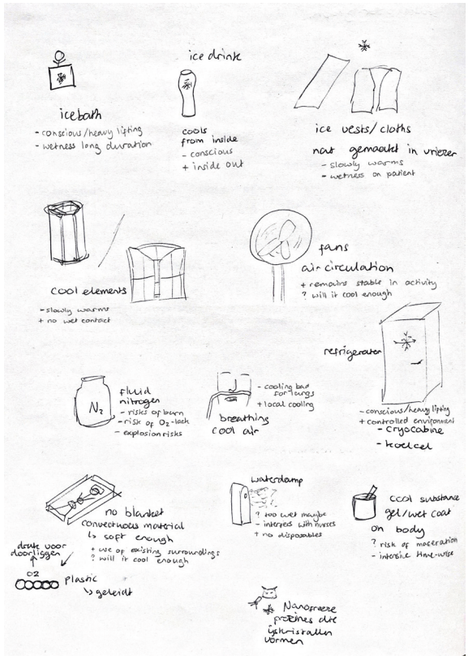
Existing fields of cooling a human

Then, first ideas for a cooling method were created, after which the PMI-method was used to gain insights into the identified methods and their values and weaknesses. To gain a better understanding of interesting and promising ideas, but also an overview of bad ideas, the PMI-method was used, which highlights positive, negative and interesting factors of the ideas.

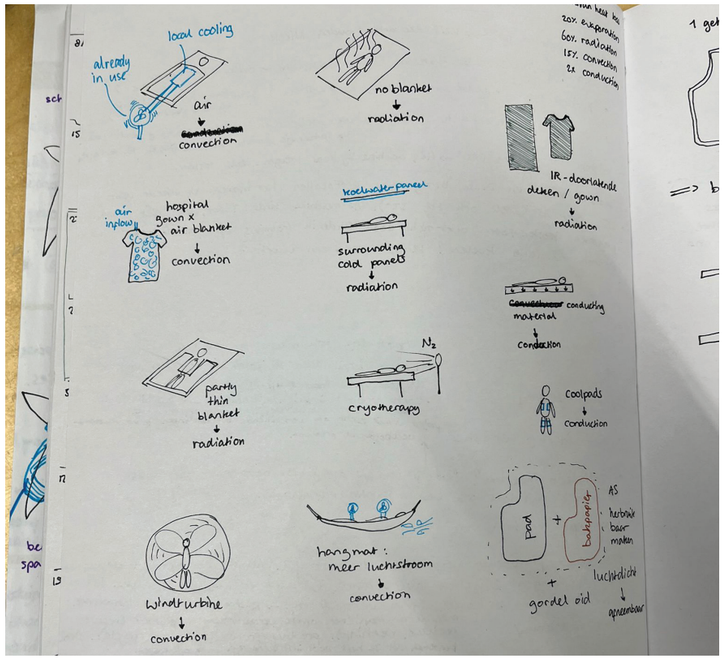
Figure 98: Other fields of cooling humans

First ideas





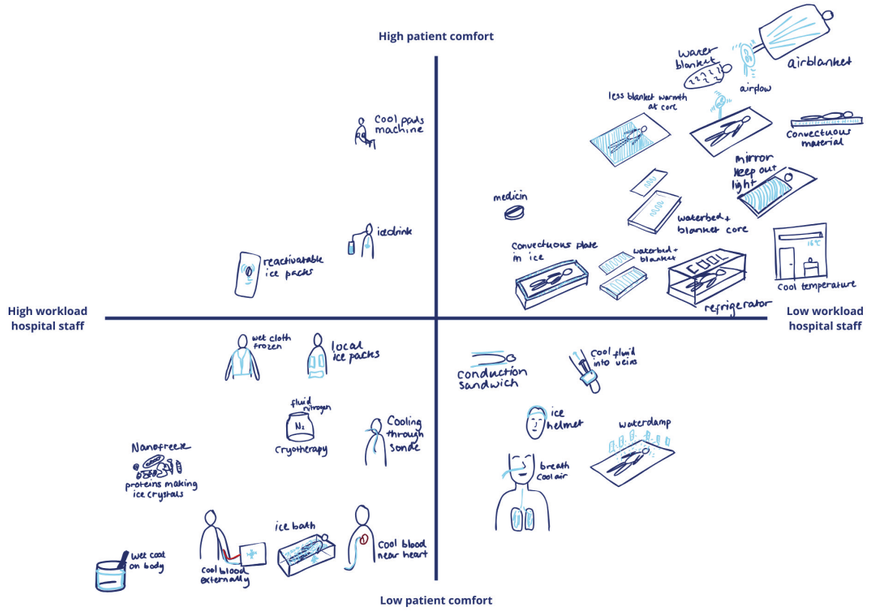
Keeping in mind the different mechanisms of heat loss in humans, several ideas were categorised into these different mechanisms. Aiming for a product with a high heat loss mechanism would increase sustainability, however, since the main requirement of the method is being able to cool actively, this weighs higher than a high mechanism.

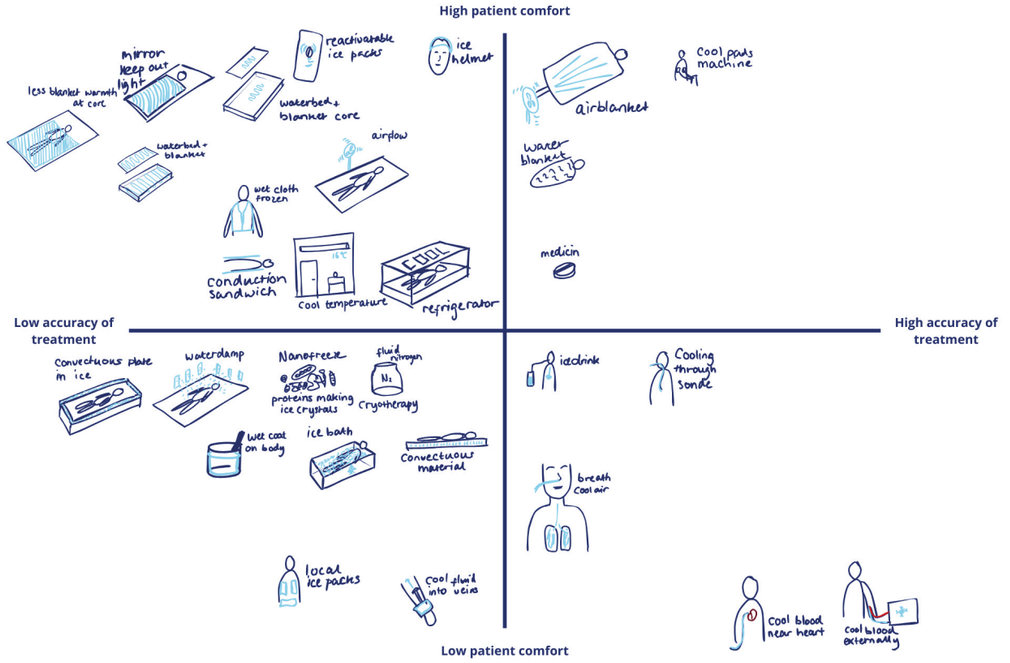


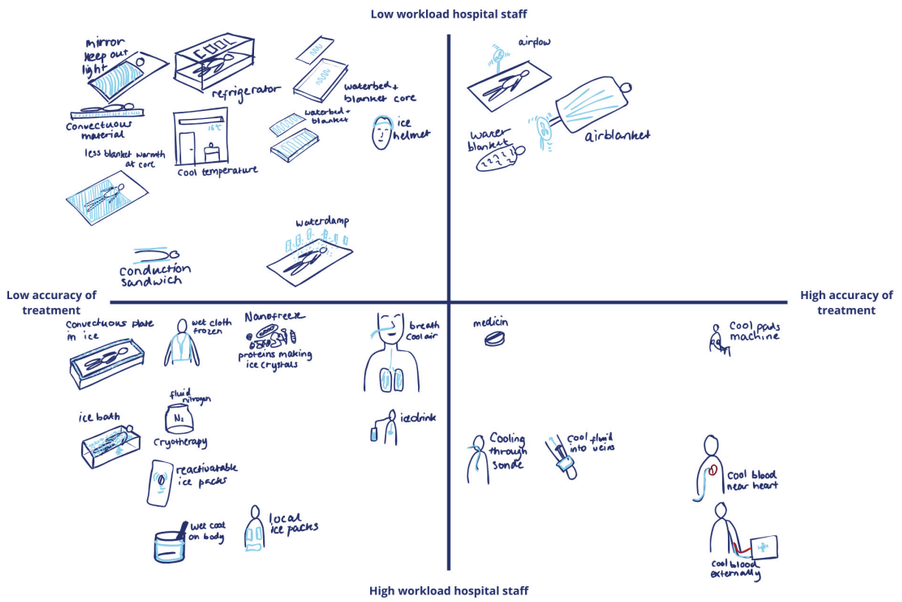
Mechanisms of heat loss in ideas

C-boxes

The first ideas created were evaluated in three different c-boxes to see how they score with regard to patient comfort, workload on hospital staff, and accuracy of treatment, each c-box has a different combination of the three pillars. Ideas which have a high patient comfort, low workload and high accuracy of treatment are preferred.

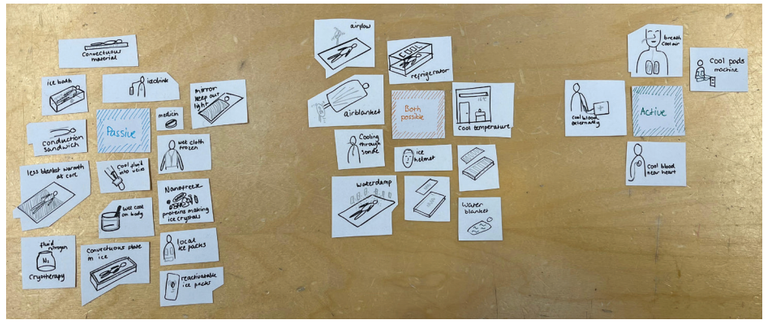




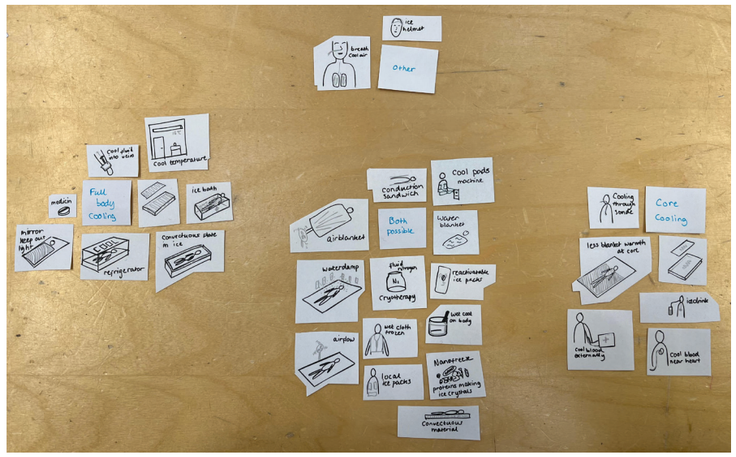


Evaluating ideas on requirements

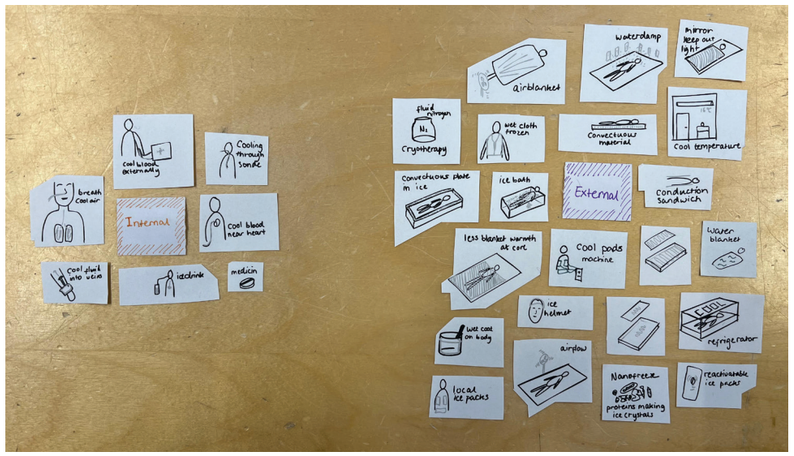
The first ideas were then evaluated on five essential requirements.



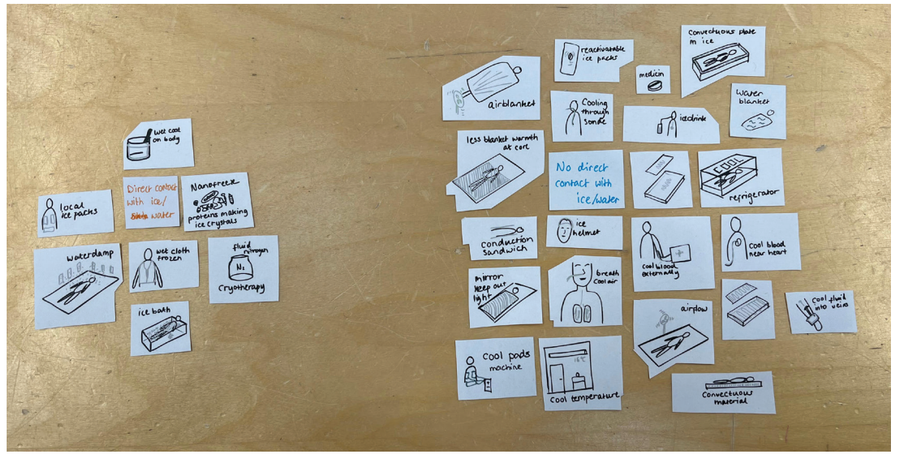
The way of cooling was divided into passive, active or both possible



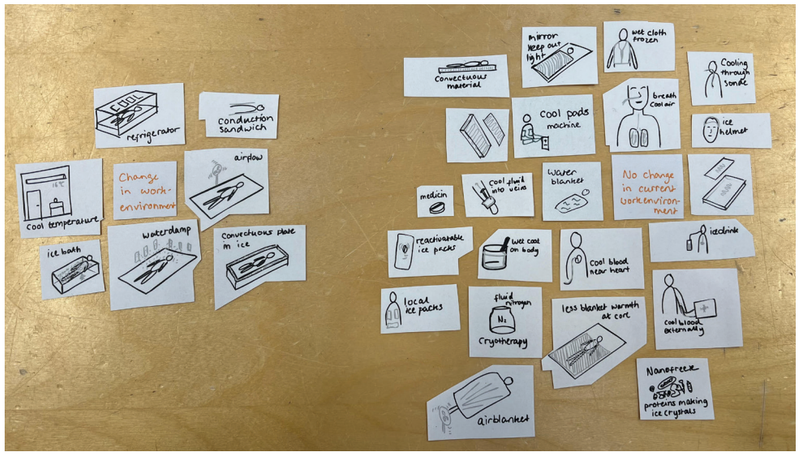
The area of cooling was divided into core cooling, full-body cooling, both possible or other



The cooling methods were divided into internal or external cooling

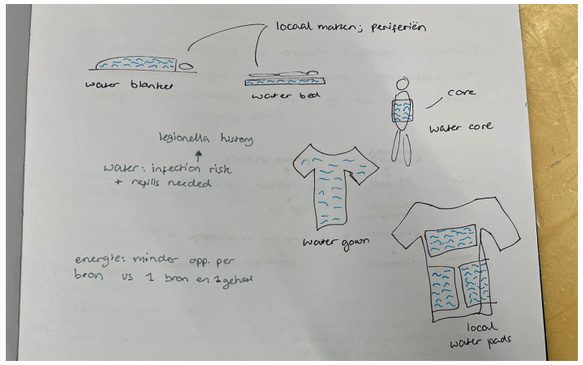


The skin does not come in contact with fluids or ice, for risk of maceration and freezing

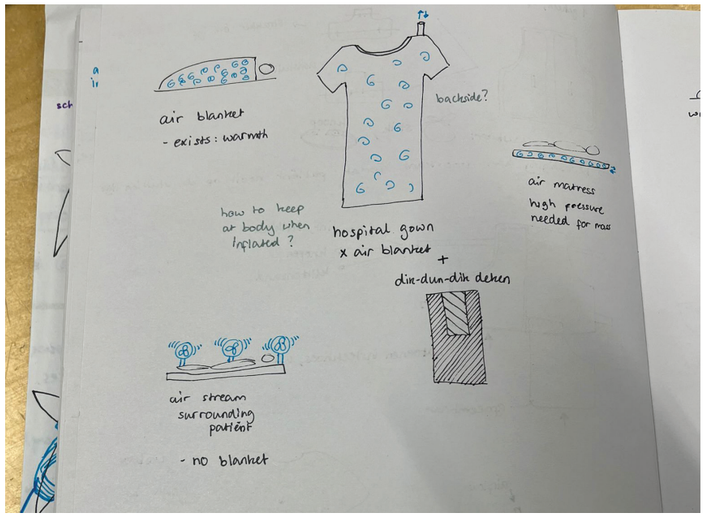


There are no drastic changes in work environment for medical staff

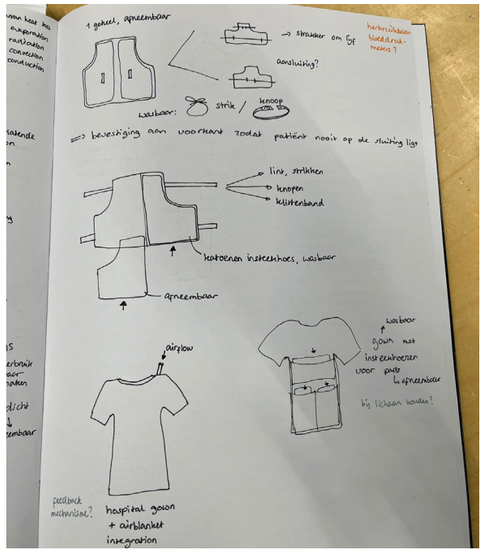
APPENDIX 3: SECOND DIAMOND



Watereds and blankets



Airbeds and blankets



Cooling pads

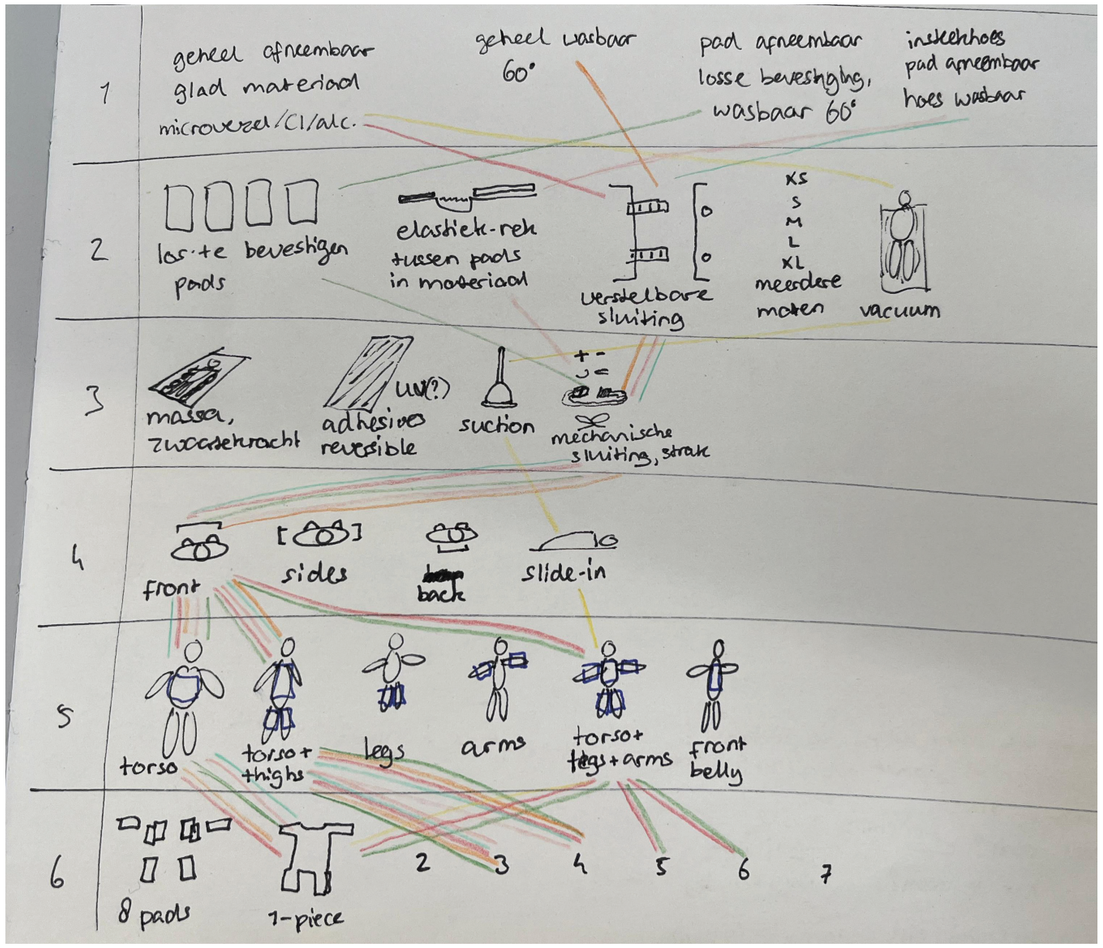
APPENDIX 4: THIRD DIAMOND

Morphological chart

Further ideation of cooling pads was started based on a morphological chart. The main subfunctions identified were:

- The pads should be cleanable
- The pads should be adjustable to body size
- The pads should be kept in contact with the body
- The locations of closure systems of the pads
- The pads should cover the body
- The amount of pads

This morphological chart resulted in several ideas. However, not all were feasible given the surroundings of the product. For example, a fully wipeable cooling mechanism based on a vacuum to keep in contact with the patient's skin is not usable in the setting of use, due to the patient's skin needing to be available for medical tests and care. Furthermore, the attachment of the cooling mechanism was determined to be on the front of the body, and cooling only the torso was proven sufficient enough, so to aim for as little material as possible, this is the preferred placement of pads.



Morphological chart

APPENDIX 5: ERGONOMICAL DATA

The DINED database did not provide all the measurements needed, thus other databases were also researched. Based on the current length of Dutch citizens (CBS, 2022) and the conversion theory presented by Dekker and Molenbroek (1999), the measurements described by NASA (1978) and Gordon et al. (1989) can be translated to current Dutch citizens. For example, mean length of males in the database by Gordon et al. is 175.58 cm, 20-30 is the most common age group whereas the mean length of Dutch males of +25 years old is 182.9 cm. The factor necessary for conversing measurements of this database to Dutch males is therefore 4.2%. This conversion is only used for length measurements, since breadth, depth and circumference measurements are less consistent between populations and have different conversion factors.

Table 5: DINED database, Dutch population, aged 20-97, measurements in centimetres.

	Total	Female	Male
Hip circumference	84 – 142	84 – 142	85 – 130
Waist circumference	54 – 136	54 – 136	66 - 134
Shoulder breadth	36 – 51	36 – 48	40 – 51
Shoulder height	48 – 68	48 – 63	53 – 68

Table 6: Measurements of US military forces measured in 1988, with 1774 men and 2208 woman (Gordon et al., 1989)

	Original measurement		Conversed measurement		Total range of (conversed) measurements
	Female	Male	Female	Male	
Biacromial breadth (10)	30.10 – 41.70	33.00 – 45.10			30.10 – 45.10
Waist back length (111)	36.30 – 55.50	38.50 – 57.10	37.82 – 57.83	40.12 – 60.26	37.82 – 60.26 (conversed)
Chest circumference under breast (35)	64 – 98.8	72.30 – 121.10			64 – 121.10

Table 7: Measurements of ergonomics test, measurements in centimetres.

	Total	Female	Male
Above pressure point at lower back	77 – 104	77 – 90	89 – 104
Directly under breast	73 – 107	73 – 88	93 – 107
Waist	69 – 98	69 – 83	83 – 98
Heigth of shoulders to pressure point at lower back	46 – 70	46 – 56	49 - 70

APPENDIX 6: GENERAL PROPERTIES OF MATERIALS

Benchmark materials

Table 8: Overview of properties of benchmark materials

Property	Nylon (PA)	Neoprene (CR)	Natural Rubber (NR)	PVC	Polyurethane (PU)
Material type	Engineering thermoplastic	Synthetic rubber (thermoset elastomer)	Natural elastomer (biopolymer)	Thermoplastic (rigid or flexible)	Thermoplastic or thermoset polymer
Typical uses	Gears, bearings, ropes, housings, automotive parts, textile fibers	Wetsuits, seals, hoses, O-rings, protective clothing, footwear	Tires, gloves, seals, belts, tubing, vibration dampers	Pipes, fittings, windows, flooring, packaging, cables, medical tubing	Foams, insulation, shoe soles, wheels, coatings, adhesives, flexible fibers
Price (€/kg)	€1.85–€2.45	€4.32–€4.42	€1.36–€1.52	€1.19–€1.64	€1.73–€2.61
Transparency	Usually translucent	Usually opaque (technically translucent)	Translucent	Can be transparent	Can be transparent
Resistance to water	Good	Excellent	Excellent	Excellent	Excellent
Resistance to alcohol	Limited	Excellent	Excellent	Excellent	Poor
Processability	Injection molding, extrusion, machining, welding	Molding and casting (not weldable)	Molding and vulcanization	Extrusion, molding, machining, welding	Casting, molding, extrusion, foaming
Typical form/ products	Structural plastic parts	Flexible rubber parts	Elastic components	Rigid or flexible plastic products	Foams, elastomers, structural parts
CO_2 footprint (kg CO_2/kg)	~7.7–8.5	~1.4–1.5	~2.35–2.6	~2.9–3.2	~3.0–3.4
Recyclability	Recyclable (limited rate)	Not recyclable	Not recyclable after vulcanization	Recyclable (limited rate)	Some grades recyclable
Environmental notes	Durable, non-toxic but petroleum-based	Long life but difficult disposal	Renewable source but difficult disposal	Cheap but disposal can release chlorine compounds	Versatile but involves toxic chemicals during production
Key advantages	Strong, tough, wear resistant	Flexible, chemically stable	Very elastic, low cost	Cheap, chemically resistant, versatile	Extremely versatile, foam and elastomer forms
Key disadvantages	Higher CO_2 footprint	Expensive and not recyclable	Poor oil/solvent resistance	Limited temperature resistance	Sensitive to some chemicals

Possible materials

Each material is based on petrochemical resources and therefore not biodegradable. All materials have excellent water resistance and a temperature range of at least -18°C to 50°C.

Table 9: Properties of possible materials

Property	PET	POM (Acetal)	Polystyrene (PS)	PVC
Material type	Polyester thermoplastic	Engineering thermoplastic	Commodity thermoplastic	Thermoplastic (rigid or flexible)
Typical uses	Bottles, food packaging, polyester fibers	Gears, bearings, precision mechanical parts	Packaging, disposable products, foam insulation	Pipes, fittings, windows, flooring, packaging, cables, medical tubing
Price (€/kg)	€0.74–€1.43	€1.49–€1.57	€1.41–€1.70	€1.19–€1.64
Transparency	Transparent	Opaque	Transparent	Can be transparent
Alcohol resistance	Excellent	Excellent	Moderate	Excellent
Chlorine resistance	Good	Poor	Poor	Poor
Processability	Injection molding, blow molding, extrusion	Injection molding, extrusion, machining	Injection molding, extrusion, foaming	Extrusion, molding, machining, welding
Typical form/ products	Bottles, packaging trays, fibers for clothing, thermoformed sheets	Mechanical parts, precision components, injection-molded parts	Foam packaging, disposable cups and cutlery, rigid sheets, CD cases	Rigid or flexible plastic products
CO_2 footprint (kg CO_2/kg)	~3.5–3.9	~3.0–3.4	~3	~2.9–3.2
Recyclability	Widely recyclable	Recyclable	Recyclable but low rates	Recyclable (limited rate)
Environmental notes	Highly recyclable, chemical-resistant, non-toxic. Production uses moderate energy and CO_2.	Recyclable, low toxicity. Production energy moderate. Durable and chemically resistant.	Recyclable, but often not collected. Non-toxic but not biodegradable	Cheap but disposal can release chlorine compounds
Key advantages	Transparent, good for packaging	Low friction, precise mechanical parts	Cheap and easy to process	Cheap, chemically resistant, versatile
Key disadvantages	Moderate heat resistance	Sensitive to strong chemicals	Brittle, poor solvent resistance	Limited temperature resistance

Table 9: Properties of possible materials, continued

Property	Polycarbonate (PC)	PEEK	Polyethylene (PE)	Polypropylene (PP)
Material type	Engineering thermoplastic	High-performance thermoplastic	Commodity thermoplastic	Commodity thermoplastic
Typical uses	Safety glasses, shields, lenses, housings	Aerospace parts, medical implants, bearings	Packaging, bottles, pipes, films	Packaging, containers, automotive parts, textiles
Price (€/kg)	€2.6–€2.9	€54–€56	€0.89–€0.98	€1.05–€1.13
Transparency	Transparent	Opaque	Translucent	Translucent
Alcohol resistance	Excellent	Excellent	Excellent	Excellent
Chlorine resistance	Poor	Excellent	Limited	Poor
Processability	Injection molding, extrusion, thermoforming	Injection molding, extrusion, machining	Injection molding, extrusion, blow molding	Injection molding, extrusion, fiber spinning
Typical form/ products	Safety shields, lenses, optical sheets, housings, bulletproof glazing	High-performance parts: bearings, bushings, aerospace & F1 components, medical implants, filaments & sheets	Films, sheets, rods, pipes, bottles, blow-molded containers, fibers	Sheets, pipes, bottles, containers, fibers, packaging, injection-molded parts
CO_2 footprint (kg CO_2/kg)	~5	~16–18	~2.2–2.5	~2.8–3.1
Recyclability	Recyclable	Recyclable (limited)	Recyclable	Recyclable
Environmental notes	Recyclable if unreinforced, high production energy and CO_2 footprint. Transparent and chemically resistant, non-toxic	High production energy, expensive, recyclable if uncontaminated, non-toxic. Exceptional chemical resistance, very durable; not biodegradable	Very low energy to produce, recyclable, FDA-compliant for food and medical use, non-toxic, can be made from renewable sources (bio-PE). Non-biodegradable.	Low energy for production, recyclable, chemically inert, can be incinerated for energy. Non-toxic, not biodegradable
Key advantages	Very strong and transparent	Exceptional strength & heat resistance	Very cheap, chemically resistant	Lightweight, cheap, versatile
Key disadvantages	High production energy	Extremely expensive	Limited mechanical strength	Limited temperature resistance

DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Cathelijn Bogers **Student number** 5,031,591

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Towards sustainable cooling in cardiovascular patients in the ICU

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

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

There are multiple cooling methods for patients after a cardiac arrest. These patients are treated in the Intensive Care Unit of a hospital. In the Erasmus MC, Rotterdam, the Netherlands, two different treatments are available: the Coolguard (image 1) and the Arctic Sun (image 2). A third is currently being developed.

The protocol for treatment of these patients includes preparing of the cooling, but it is unclear, when, which, for whom etc. This is a problem experienced by the nurses and they have raised awareness of this issue. Oftentimes, cooling is prepared but eventually not needed, resulting in unnecessary preparation time and waste. Furthermore, Erasmus MC is changing their care to be more sustainable. The task raised is thus to evaluate the current methods available, on sustainability and protocol.

The main stakeholders are the nurses, doctors, patients and their family, and the Green Team of Erasmus MC.
Nurses: want clarity in the protocol and a more appropriate protocol with sustainable care.
Doctors: want an appropriate sustainable protocol which improves the care and does not limit their work.
Patients and their family: want their treatment results to remain as good, or improve.
Green Team: wants the care provided in Erasmus MC to become more sustainable.

The biggest limitation is guarding the treatment, the effectivity and efficiency must remain the same; the healthcare should never be compromised. Many regulations apply to the medical field, they need to be adhered.

➔ *space available for images / figures on next page*

introduction (continued): space for images

image / figure 1 CoolGuard, internal cooling method

image / figure 2 ArcticSun, external cooling method

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

Several cooling methods exist for cardiovascular patients in the ICU, which result in unclarities. It is not specified in which scenario which method is used, or why. Furthermore, sometimes the methods are prepared but eventually not needed. These cooling methods will be evaluated with regards to effectivity, i.e.: sustainability, costs, personel, time and implementation in the medical care system. This will help the hospital to become more sustainable and help medical personal with appropriate treatment for patients. This evaluation will help the care to become more efficient, effective and better.

Then, an appropriate intervention will be created, in order to strive for more sustainable healthcare, without compromising the outcomes. This will result in a more sustainable method of cooling in the cardiovascular ICU in the EMC.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

Create an intervention to improve the healthcare of cardiovascular patients with regard to cooling methods in the ICU of Erasmus MC.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

A literature review will help gather data on the effectivity of the available cooling methods, their advantages and disadvantages.
A journeymap of the available cooling methods will provide insights into the current integration in the health care system. This journey map will be made through research (i.e. interviews, shadowing) amongst the stakeholders, e.g. nurses, doctors, if possible patients.
I will formulate key research questions through stakeholder evaluations.
A material and energy analysis will provide insights into the sustainability of the available methods.
Consultations with doctors and the green team will help to ensure a suitable outcome of this evaluation.

Presumably, several hot spots will be discovered. Based on an analysis of these, an intervention will be created, with the help of e.g. a co-creation session, in order to provide more sustainable care with regard to cooling cardiovascular patients in the ICU.

Project planning and key moments

*To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting**, **mid-term evaluation meeting**, **green light meeting** and **graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).*

Make sure to attach the full plan to this project brief.
The four key moment dates must be filled in below

Kick off meeting	3 sept 2025
Mid-term evaluation	24 okt 2025
Green light meeting	19 dec 2025
Graduation ceremony	30 jan 2026

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	
For how many project weeks	
Number of project days per week	

Comments:
Christmas break between 20 dec - 4 jan.

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

I am motivated to start this medical project because it aligns with my passion for designing for and thus helping people, and my fascination with the hospital environment. I hope I can contribute to better healthcare (e.g. more sustainable, more comfortable, more efficient, more effective) with this project.

I would like to experience working in the Erasmus MC up close, and gain experience in working with professionals, as well as in the public sector. Through this project, I aim to deepen my understanding of design in the medical field. This design will adhere to the lenses of desirability, feasibility and viability.

Stakeholder management is important within this project, how to keep the parties involved updated and ensure every party has a shared understanding of the project and managing their expectations. I want to keep them involved through providing clear agendas in time and sharing notes and improve on this. I want to learn how to manage a project by myself.
Furthermore, I would like to improve my visual communication skills, to share thoughts visually for easier understanding. I would like to learn about co-creation, in order to gain useful insights from stakeholders.