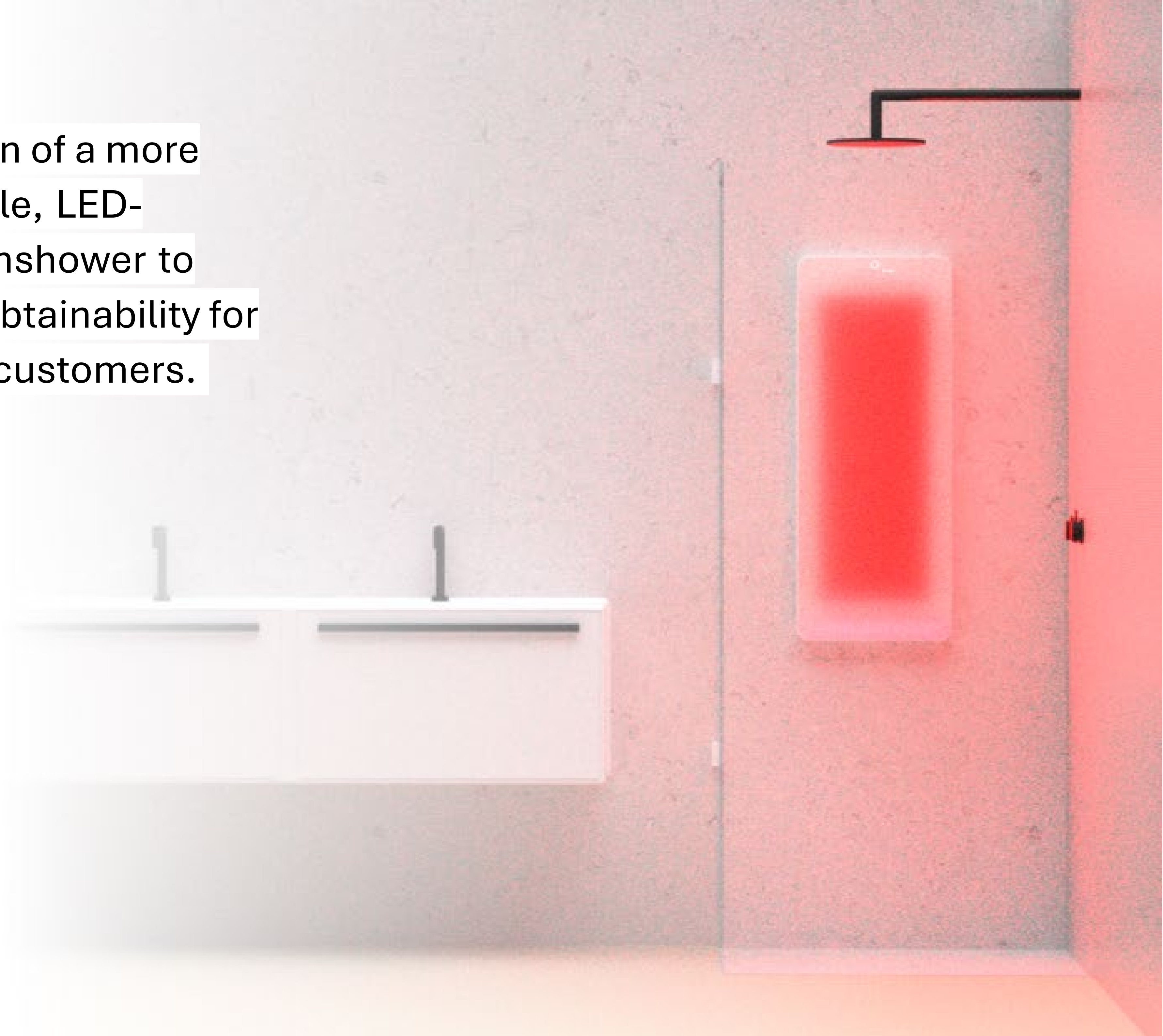
The design of a more sustainable, LED-based Sunshower to improve obtainability for potential customers.



Master Thesis

Koen van der Park

June 2026

The design of a more sustainable, LED-based Sunshower to improve obtainability for potential customers.

June 2026

Author	Koen van der Park 5109930
Supervisory Team Chair/ Responsible Supervisor	 Gonny Hoekstra Department of Human Centered Design
	Sonja Paus-Buzink Department of Human Centered Design
Mentor/ Supervisor	Ernest van Breemen Department of Sustainable Design Engineering
Company Mentor	Merijn Wegdam Founder and Technical Director

Faculty of Industrial Design Engineering
Landbergstraat 15, 2628 CE, Delft
The Netherlands

Sunshower BV., Hoogoorddreef 63-65,
1101 BB, Amsterdam, The Netherlands

Abstract

Photobiomodulation (PBM) uses red and near-infrared light to stimulate biological processes in the body and has been associated with benefits including skin rejuvenation, pain relief and muscle recovery. As scientific evidence supporting PBM continues to grow, an increasing number of home-use products have become available. However, most require users to expose bare skin while remaining stationary for extended periods, limiting convenience and user adoption.

Sunshower addresses this challenge by integrating PBM into the daily shower routine. Existing Sunshower products use halogen infrared lamps, which provide a broad light spectrum and a pleasant warming sensation but also result in high energy consumption, elevated operating temperatures and bulky product dimensions. This thesis investigates how LED technology can replace halogen lamps while maintaining therapeutic effectiveness and improving sustainability, usability and product accessibility.

The result is the Sunshower Nova, a wall-mounted LED-based PBM device designed for use during a regular shower session. The product combines red and near-infrared LEDs to deliver a therapeutic light dose that is consistent with current scientific literature within a ten-minute treatment. To support effective use, the system provides real-time feedback on treatment duration and user distance, helping users achieve the intended dose. The product architecture consists of a thermally optimised housing, a modular LED assembly and an optical front cover that together enable a compact, energy-efficient and manufacturable design.

The final design was validated through engineering analyses, performance measurements, user evaluations and a life cycle assessment. Compared with the existing halogen-based Sunshower, the LED-based design significantly reduces energy consumption and environmental impact while maintaining therapeutic performance and improving installation flexibility. The project demonstrates that LED technology enables a new generation of integrated shower-based PBM devices that combine scientific effectiveness with a more sustainable and accessible user experience.

Preface

This thesis marks the completion of my Master's degree in Industrial Design Engineering at Delft University of Technology. The project was carried out at Sunshower and focuses on the development of an LED-based photobiomodulation product for use in the shower environment.

When I started this project, I had little knowledge of photobiomodulation and the science behind light therapy. Throughout the graduation project, I discovered how fascinating the interaction between light and the human body can be. What started as a product development assignment gradually developed into a genuine interest in photobiomodulation, LED technology and the engineering challenges involved in delivering therapeutic light effectively and safely. Exploring the fields of optics, thermal management, electronics, sustainability and user experience within a single project made this a particularly rewarding graduation assignment.

One of the aspects I enjoyed most was working on a project that combined scientific research with practical product development. Translating findings from scientific literature into tangible design decisions and validating those decisions through testing provided a valuable insight into the complete development process. The project continuously challenged me to balance technical performance, user experience, manufacturability and sustainability, and has taught me a great deal as both an engineer and a designer.

I would like to express my gratitude to everyone who contributed to this project. First, I would like to thank my graduation committee for their guidance, constructive feedback and critical questions throughout the process. Their support helped me strengthen both the design and the underlying research.

I am especially grateful to the entire team at Sunshower for welcoming me into the company and allowing me to be part of the team during my graduation project. Thank you for sharing your knowledge, expertise and enthusiasm throughout the project. A special thank you goes to my colleagues for the many discussions, ideas and pieces of advice that helped shape the project. I also greatly appreciated the more informal moments, whether during lunch breaks or during our games of ping-pong, which made my graduation project period so much more fun.

I would also like to thank my family and friends for their support throughout my studies. In particular, I would like to thank my girlfriend for her patience and encouragement during this graduation project. Thank you for listening to countless conversations about LEDs, infrared light and Sunshower.

Looking back, this project has been a fitting conclusion to my master's programme. It allowed me to combine engineering, design and scientific research while working on a product that has the potential to improve people's daily wellbeing. I am proud of the result and grateful for everyone who contributed to the journey. I hope you enjoy reading this thesis.

Koen

Abbreviations

PBM(T)	PhotoBioModulation(Therapy)
LLLT	Low level Laser/LED Therapy
IR	Infrared
NIR	Near-Infrared
LED	Light Emitting Diode
SMD	Surface Mount Device
COB	Chip on Board
PCB	Printed Circuit Board
LCA	Life Cycle Analysis
IEC	International Electrotechnical Commission
ICNIRP	International Commission on Non-Ionizing Radiation Protection
MDR	Medical Device Regulation
WALT	World Association for Photobiomodulation Therapy
IP	Ingress Protection
SELV	Safety Extra Low Voltage
BOM	Bill of Materials

Table of Contents

1. 1 Introduction 7
   1.1 Project introduction 8
   1.2 Sunshower BV. 9
   1.3 Research goals and questions 10
   1.4 Scope and limitations 11
   1.5 Project Approach 12
2. Discover phase 13
   2.1 The science of photobiomodulation 14
   2.1.1 Introduction 14
   2.1.2 Possible benefits 14
   2.1.3 Therapeutic window 15
   2.1.4 Design takeaways 17
   2.2 Stakeholder analysis 18
   2.2.1 Relevant stakeholders 19
   2.2.2 Power-interest matrix 19
   2.2.3 Design Takeaways 22
   2.3 Analysis of the current Sunshower 23
   2.3.1 Introduction 23
   2.3.2 Product Components 23
   2.3.3 Radiated output 25
   2.3.4 User experience 26
   2.3.5 Carbon footprint of the current Sunshower 28
   2.3.6 Aesthetics 29
   2.3.7 Design Takeaways 30
2.4. Analyzing the differences between Halogen and LED technology 32
   2.4.1 Working mechanism 32
   2.4.2 Optical and thermal output 32
   2.4.3 Product integration 33
   2.4.4 Design Takeaways 34
2.5. Competitive landscape 35
   2.5.1 Introduction 35
   2.5.2 Existing LED devices 35
   2.5.3 Existing Halogen products 38
   2.5.4 Design Takeaways 40
2.6. Bathroom Context 41
   2.6.1 Regulatory implications 41
   2.6.2 Use context 45
   2.6.3 Design Takeaways 46
3. Defining phase 47
3.1 Compilation of Design Takeaways 48
3.2 List of Requirements 49
3.3 Main Design Drivers 50
4. Developing phase 51
4.1 Developing product Concepts 52

4.1.1 Ideation starting point........53
4.1.2 Product Architecture Concepts........54
4.2 Conceptualization........57
4.2.1 LED hardware........59
4.2.4 Housing shape........62
4.2.5 Installation method........63
4.2.6 Thermal Management........65
4.2.7 Front cover........66
4.2.8 Interaction........68
5.Delivering the Sunshower Redesign........72
5.1 Final design overview........74
........75
5.1.1 A safe and meaningful dose........76
5.1.2 Compact and easy installation........77
5.1.3 Efficient energy use........78
5.1.4 Trust in a comfortable experience........79
5.2 Design Detailing........80
5.2.1 Front cover........80
5.2.2 Housing........81
5.2.3 Electronics........82
5.2.4 Interaction........83
5.2.5 Installation........84
6.Validation........85
6.1 User Testing........86
6.2 Carbon Footprint........90
6.3 Radiation Output........91
6.4 Cost estimation........93
6.5 Energy usage........95
7. Discussion........96
8. Recommendations........98
9. Reflection........99
10. References........100

1.1 Introduction

The function of this chapter is to introduce the context, research questions, company and goals of this project. First, it outlines the challenges of the current technology and how a transition to an upcoming technology could help.
Next, the client company Sunshower BV is presented, showing the relevance this project has for them.
After that the assignment is elaborated upon in the problem statement and broken down into the main research question and its sub-questions. Lastly, the boundaries of this project will be framed by the scope and limitations of the project.

1.1 Project introduction

In recent years, people have spent an increasing amount of time indoors. Not only have jobs changed to be more indoor-based, but digital entertainment has also caused people to spend more time away from sunlight, especially during winter. This lack of direct sunlight can contribute to a number of health problems (Alfredsson, 2020).

The lack of sunlight can be addressed by using artificial light sources to mimic sunlight. This process, known as light therapy or photobiomodulation, is dependent on the wavelength and power of the light.

Traditionally, ultraviolet (UV) and infrared (IR) halogen lamps have been used for this purpose. These lamps typically emit a broad spectrum of light together with a sizable amount of heat, which can provide some of the health effects associated with sunlight while creating a comfortable wellness experience. However, these characteristics also create challenges regarding energy consumption, safety, and product engineering. As a result, barriers arise for users wishing to purchase these products, as they can become large, unsustainable, and expensive.

Additionally, due to their inefficiency and toxic contents, the use of halogen lamps is gradually being phased out. The European Union has been introducing regulations on the production and use of certain types of halogen lamps since 2010. In 2025, a series of manufacturing and export bans on halogen UV lamps came into effect (Regulation (EU) 2024/1849), making research into alternatives increasingly relevant.

Recent years have seen the development of UV and infrared LEDs, as well as a growing body of scientific research on their therapeutic effects. The characteristics of this alternative technology offer opportunities for more efficient and compact products. To explore the opportunities of this emerging technology, this project focuses on the design of a light therapy device based on LED technology.

1.2 Sunshower BV.

This project is carried out in commission of the company Sunshower BV. The company was founded in 2001 by Merijn Wegdam en Oscar Meijer as a result of a master thesis project. Currently based in Amsterdam, Sunshower BV (hereafter referred to as Sunshower) is focused on the design, marketing, sale and maintenance of the various forms of their product: The Sunshower.

Figure 2: A Sunshower installed in a bathroom

The Sunshower is a device that uses halogen IR and UV light to provide its users with the benefits of sunlight while they shower. Originally designed as a UV tanning device to be used in the shower, the focus of the Sunshower was shifted towards the health effects of sunlight as the harmful effects of excessive UV light became known. Supported by researchers from the Amsterdam Medical Centre (AMC) and the Leiden University Medical Centre (LUMC), the light from the Sunshower was adjusted to no longer be harmful and improve health instead. Using this controlled dose of UV light can prepare the skin for the summer sun, lead to improved vitamin D levels and help treat skin conditions like psoriasis and eczema (De Boer et al., 2024). After several years infrared functionality was added to complete the replication of sunlight. This part of the sunlight spectrum can help muscles and joints relax as well as improve blood circulation leading to improved energy levels (Sunshower, 2025).

The production of the Sunshower takes place in a social workshop in Dordrecht. With the production close to the headquarters, the process can be controlled and adjusted quickly.

The product portfolio consists of the original “Square” line and the newest “Round” line. Both product lines consist of full-body, half-body and quarter-body products that can be either built into or mounted on the wall. All of these products are available in infrared+UV and infrared-only configurations.

Figure 1: The Sunshower Large, Medium and Small

Figure 3: The Sunshower Office in Amsterdam

1.3 Research goals and questions

The main goal of this project is to design a more sustainable LED-based Sunshower that allows for a more sustainable product that reduces the barriers to purchasing a Sunshower.

Therefore, the main research question is phrased as:

"How can a Sunshower be designed to be more sustainable and reduce barriers to purchase, utilizing LED technology? "

This main research question can be broken down into several sub-questions, that will help understand the challenges in this project.

1. What are the easiest and cheapest ways to produce an infrared LED array in a waterproof embodiment?
2. What is the context in which a Sunshower is used?
3. What health benefits are desired by the target group and what wavelengths of photobiomodulation are affiliated with them in scientific literature?
4. Is heat necessary for the user experience and therapeutic effect?
5. What elements of the Sunshower are obsolete when using LED technology instead of halogen and what elements should be retained?
6. What parts of the Sunshower have the largest environmental footprint and how can this be reduced?
7. How can the installation of the Sunshower be less of a commitment?
8. What are the barriers to purchase for potential customers?

1.4 Scope and limitations

Preceding this Master's thesis project, I did an internship at Sunshower. During this internship, I was introduced to the possibilities of LED technology and the interest of the company to research a LED-based Sunshower. During this first period at Sunshower I did research and carried out some tests to verify whether LEDs were capable of producing comparable output to the current Sunshower. This research resulted in a proof of concept and the model that is shown in Figure 4. The model showed that a collection of LEDs could produce a somewhat evenly distributed field of red/infrared light that had higher irradiance than a single LED, in a product that loosely resembled the Sunshower. This is the starting point of this thesis.

To limit the scope of this project, the LED-based product that will be designed will be an infrared-only, half-body device. As this corresponds to the most popular current Sunshower product, this will ensure the relevance of the redesign.

The design will be evaluated on technical performance, user perception and usability of the interface with the use of several prototypes. However, due to limitations in medical knowledge, equipment and time the therapeutic effect of the final design will be considered beyond the scope of this project.

While regulatory requirements will be considered during the project, the development of certification documentation, including manuals and training materials for production and assembly, falls outside the project's scope.

Furthermore, a fast-track life cycle analysis (LCA) of both the current model and the proposed design will be carried out. The analysis will not go into more detail than the fast-track level, as the method will primarily be used to map how the carbon footprint of the product is divided between material acquisition, production, transportation, and use. Next to that, the level of detailing of the proposed final design will not allow very precise carbon footprint estimations.

Figure 4: LED prototype from internship

1.5 Project Approach

In Figure 5, the project approach is displayed from start to end. An adaptation of the double diamond model (Design Council, 2004) was used to structure the project and along the way adjustments were made. This thesis project was preceded by an internship in which the proof of concept for this technology was discovered and the project definition was determined.

This project was structured into 4 main phases: Discover, Define, Develop and Deliver.

In the Analysis phase desk research, interviews and a literature review were done to understand the technology, context and stakeholders. The define phase concluded all the insights from the previous phase and transformed them into useable starting points for the next phase. In the Develop phase, ideas and concepts were generated, tested and compared. Lastly, the Deliver phase presents the final design and validates its performance.

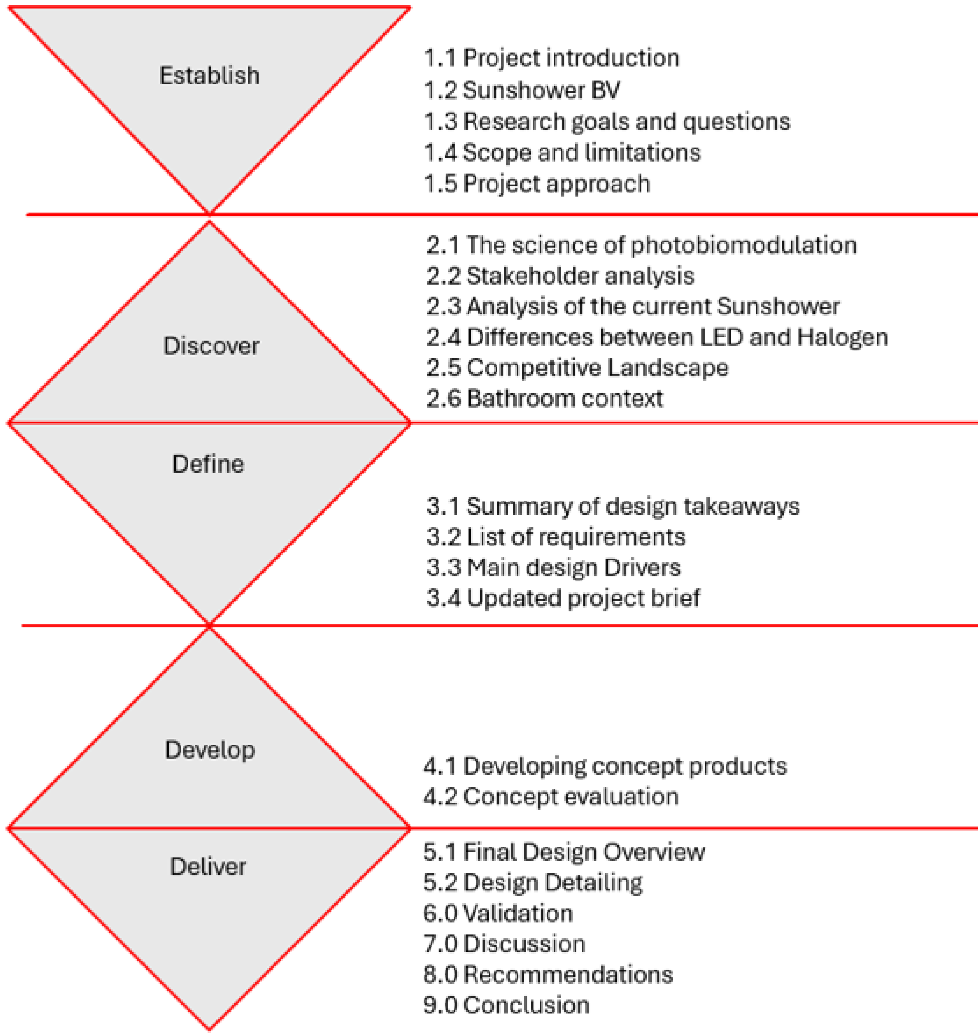


Figure 5: Double Diamond method with corresponding chapters of this report

2. Discover phase

In this chapter, the first phase of the project is presented. During this phase, the project context was analyzed to identify the design requirements and desired features. This analysis considered multiple factors, including scientific literature, stakeholder needs, regulations, existing technologies, and the use context. The outcome of this phase is a set of requirements and wishes that guide the next stage of the project.

2.1 The science of photobiomodulation

2.2 Stakeholder analysis

2.3 Analysis of the current Sunshower

2.4 Differences in Halogen and LED technology

2.5 Competitive Landscape

2.6 Physical Context

2.7 Regulatory implications

2.1 The science of photobiomodulation

2.1.1 Introduction

The scientific principle behind red and infrared therapy is called photobiomodulation. This therapy has many applications and parameters that can influence the success of a session. The function of this chapter is to understand the parameters that have been proven scientifically to cause health benefits and are useful to the Sunshower usecase.

One of the first scientific discoveries of photobiomodulation was done on accident by Endre Mester in 1967. Mester was studying the effects of red laser light (~694 nm) on the growth of cancer in mice when he noticed that the mice exposed to the laser grew hair back significantly faster (Mester & Mester, 2017). This phenomenon was initially called “Laser Biostimulation” and would eventually be known as “Low Level Laser Therapy (LLLT)” for a long time. The leading theory was that only coherent light sources like lasers were useful for this process. When more clinical research and trials were conducted with differing sources of light such as LEDs or incandescent lamps, this theory was quickly debunked (Heiskanen & Hamblin, 2018). As it was now known that lasers were no longer a requirement and the fact that ‘low-level’ is a very subjective term, the name LLLT was no longer suitable. More researchers started to use other terms like Photobiomodulation and in 2015 it was officially adopted into the MeSH library to also prevent confusion with other technologies using light (Anders et al., 2015).

2.1.2 Possible benefits

The word photobiomodulation(PBM) can be dissected into three parts. ‘Photo’ refers to the use of light, ‘bio’ refers to the biological tissues that the technique is used on and ‘modulation’ refers to the effect that the light has on the tissues. In practice, the term describes the process of irradiation of the human body with visible or infrared light to induce certain health benefits. Clinical research shows evidence that these benefits include:

- Reduced inflammation (Hamblin, 2017)
- Pain relief (Yadav & Gupta, 2016)
- Improved muscle recovery (Ferlito et al., 2021)
- Improved mood (Montazeri et al., 2022)
- Improved overall energy (Vassão et al., 2015)
- Wound healing (Mgwenya et al., 2024)
- Skin rejuvenation (Mota et al., 2023)
- Acne treatment (Chopra et al., 2025)

The effect that PBM has depends on several factors. PBM works by photoactivation of the mitochondrial chromophores, meaning that mitochondria of the cells in the targeted tissues are stimulated by the absorption of photons. This in turn leads to higher cellular energy efficiency, vasodilation and improved mitochondrial signaling (Dompe et al., 2020).

2.1.3 Therapeutic window

Depending on the tissue that is targeted by the therapy, these mechanisms could lead to the therapeutic effects listed above. However, to achieve these therapeutic effects, there are a number of other parameters that need to be considered.

Zein et al. (2018) reviewed the following parameters to be directly related to an optimal dose.

- Wavelength
- Depth of target tissue
- Type of treatment being delivered
- Irradiance
- Fluence
- Spot size

When tissues close to the surface of the skin are targeted, the light can immediately be absorbed by the skin cells. However, when deeper tissues are targeted, the light has to travel through other tissues to reach its target. This can lead to the light being reflected or absorbed by untargeted tissues. The depth to which light can travel in a material is called the optical penetration. The optical penetration of the human skin and muscles is greatly dependent on the wavelength of the light (see figure 7).

Red light (around 600-700 nm) cannot penetrate deep into the skin and does not pass beyond the dermis. NIR light (starting at 700 nm) has increasingly more optical penetration with a peak at 860 nm. This peak is where the light can penetrate several centimeters into the skin and reach muscles or joints (Figure 7).

This difference in optical penetration and depth of tissues makes wavelength a very important factor to consider in deciding on the optimal dose.

In determining the optimal dose for effective treatment, the amount of light should also be considered. In this consideration, there are two important parameters. Firstly, the fluence, the total amount of energy that is radiated. Secondly, the irradiance, the rate at which the energy is radiated.

In research, both of these parameters have been proven to adhere to a biphasic dose response (Huang et al., 2009). This means that the mechanism will not work if the administered dose is too low, but also that there is a point where increasing the dose will have inhibitory effects. This leaves area in the middle where the therapeutic effect is the highest, commonly referred to as the therapeutic window (see figure 6).

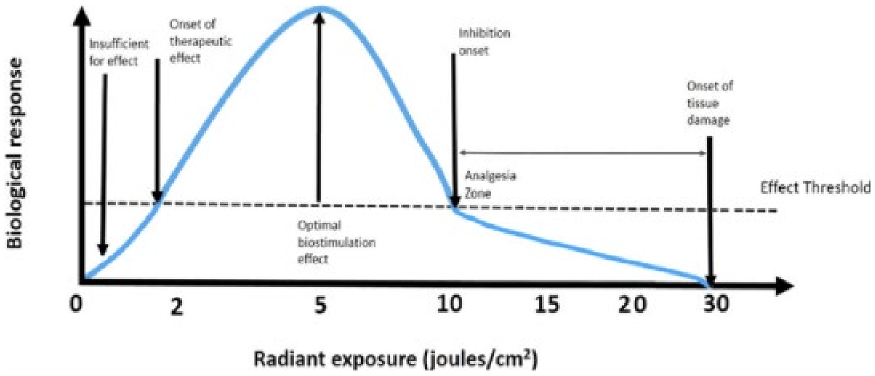


Figure 6: The therapeutic window of photobiomodulation

If the fluence administered would be too low, the cells would not receive enough energy to overcome the modulation threshold. If the fluence is too high, cells might be overloaded and not have the capacity to deal with the modulations, leading to counterproductive effects. With too low irradiation, energy will not be able to cross the cells' threshold to evoke a biological response. When the irradiance is too high, it can cause cellular inhibition and stress due to the cells not being able to process the photons fast enough.

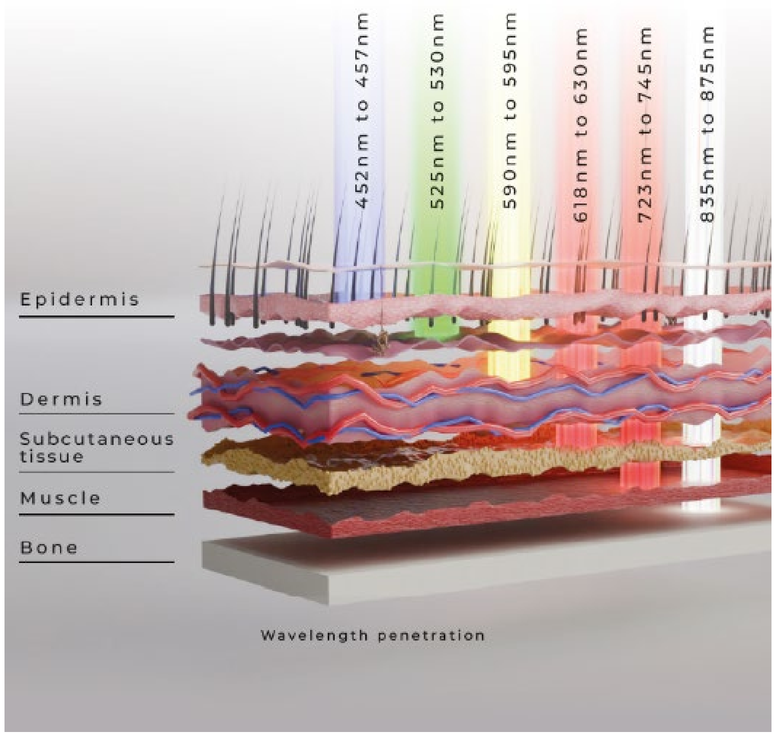


Figure 7: Visualization of the influence of wavelength on the penetration depth of light in the human skin

Although the number of clinical studies on this subject is rapidly growing, there are very little studies that conclude with a recommended set of parameters for specific health benefits. However, the World Association for Photobiomodulation Therapy (WALT) has presented recommendations regarding irradiation time, total dose and mean output (WALT, 2022)

For anti-inflammatory dosage, the WALT recommends a power output above 5 mw/cm2 and below 100 mw/cm2. Recommended irradiation times range between 30 and 600 seconds, matching well with the current Sunshower session time. Depending on the depth of the targeted tissue, they recommend a total dose of 1-4 J/cm2 for most tissues. An outlier is the hip, which has a recommended dose of 10 J/cm2. They also report therapeutic windows to typically range from the recommended values.

Desired health benefit	**Wavelength**	**Dose (J)**	**Irradiation (mW/cm2)**
Reduced inflammation	850, 940 nm	4	7
Pain relief	810, 830, 850 nm	4	7
Improved muscle recovery	830, 850 nm	4	7
Improved mood	940 nm	1	2
Improved overall energy	850, 940 nm	2	3
Wound healing	630, 680 nm	2	3
Skin rejuvenation	630, 680 nm	2	3
Acne treatment	650 nm	1	2

2.1.4 Design takeaways

This chapter shows that photobiomodulation (PBM) is not simply about applying light, but about carefully controlling how light interacts with biological tissue. Its effectiveness depends on a narrow therapeutic window where wavelength, intensity, and exposure time are correctly balanced. Outside of this range, the same treatment can become ineffective or even counterproductive. This makes precision and control central to any PBM system design.

A key insight is that PBM outcomes depend on multiple interacting parameters rather than a single adjustable setting. Wavelength determines how deep the light penetrates, while irradiance, fluence, and exposure time together define the total biological dose. Because different tissues require different depths and energy levels, a flexible

but controlled system is necessary to ensure safe and effective treatment.

- The device should operate within a defined dose window of approximately 1–4 J/cm^2 depending on target tissue
- Systems must regulate both irradiance (5–100 mW/cm^2) and time (30–600 s) together
- Wavelength selection should align with treatment depth:
    - ~600–700 nm for skin-level applications
    - ≥700 nm (especially ~800–860 nm) for deeper tissues
- Built-in safety limits should prevent exceeding the upper therapeutic range

2.2 Stakeholder analysis

This subchapter shows the stakes that the several stakeholders involved in this project have. The analysis identifies the levels of influence and interest, which allows the categorization of the stakeholders into 4 stakeholder management strategies. The two most important stakeholders are analyzed in more detail. The needs of the stakeholders are considered and eventually translated into requirements for the design.

2.2.1 Relevant stakeholders

The relevant stakeholders identified for this project are shown in Figure 9. Semi-structured interviews were held with several stakeholders to find out what their stakes and needs are in the result of this project. The structure of these interviews can be found in appendix A. The interests and needs of the 2 most important stakeholders are explained in more detail in .

Table 1: Relevant stakeholders and their needs

Stakeholder	Needs
Potential user	A product that is easy to purchase and install, sustainable, helps muscles, joints and skin, gives efficacy that it works.
Sunshower BV	A product that opens a new market and prepares for shift in technology regulations. Also, a product that is in line with their vision and reputation.
Regulation Authority	Safe product that meets the requirements of regulations
Bathroom retailers	A product that stands out and has unique selling points
Service technicians	Product that is easy to diagnose and repair
Environment	No material depletion and as little carbon emitted as possible
Dermatologists	Safe and useful treatment options that have been clinically proven
Suppliers	New market and promise of large orders with growth opportunities
Users	A premium wellness product with a comfortable and relaxing experience
Production	A product with simple architecture, using known technologies and equipment to assemble
Competitors	Technology that is easy to copy
Marketing	A beautiful, trendy product that interests potential users and has unique selling points

2.2.2 Power-interest matrix

Some stakeholders require a different management strategy than others. To determine strategies for each stakeholder and how to treat their needs and wants, a ‘Power-Interest Matrix’ (see Figure 8) was used.

In the ‘high power, high interest’ quadrant (Manage Closely) are Sunshower BV and potential users. Sunshower BV is central to all strategic and design decisions, while potential users are key to future market success and adoption of the redesigned product. Their strong interest and influence on the product’s direction mean they should be actively involved, with continuous feedback and close collaboration.

The ‘high power, lower interest’ quadrant (Keep Satisfied) includes regulation authorities and dermatologists. These stakeholders have significant influence over approval and credibility but are less involved in day-to-day development. Regulatory bodies determine compliance, while dermatologists validate the health aspects of the product. Keeping them satisfied by meeting standards and addressing concerns is essential to avoid delays or rejection.

In the 'low power, high interest' quadrant (Keep Informed) are users, production, bathroom retailers, suppliers, marketing, service technicians, and the environment. These stakeholders are directly affected by the product or contribute to its realization but have limited decision-making power. They should be regularly informed and engaged through feedback loops, as their insights can improve usability, feasibility, communication, and sustainability.

Finally, the 'low power, low interest' quadrant (Monitor) includes competitors. While they do not directly influence the project, they shape the competitive landscape. Monitoring their activities helps ensure the product remains differentiated and aligned with market developments.

The placement explanation for all stakeholders within the matrix can be found in Appendix B.

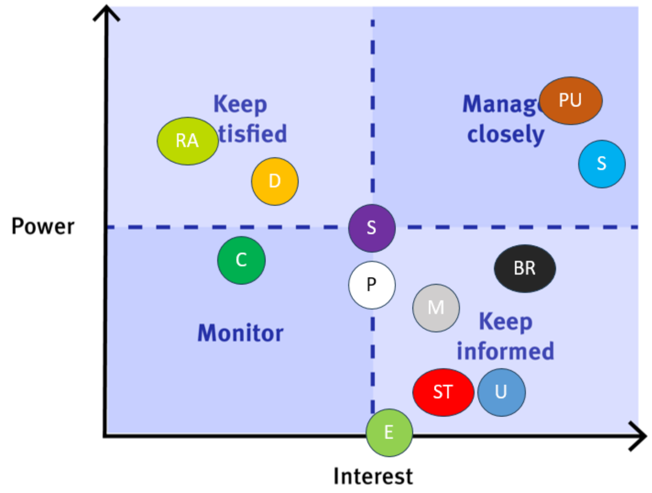


Figure 8: Power-Interest matrix

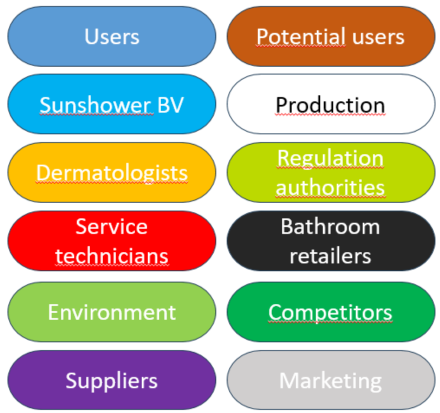


Figure 9: Relevant stakeholders

Sunshower BV

One of the biggest stakeholders is the company itself. During interviews it became clear that Sunshower would like to be on the forefront of new technological developments in this market. This will also prepare them for when regulations prohibit the use of the current halogen lamps. Additionally, they would like to expand their business to untapped markets. Their current products mostly appeal to older age groups that have the resources to spend on luxury and wellness. They have noticed new (online) trends among a younger age group that likes to take care of their body and is really into sports. This group that spans roughly from 15 – 35 year olds does not mind spending money on beauty and health products like skin serums and dietary supplements.

On the other hand, the company wants to be cautious. When looking at the LED-photobiomodulation devices are already available, they see some issues and challenges. These devices are very heavily marketed with extreme claims about the benefits and often sold through online shops like Alibaba. This does not match the brand image that Sunshower aims for, both in product quality and in trustworthiness as a leader in sunlight health research.

Lastly, concerns were raised about a LED product being easy to copy for competitors. As many of the available LED products are coming from OEM and ODM manufacturers, it is important to know how these parties can be prevented from copying the design.

Potential Users

As mentioned above, there is a potential target group that is currently not fully addressed by the Sunshower offering. This group is interested in the benefits associated with products like the Sunshower, particularly skin rejuvenation, muscle recovery, relaxation, and overall systemic health, but faces practical and financial barriers that prevent adoption.

Interviews with people within this segment revealed that the purchase price is only one part of the challenge. Their living situation also plays a significant role in making a product like the Sunshower feel impractical. Many of these users live in smaller apartments or rental housing where bathrooms are compact and space is limited. Large, permanently installed wellness devices are therefore perceived as intrusive and unsuitable for their daily environment. In addition, rental agreements often prohibit drilling into bathroom walls or making structural modifications, creating further barriers to installation.

Another recurring concern was flexibility. Many participants indicated that they do not expect to stay in their current home for more than three to five years, making them hesitant to invest in a large, fixed product. The uncertainty around whether the product can easily be removed, transported, and reinstalled in a future home contributes to the perception of risk. As a result, ownership of a Sunshower is often associated with long-term homeownership and luxury living, rather than with the lifestyle of younger, more mobile consumers.

Despite these barriers, this target group showed strong interest in the underlying health and wellness benefits. They were particularly attracted to features related to recovery after exercise, relief of muscle tension, improved energy levels during darker months, stress reduction, and skin health. Compared to traditional Sunshower users, this audience tends to approach wellness in a more holistic and preventative way. They value products that can easily fit into their daily routines and contribute to both physical and mental wellbeing without requiring a dedicated spa-like environment.

In terms of product expectations, this group expressed a preference for solutions that are compact, flexible, and non-permanent. A smaller product footprint, portable or modular designs, and installation methods that do not require drilling would make the concept significantly more appealing.

2.2.3 Design Takeaways

The stakeholder analysis highlights that the product must balance safety, wellness, usability, and market appeal. Regulatory authorities and dermatologists require a safe, clinically validated solution, meaning the design must be compliant, evidence-based, and use certified materials. Users expect a premium wellness experience that feels relaxing while delivering clear benefits for muscles, joints, and skin. At the same time, Sunshower BV and marketing emphasize the need for a distinctive, visually attractive product that strengthens brand positioning and stands out in retail environments. Service technicians and production teams stress simplicity, requiring an easy-to-install, modular, and repairable system built from proven technologies. Environmental considerations demand sustainable material choices, low energy use and long product lifespan. Suppliers and retailers further support a scalable, commercially attractive design with clear unique selling points. Overall, the design should combine clinical credibility, premium user experience, sustainability and manufacturability into a simple and future-proof wellness product.

2.3 Analysis of the current Sunshower

2.3.1 Introduction

To be able to redesign the Sunshower, it is important to know what the current product and its challenges are. Therefore, an analysis was made of a Sunshower regarding its components, output, experience and sustainability. Sunshower sells a number of variations of their product. The 'Sunshower Round Medium' was determined to be the focus for this project. Therefore, this is the model that is analyzed in this chapter. However, due to the design of the modular design of the Sunshower, most of the information and challenges are applicable to other models as well.

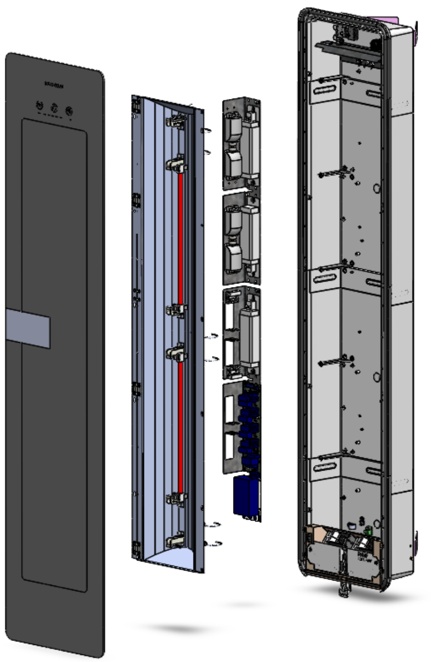


Figure 10: Exploded view of the Sunshower Medium

2.3.2 Product Components

The Sunshower Round Medium is made up of 3 main assemblies: the housing, the reflector and the glass panel (figure 10). These components all serve their own purpose in the design. The housing allows the installation of the Sunshower and holds most of the electronics that make the product work. The reflector assembly carries the infrared lamps that produce the light, and the reflector itself makes sure that all the light is reflected towards the user. The glass panel protects the internal components from water while allowing a safe and functional amount of warmth and light to pass through.

The housing assembly

The housing consists of an injection molded polycarbonate shell that is heat resistant and stiff. Like mentioned above, the housing assembly facilitates the installation of the Sunshower on or in the wall and the connection of all components. To allow installation on the wall, the housing is equipped with a cavity at the back side where a metal mounting plate is attached. By putting this mounting plate in a cavity instead of straight on the back of the housing, the Sunshower can be mounted flat on the wall.

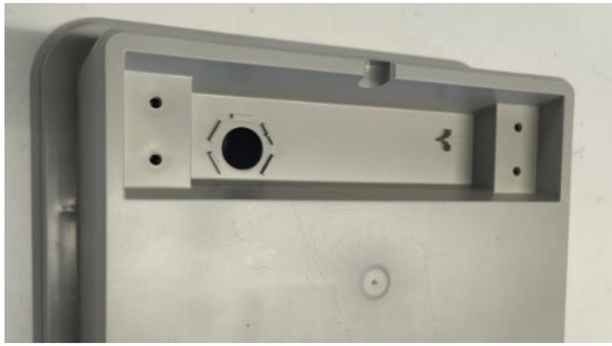


Figure 11: Photo of mounting cavity

To allow the connection of the other components, the housing is equipped with several threaded bosses and wedges. With screws and starlocks, the electronics and reflector are connected to the housing. These connections allow easy maintenance as they can be easily manually dis- and reconnected.

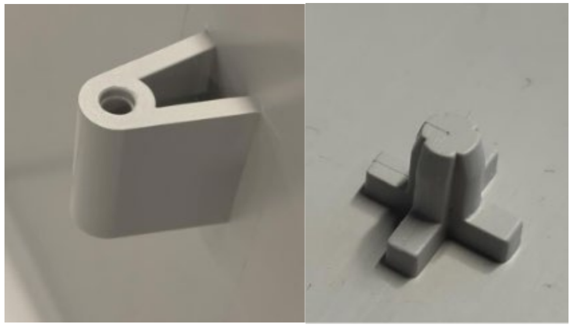


Figure 12: Injection moulded connection features

Additionally, the housing enables ventilation through a set of fans and ventilation openings. These components are positioned at the bottom of the housing. Cool air is drawn in through two openings at the bottom of the product and guided upward through an internal channel. The airflow first rises along the front side of the product. At the top, it is redirected downward through a return channel and then expelled through two outlet openings located at the bottom. Along this channel, the air takes heat from the reflector and electronics to cool them down.

However, as the warmed-up air can only be expelled through the bottom and warm air naturally moves upwards, some heat maintains at the top of the product. Heat measurements at 4 points in the housing (Appendix C) show that the temperature at the top of the housing can become 25% higher than at the bottom.

The reflector assembly
As the halogen lamps that are used in the Sunshower emit light in 360 degrees, a reflector is needed to direct as much of the light towards the user. The reflector is made up of a layer of highly reflective aluminum that is bolted to a layer of strong and heat-reflecting steel. This reflector is designed to reflect as much of the light towards the user while protecting the inner components against heat. On this component, several lamp holders are bolted to allow the attachment of the halogen infrared lamps.

Glass panel assembly
The function of the glass panel is to protect the user from heat generated by the lamps and to protect the internal components from the water of the shower. In this process, it is important that as much of the infrared light is transmitted.

For this purpose, the assembly is made up of 2 separate glass panes that are held together by a steel frame. Special grade, highly transparent glass is used to maintain high light output for the user. The outer glass pane is sandblasted to prevent the user from looking into the product.
As heat is part of the product experience (which will be elaborated upon in the next subchapter), a part of the heat is still transmitted to the user. The rest of the heat is reflected into the housing, causing the internal temperature to rise. It seems contradictory to generate a large amount of heat with the lamp, only to reflect part of it back into the product, where it can create challenges for other components. This creates an opportunity for the redesign to save energy as well as materials.

Cutouts in the steel frame allow the glass panel assembly to be slid on extruded bosses on the housing. The shape of the cutouts creates pressure between the glass panel assembly and the rubber profile on the housing. This pressure ensures that water cannot get through this connection. However, this pressure on the extruded bosses can cause them to deform or become damaged, especially at higher temperatures. This can affect the waterproofing of the connection.

2.3.3 Radiated output

As mentioned before, the current Sunshower uses incandescent halogen lamps to generate light. In Figure 13, the specific light spectrum from the Sunshower is shown. The spectrum ranges from 500 nm to 3000+ nm and peaks around 1200 nm and 1350 nm. Even though the broad spectrum ensures the inclusion of the right wavelengths that were determined in chapter 2, it also wastes a lot of energy on wavelengths that do not necessarily provide the desired benefits. In Figure 13, the energy distribution per infrared region is shown. This table shows how close to 50% of the energy is used for IR-B and IR-C, which are mostly experienced as heat and are not recommended for photobiomodulation. Even within the IR-A region, a lot of energy is directed towards unrecommended wavelengths, ultimately wasting energy.

The irradiance levels per wavelength seen in this graph are typically lower than the recommended irradiance levels in literature.

The light of the Sunshower is emitted over a certain surface area. Figure 14 shows how the light is divided over a flat surface at a 30 cm distance. The area straight in front of the lamp receives the highest amount of light. The intensity of the light becomes lower the further from the center it is measured. The most effective zone is about 10 cm away from the center. Beyond this distance, the irradiation drops to about 40% of the irradiation in the center. This means that the most effective zone is only 20 cm wide, which is not enough to cover the front or back of the human body.

Parameter	Spectral region			
	VIS (380 ≤ λ ≤ 780 nm)	IR-A (780 ≤ λ ≤1400 nm)	IR-B (1400≤λ≤3000nm)	IR-C (λ>3000nm)
Distribution [%]	6	46	43	5

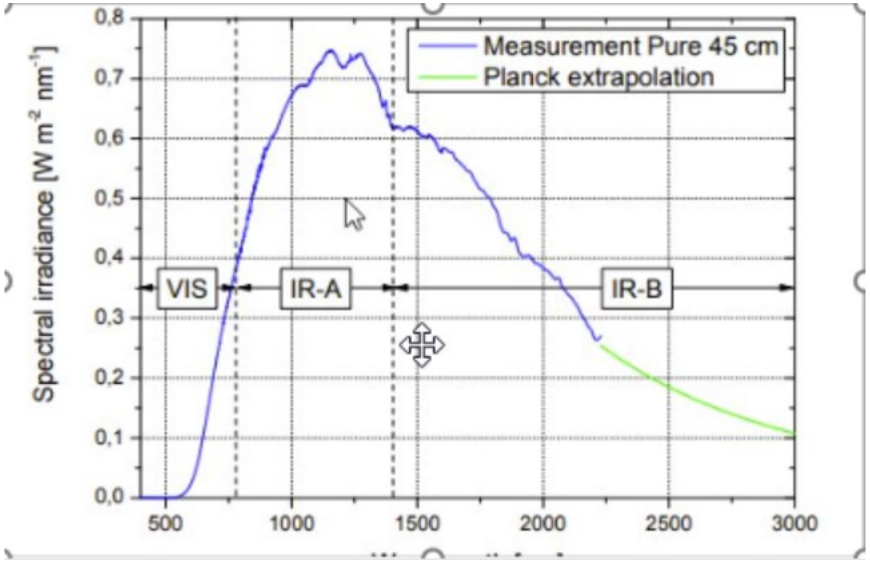


Figure 13: Radiated light spectrum of the Sunshower

	-30	-20	-10	0	10	20	30
200	0	0	0	1	1,2	1,2	0
190	0	2	4	17	8,9	5	1,1
180	4	12	26	48	27	16	5
170	10	18	40	92	35,1	22	8,9
160	18	37	78	110	83,2	48	12,8
150	22	42	88	130	92,3	54,5	16,7
140	22	63	123	150	125	61	20
130	28	69	133	170	136	67	25
120	30	74	140	171	145	75	28
110	34	76	143	170	146	80	34
100	26	66	132	161	140	78	35
90	34	80	146	170	146	80	34
80	28	75	145	171	145	75	28
70	25	67	136	170	136	67	25
60	20	61	125	150	125	61	20
50	16	54	92	130	92	54	16
40	12	48	83	110	83	48	12
30	9	22	35	92	35	22	9
20	5	16	27	48	27	16	5
10	1	5	9	17	9	5	1

2.3.4 User experience

A big part of the value of the Sunshower is the wellness experience. “Healthy light, happy people” (Sunshower, 2025) is one of the slogans of the company. This can be achieved by providing a positive experience. To ensure that the redesigned Sunshower still provides this positive experience, it is important to know what elements of the current design contribute to that.

To analyze what shapes the experience of the Sunshower, 10 regular Sunshower users were asked about their experiences using the product in a semi-structured interview.

In this interview, the participants were asked about their reasons to use a Sunshower and what value they get from using it.

During these interviews, most participants (9) mentioned the warmth or heat from the Sunshower to be a significant factor in the experience. However, when asked to elaborate on this, several participants described how they associated the warmth with the therapeutic benefits of the product. In fact, 5 of the participants admitted to not even feeling the warmth of the Sunshower due to the temperature of the shower water. 1 participant pointed out that he found the heat of the Sunshower to be too hot.

This showed that warmth itself is not necessarily a very important factor in positive experience. However, the warmth does help the user to trust that the product works.

Other elements that were named during the interviews are the color and shape of the light. A common theme among the participants was the relaxing qualities of the gradient red light. The light in the Sunshower as well as the light on the shower walls contributed to a positive experience for several participants.

For some participants, the control panel of the Sunshower can cause some irritation. The slow reaction speed and unreliability of the power button make the experience less smooth and add frustration.

Lastly, some participants (3) noted that the aesthetics of the Sunshower gave them a feeling of luxury and style. At face value, this means that they enjoy seeing the product. After follow-up questions, it was however revealed that this feeling was connected to the experience of owning such a luxury product. Participants name smooth finished shapes and high-quality materials as elements that inform this aesthetic of luxury and style.

2.3.5 Carbon footprint of the current Sunshower

In order to determine useful sustainable redesign concepts it is important to know what factors contribute the most to making the current design less sustainable. To identify these factors, a fast-track Life Cycle Assessment (LCA) was carried out. This tool allows for quantification and comparison of the environmental impact of certain elements of a design. The impact is calculated in CO2 equivalent, meaning that all impacts are converted to CO2 to allow easy comparison.

A functional unit was defined to enable a consistent comparison, taking into account that different designs may have varying environmental impact profiles. Functional units divide environmental impacts by how much service is performed for users (Faludi, 2025). For this redesign that means comparing the products on the amount of meaningful therapies delivered. Therefore, the functional unit of this LCA is: 2000 sessions of infrared light therapy.

To carry out this fast-track LCA, the LCA format tool from Jeremy Faludi was used in combination with the Idemat 2026 and EcoInvent V3.3 database.

In figure 14, the total calculated kg CO2 equivalent impact of the Sunshower is shown. The total impact is broken down into the phases Materials and manufacturing, Transport, Use and End of Life. The biggest impact is clearly created by the impacts of the use phase. This also means that this phase carries the biggest potential to reduce the impacts. During use, the Sunshower uses about 2000 W to power the lamps and other electronics. The impact of this phase can be

When looking closer at the materials and manufacturing phase, it is evident that the housing is the most impactful component. This is both due to the impact of the material extraction and the weight factor of the component. The full LCA table can be found in Appendix G.

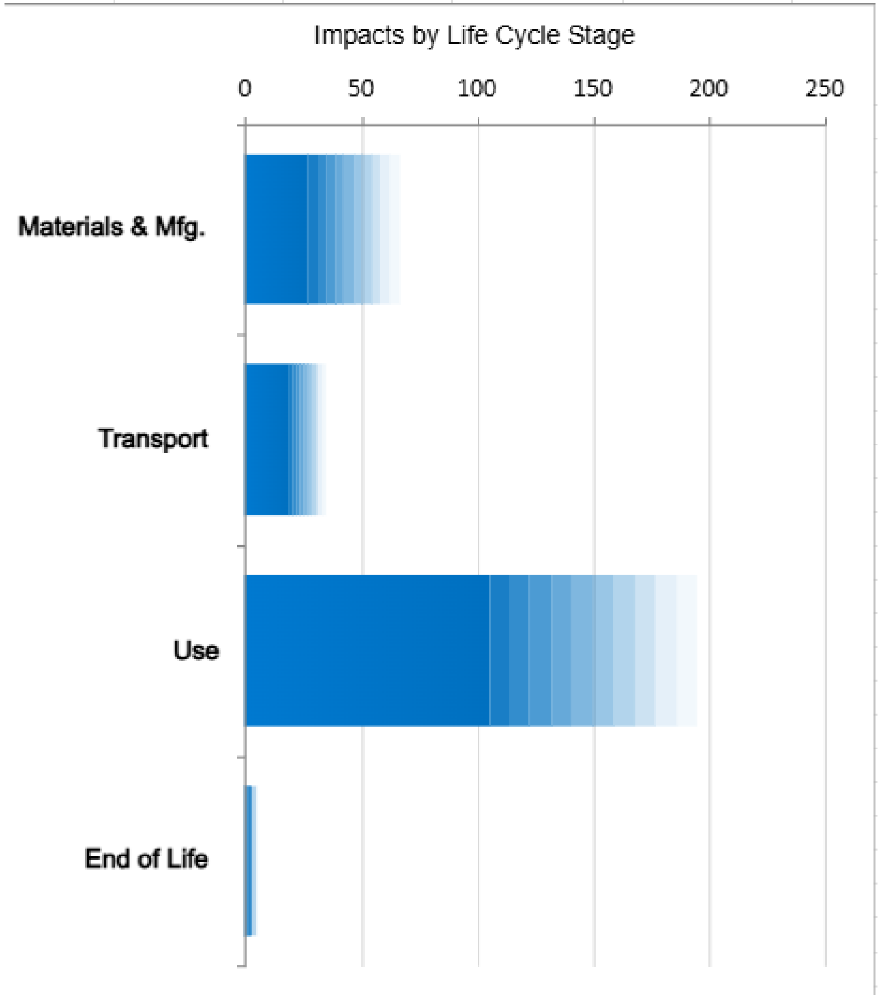


Figure 14: Division of carbon footprint of the current Sunshower over different product life stages

2.3.6 Aesthetics

Next to providing wellness and health benefits, the Sunshower is also a product that is meant to be aesthetically pleasing. The current Sunshower is designed to look modern and luxurious. Depending on the color and model, the current design can either blend in or stand out in bathrooms (see figure 15).

Figure 15: Examples of Sunshower styling

Several elements that contribute to the look of the current design are shown in Figure 16.

Figure 16: Elements of the Sunshower aesthetic experience

2.3.7 Design Takeaways

From this analysis of the current Sunshower, several design takeaways have been identified. In Table 2, these takeaways have been categorized per subchapter.

The analysis of the current Sunshower reveals several opportunities for improvement in functionality, user experience, and sustainability. A key technical challenge is the management of heat and infrared output. The current halogen lamps emit a broad spectrum of infrared radiation, of which a significant portion does not contribute to the intended therapeutic effect. Much of this energy is experienced only as heat, reducing efficiency and increasing energy consumption. At the same time, the effective irradiation area is relatively small, limiting the coverage of the user's body. A redesign should therefore focus on generating more targeted wavelengths while increasing the effective radiated surface.

The product architecture also presents opportunities for simplification. The reflector and double-glass construction add weight, material use, and thermal challenges by reflecting heat back into the housing. In addition, the current housing design relies on bottom ventilation, which causes heat accumulation near the top of the product. Reducing unnecessary internal heat and simplifying the assembly could improve reliability, reduce material usage, and lower the environmental impact of the product. Particular attention should also be given to vulnerable connection features, such as the deformations occurring at the glass mounting bosses under high temperatures.

From the user analysis, it became clear that the perceived wellness experience is not solely dependent on physical warmth. Instead, users strongly associate the red light, soft gradients, and luxurious appearance with relaxation and therapeutic effectiveness. Smooth finishes, premium materials, and seamless interaction contribute to the product's perceived value. Therefore, the redesign should preserve the calming visual identity and premium aesthetic of the Sunshower while improving usability and responsiveness.

Finally, the LCA demonstrated that the use phase dominates the overall carbon footprint. This indicates that reducing energy consumption offers the greatest opportunity for improving sustainability.

Table 2: Design takeaways per subchapter

Product components	Radiated output	User Experience	Carbon footprint
Ventilation openings at bottom and top	Wider radiated surface	Heat is not vital	Lower energy usage
Cavity for installation frame	Less unfunctional wavelengths	Reduce Housing size	Different material for housing
No reflector		Gradient red is relaxing	Reduce housing weight
Single glass pane		Smooth finish	

2.4. Analyzing the differences between Halogen and LED technology

In this subchapter, the differences between halogen and LED technology are analyzed. Halogen is a collective term for a lot of different lamps, therefore this chapter will focus on the lamps used in the current Sunshower. The lamps that are currently used are quartz tube tungsten lamps. This analysis will show design opportunities and challenges that the switch from halogen to LED creates.

2.4.1 Working mechanism

LED and halogen lamps produce light in fundamentally different ways, especially when it comes to infrared. A halogen lamp is a type of incandescent bulb: an electric current heats a tungsten filament until it glows.

An LED lamp, by contrast, generates light through electroluminescence in a semiconductor junction. When current passes through the LED, electrons recombine with holes and release energy mostly as photons in a relatively narrow wavelength range.

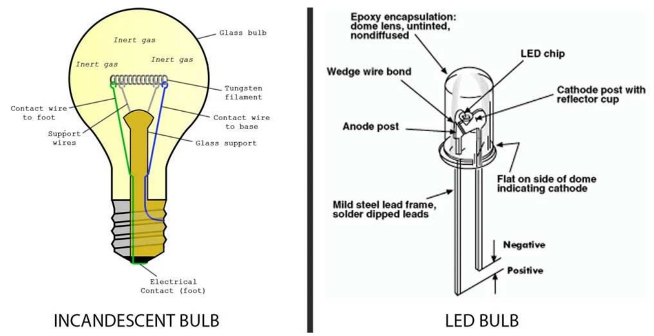


Figure 17: Working mechanisms of incandescent and LED lamps

2.4.2 Optical and thermal output

As a result of their fundamentally different working principles, the thermal and optical output of LED and halogen light sources differs significantly. Halogen lamps operate through thermal radiation, in which a filament is heated to very high temperatures. This process results in a broad and continuous emission spectrum, typically ranging from approximately 600 nm to beyond 3000 nm. Within this range, a substantial portion of the emitted energy lies in the red, near-infrared, and infrared regions. Consequently, a large share of the electrical input is converted into heat rather than visible light, leading to high radiant heat output directed into the surrounding environment and towards the user.

In contrast, LEDs generate light through electroluminescence, a process that does not rely on high temperatures to produce radiation. This allows LEDs to emit light within a relatively narrow spectral band, often centered around a specific wavelength depending on the semiconductor material. As a result, LEDs can be tuned to emit primarily within the visible or near-infrared range with minimal emission outside the desired spectrum. This spectral specificity leads to a more efficient conversion of electrical energy into usable light, with comparatively limited radiant heat emission in the form of infrared radiation.

From a design perspective, this distinction has important implications. Halogen lamps inherently introduce significant radiant heat into the system and the surrounding space, which must be managed at the product level and may influence user comfort and safety. LEDs, while still generating heat at the component level, emit far less heat as radiation and instead concentrate thermal loads within the device itself, requiring internal heat dissipation strategies. Overall, halogen sources act as broad-spectrum radiators with high external heat output, whereas LEDs function as spectrally selective sources with more localized and controllable thermal behavior.

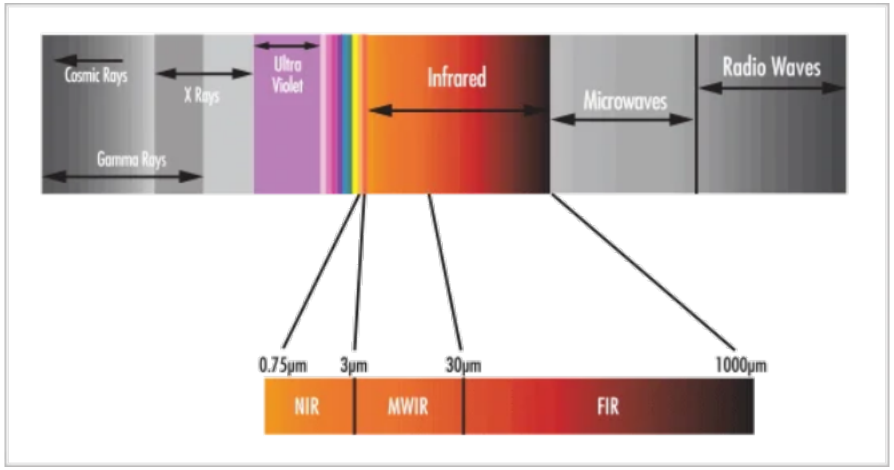


Figure 18: Visualization of the (infrared) light spectrum

2.4.3 Product integration

The integration of light sources into products differs fundamentally between LED and halogen technologies, particularly in terms of spatial requirements and implementation methods. LEDs are highly compact and adaptable, allowing integration at multiple scales within a product. Common configurations include surface-mount devices (SMD) directly soldered onto printed circuit boards, as well as chip-on-board (COB) modules and flexible LED strips for creating continuous light-emitting surfaces. Through-hole (pin) LEDs are also used in applications requiring mechanical robustness or simpler assembly, though they are less space-efficient. These formats enable LEDs to be distributed across surfaces and embedded within thin or complex geometries, making them well-suited for highly integrated product designs.

In contrast, halogen lamps are discrete components that require standardized sockets or lamp holders (e.g. GU10 or G4), which define both their positioning and electrical interface. This results in fixed spatial requirements not only for the lamp itself, but also for the holder, wiring, and necessary installation clearance. Consequently, halogen integration is typically more volumetric and modular, often requiring dedicated cavities and access for replacement. Compared to LEDs, which can be seamlessly integrated into the product structure, halogen systems impose more rigid design constraints and tend to result in bulkier assemblies with clearly defined component boundaries.

In conclusion, LEDs support a more integrated and space-efficient design approach, enabling compact form factors and greater geometric flexibility. Halogen lamps, by contrast, necessitate a component-based integration strategy with predefined spatial envelopes and accessibility requirements, which can limit design freedom. As a result, the choice between these technologies has direct implications for product architecture, particularly in applications where space constraints and integration are critical.

2.4.4 Design Takeaways

The comparison between halogen and LED technology highlights several key design implications for the redesign of the Sunshower. First, the shift from halogen to LED fundamentally changes how radiation is generated and controlled. LEDs offer narrow, wavelength-specific output, enabling precise targeting of photobiomodulation ranges, whereas halogen sources emit a broad spectrum with less control. This creates opportunities for more efficient and application-specific dosing, but also requires careful selection and configuration of LED wavelengths to achieve the desired therapeutic effect.

Second, the thermal behaviour shifts from external radiant heat (halogen) to internally concentrated heat (LED). While LEDs reduce heat exposure to the user, they introduce stricter requirements for internal thermal management, such as heat sinks and conductive pathways. This allows for safer user interaction but demands more deliberate integration of cooling within the product architecture.

Finally, LEDs enable a significantly higher level of design integration. Their compact size and flexible formats (e.g. SMD, COB, strips) allow for thinner, more adaptable designs that can better fit within the spatial constraints of a shower environment. In contrast to the bulky, modular nature of halogen systems, LED-based designs can be more seamlessly embedded into surfaces and tailored to different configurations. Overall, the transition to LED supports a more compact, controllable, and user-oriented product, but requires careful attention to thermal management and system-level integration.

2.5. Competitive landscape

2.5.1 Introduction

In this chapter, existing products will be discussed that target a similar market compared to Sunshower. These products use either LED or halogen technology to provide light to users. Their use context, product features, embodiment and scientific backing were analyzed. Additionally, several products were analyzed that promise to deliver similar health benefits without the use of light.
By analyzing these products, elements can be identified which can be used to redesign the Sunshower and which elements should be avoided. A side-by-side comparison of these products can be found in Figure 24.

2.5.2 Existing LED devices

In recent years, the availability of LED-based red and near-infrared (NIR) light therapy devices has increased significantly for home, wellness, cosmetic, and clinical use. These devices are available in multiple form factors including large LED panels for whole-body or large-area exposure, face and neck masks, handheld units, and belts or pads designed for localized therapy (Figure 19). Despite the variety of brands and designs, many of these devices share common manufacturing origins. Several China-based companies, particularly in the Shenzhen and Guangdong region, serve as major OEM and ODM producers of red and NIR LED therapy panels, masks, and wearable devices, supplying multiple international brands with identical or minimally modified LED modules, driver electronics, and enclosures. Consequently, devices marketed under different brand names may utilize the same core LED modules while differentiating themselves through housing design, user interface, or marketing (Therapy-Light, 2023).

Most commercially available LED therapy devices use similar wavelength combinations, typically including a red-light band around 630 to 660 nanometers and a near-infrared band between 810 and 850 nanometers. These wavelengths are widely considered to represent the therapeutic window suitable for tissue penetration and mitochondrial activation, with red light primarily targeting superficial tissues and NIR light reaching deeper muscle, joint, and nerve tissues (Red Light Therapy Machines, 2023). Because many devices are sourced from the same manufacturers, their output irradiance and spectrum often look very comparable. Differences among products therefore often reflect variations in build quality, heat management, safety certification, cooling systems, and user experience rather than fundamental differences in LED performance (Red Light Therapy Machines, 2023).

Most LED therapy devices are designed for dry environment use and are not intended to be exposed to water or high humidity. Their embodiment, power supplies, and electrical components are engineered to operate safely in dry conditions. As a result, LED panels, masks, belts, and handheld devices are rarely marketed for use in a shower.
These devices are being marketed on social media such as Instagram and Tiktok. Companies share their products and hire influencers to talk about their experiences with the products. In 2024 several red and infrared therapy products went viral on social media, attracting a lot of attention from young potential users (Shen & Zhao, 2025). From that year, the number of devices on the market skyrocketed and more diverse products started to appear. Most of these products are marketed heavily with claims of broad ranging therapy effects.
Appendix D shows an overview of the health benefits claimed by 8 large market players in red and NIR light therapy. The claimed benefits range from the improvement of sleep quality and muscle recovery to

fat loss and improved fertility. Many of these claims are not backed up by proper scientific research. These unfounded claims hurt the public opinion on photobiomodulation, as people tend to dismiss the proven therapeutic effects as nonsense as well. The combination of the shady marketing with these wild claims with cheap build quality and premium pricing presents opportunities for Sunshower to move into this market. Relying on the established reputation of Sunshower and using transparent research that is done with the product itself can position a new product as a reliable option.

Figure 19: Existing LED products

Liroma Kinpro600

The Liroma Kinpro600 is a small red and infrared LED panel. With about 90 LEDs it can cover about a quarter of the human body. Equipped with a foldable stand, the product can be used desktop or from the ground. The product has LEDs in 2 wavelengths: 680 nm and 830 nm. With the touchscreen display the 2 wavelengths can be controlled separately and the session can be defined using a built-in timer.

The LEDs of the Kinpro600 are SMDs mounted on a metal core PCB (MCPCB). Next to providing a structure for the SMDs to be mounted on, this metal core also functions as a heat sink. The PCB is cooled actively by 2 axial fans that ventilate air through the holes in the housing. To power the LEDs, fans and the display, several power supplies are installed in the housing.
To align the light emitted by the LEDs, every LED is fitted with a lens. These lenses can be clamped onto the bases of the LEDs and are about 1,5 cm thick.

Labels on the back of the product signal that this is an ODM product. Online many similar products can be found, all with the same with aluminium case and technology. The original designer and manufacturer that is listed on the back of this product is called SAIDI Pro. This is a company based in Shenzhen and offers their products on Alibaba to be rebranded and resold.

Figure 20: Liroma Kinpro600

SunLED Sunbooster

The Sunsbooster is a small device that can be mounted on top of a computer screen or laptop. It was designed to supply the user with systemic benefits of infrared light while they are at work. Over the course of about 8 hours, the Sunbooster supplies the user with an effective dose of 850 nm. What sets this product apart is the scientific foundation that it has. The founder of the company, developed the product with technology that has been clinically tested to have a positive effect on energy levels. After this development, another clinical study was done to ensure the effectiveness of the product. A feature that strengthens their claim of a meaningful dose is the proximity sensor. This sensor measures the distance of the user to the device and adapts the light intensity to ensure the meaningful dose. When the user moves too far or too close to the device, it displays a warning. This feature helps the user believe in the useful effects of the product.

Figure 21: SunLED SunBooster

Taopatch Bodystation Pulse

This product is a full-body light therapy device that is not available to consumers. The design is very similar to the Liroma Kinpro600 device. The same aluminum casing and LED modules indicate a similar ODM manufacturing. However, the Bodystation Pulse is equipped with a myriad of features to allow the user to shape a personal light therapy. The 3 types of light can be controlled separately and can be adjusted in intensity on the touch screen display. Pulsing of the light can be switched on and changed to the desired frequency. Presets of these settings can be saved for up to 3 persons. Lastly a timer can be set for a desired time to complete the personalized session.

Personalization makes the product usable for everyone. However, it does require the user to research and know what settings will create a meaningful dose.


Figure 22: Toapatch Bodystation Pulse

2.5.3 Existing Halogen products

Repabad Bilbao
This product is very similar to the Sunshower in terms of use context and technology. The Repabad device can be installed in the shower and uses halogen lamps to emit its light. However, there are a few key differences in how users interact with the product. Where the Sunshower is mainly used standing up, the Repabad is meant to be used sitting down. This creates the need for a shower bench to be installed and ultimately changes the shower experience. Using the product sitting down means that the therapy can only be delivered to the back of the user.

To facilitate a safe and comfortable experience, a backrest is included that the user can sit up against. This not only prevents the user from the heat of the lamps but can also ensure a proper distance for effective light therapy. On the other hand, this backrest blocks large parts of the back that would otherwise receive therapy.

For the goals of the Repabad, which is mainly focused on delivering heat instead of light, this is not a problem. However, for the goals of the Sunshower this would restrict a big part of the targeted light area.

Other features of the Repabad include a power button and an intensity slider. With this slider, the power of the lamp can be adjusted. As the therapy is mainly focused on heat delivery, this feature makes sense. However, for effective light therapy this would not be a useful feature, as it is dependent on the right amount of light being delivered.

The device itself is relatively large. When mounted on a wall, the product extends 11 cm with the backrests adding another 10 cm. This leads to 21 cm extending from the wall, which takes up a big part of most showers.

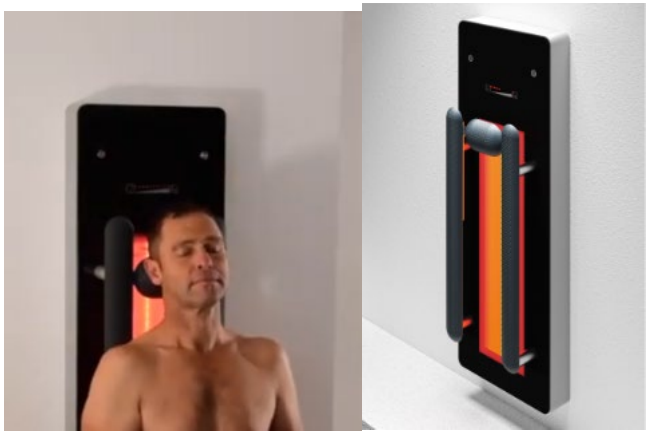


Figure 23: Repabad Bilbao

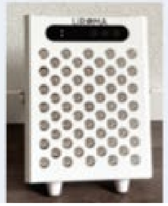
x	Liroma	Taopatch	Sunbooster	Repabad	Infrared sauna
Description	A desktop LED infrared panel with built in display and timer	A full body panel with multiple wavelengths LEDs that can be controlled by a touch screen display	Small mountable LED device that radiates infrared light on the users face during the work day	Infrared heat device that is used in the shower. Is used sitting down and uses halogen lamps	Sauna cabin with integrated carbon fiber panels that produce far infrared radiation.
Technology	LED	LED	LED	Halogen	Carbon fiber plates
Focus	Red + NIR light therapy	Red, blue and NIR light therapy	NIR therapy	Heat therapy	Heat therapy
Light spectrum	660 nm + 810 nm		850 nm	Broad spectrum between 600 and 3000 nm	Broad spectrum 3000+ nm
Use context	Product has to be used in a dry environment and can be moved to users wishes, clothes have to be taken off specially for use	Product has to be used in a dry environment and can be moved to users wishes, clothes have to be taken off specially for use	Product is clipped to computer screen and works passively while working	Product is used in the shower, but has to be used with a seat, has soft backrests that ensure the right distance	User has to sit in a dedicated cabin
Body coverage	Quarter-body	Full-body	Face	Half-body	Full-body
Energy usage	600 W		4 W		3100 W
Scientific backing			2 Clinical studies researching the effect of this technology published		
Price	€ 455	€ 2999	€ 199	€ 2958	€ 2749
Image					

Figure 24: Side-by-side comparison of competing devices

2.5.4 Design Takeaways

The competitive landscape illustrates a market that is technologically mature at the component level, yet fragmented in terms of product execution, positioning, and credibility. Within the LED segment, a clear pattern emerges in which many devices rely on standardized hardware originating from OEM/ODM manufacturers. As a result, similarities in wavelength ranges, output, and core functionality are common across competing products. Meaningful differentiation therefore tends to occur not in the underlying technology, but in areas such as industrial design, usability, and brand communication. For Sunshower, this suggests that innovation should focus less on reinventing the technology itself, and more on how it is integrated into a coherent and high-quality user experience.

Another important observation concerns the discrepancy between marketing claims and scientific substantiation. Many LED-based devices are promoted with broad and sometimes weakly supported health claims, which risks undermining user trust in photobiomodulation as a whole. This presents a clear opportunity for Sunshower to take a more transparent and evidence-based approach. By communicating realistic, research-backed benefits and linking these directly to the product, Sunshower can position itself as a more credible and trustworthy alternative within a market that is increasingly met with skepticism.

From a product design perspective, several recurring features offer useful insights. Personalization options, such as adjustable settings, timers, and user-specific presets, can enhance user engagement, but may also introduce complexity and require a certain level of prior knowledge. Similarly, features like proximity sensing demonstrate how technology can support users in achieving an effective dose, while also increasing confidence in the product's functionality. These findings suggest that future designs should aim to balance flexibility with guidance, enabling users to benefit from personalization without making the system unnecessarily complicated.

The analysis of halogen-based products further emphasizes the importance of use context and physical integration. The Repabad Bilbao, for instance, shows how differences in posture and interaction can significantly affect both the user experience and the effectiveness of light exposure. In addition, large and intrusive form factors can limit usability and reduce effective treatment areas. This underlines the importance for Sunshower to maintain a compact and well-integrated design that fits naturally within existing shower routines, while maximizing exposure to the body.

Overall, the findings point towards a clear direction: combining intuitive interaction, thoughtful safety features, and appropriate levels of personalization, while avoiding overcomplicated systems and unsupported claims. Building on its existing reputation and focusing on a seamless, evidence-based user experience within the shower environment, Sunshower is well positioned to introduce a product that stands out in a crowded and often inconsistent market.

2.6. Bathroom Context

2.6.1 Regulatory implications

To be able to place the designed product on the Dutch and European market, it must adhere to a set of laws and regulations.

The most important documents are:

- NEN 1010
- NEN-EN-IEC 60335
- NEN-EN-IEC 60529
- NEN-EN-IEC 61000
- NEN-EN-IEC 62471
- Richtlijn 2001/65/EU - RoHS Complaint
- ICNIRP "ICNIRP Statement on far infrared radiation exposure"
- ICNIRP „ICNIRP Guidelines on limits of exposure to incoherent visible and infrared radiation "
- MDR (Medical Device Regulation)

The use-context of the Sunshower subjects it to a number of risks and therefore regulations. Firstly, introducing electronics into a wet environment brings risks of electrocution. To mitigate these risks, standards such as NEN 1010 require permanent installation, proper grounding, and strict separation between electrical components and the user. Measures include insulated electronics, the avoidance of conductive parts that connect the exterior to internal circuitry, and secure cable connections. In addition, equipotential bonding must be ensured, meaning that any conductive components that could become energized are connected to protective earth. This reduces the risk of electric shock in fault conditions and has implications for both internal construction and installation.

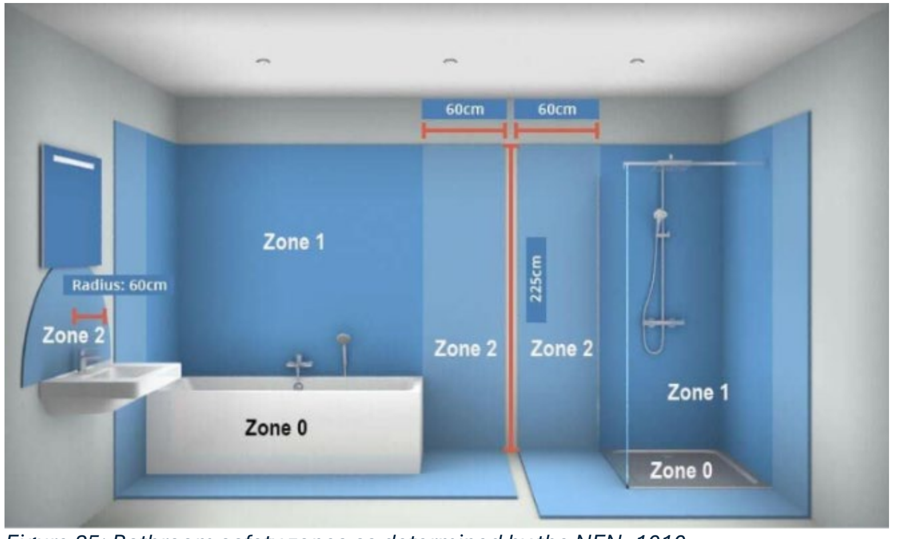


Figure 25: Bathroom safety zones as determined by the NEN- 1010

Closely related to this is the requirement for sufficient protection against water ingress. According to NEN-EN-IEC 60529, devices installed in wet zones must meet specific IP ratings. For the Sunshower, Zone 1 is applicable (Figure 25), which entails the vertical area above the shower floor up to 2.25 m. Fixed appliances may only be installed if they are minimally IPX5 and correctly protected; standard 230 V sockets and switches are prohibited. Achieving these ratings has direct design implications, particularly for sealing strategies, cable entries, and housing configuration. It also limits the use of active cooling methods such as fans, as ventilation openings must not compromise water resistance. This creates a design trade-off between thermal management and ingress protection.

Secondly, the use of radiation on the human body introduces risks of overexposure and eye damage. These risks are addressed through standards such as NEN-EN-IEC 62471 and guidelines from the International Commission on Non-Ionizing Radiation Protection

(ICNIRP). These frameworks limit the maximum irradiance and radiant exposure to which users may be subjected, particularly in the red and infrared spectrum. For example, ICNIRP guidelines restrict infrared exposure to levels that prevent excessive heating of the skin and eyes, with limits defined in terms of irradiance (W/m^2) and exposure duration. In addition, IEC 62471 classifies devices into risk groups (RG0–RG3), which determine required warning labels, user instructions, and in some cases restrictions on usage. This means that compliance is not only about limiting output power, but also about controlling exposure time, distance, and user behavior through interface design, such as timers or automatic shut-off features. In some cases, demonstrating safety and efficacy may also require clinical validation.

Thermal safety is another critical factor addressed in the NEN-EN-IEC 60335. This standard limits the maximum temperature of accessible surfaces to prevent burns. Given that the Sunshower operates in a warm and humid environment and may incorporate infrared radiation, managing surface temperatures becomes especially important. This has implications for material selection, internal heat dissipation, and the overall form factor, as surfaces that users may come into contact with must remain within safe limits under all operating conditions.

In addition to electrical and thermal safety, electromagnetic compatibility must be ensured in accordance with NEN-EN-IEC 61000. The device must not emit electromagnetic interference that could affect other equipment, nor should it be susceptible to disturbances from external sources. This influences the design of power electronics, including LED drivers and control systems, and may require shielding and filtering components.

Lastly, installation constraints defined by NEN 1010 further limit how and where the Sunshower can be implemented. Zone 2 extends 60 cm horizontally from Zone 1 and may apply to the power source of the system. Equipment in this zone must have at least IP44 protection and be connected to a circuit protected by a residual-current device (≤30 mA). As most of the wall surface within a standard shower falls within Zone 1, this creates significant challenges for installation. Devices requiring mains voltage, external power supplies, or additional control units often necessitate professional installation and structural modification to remain compliant.

In rental housing, these constraints become even more restrictive. Tenants are generally not permitted to make permanent alterations such as drilling into tiles, modifying fixed electrical installations, or installing built-in fixtures without landlord consent. Bathrooms are particularly sensitive due to the risk of water damage and electrical hazards. As a result, products that require wall penetration, concealed wiring, or permanent mounting create a high threshold for adoption. Even when technically compliant, the need for certified installers and approval increases cost and reduces accessibility. Non-invasive or reversible installation methods are therefore significantly more compatible with rental housing conditions.

Overall, these regulations show that the design of the Sunshower is shaped by an interplay of electrical safety, water resistance, thermal management, radiation exposure limits, and installation constraints. Rather than addressing these aspects in isolation, an integrated design approach is required to balance safety, usability, and feasibility within the unique context of the shower environment.

As a result, products that require wall penetration, concealed wiring, or permanent mounting create a high threshold for adoption in rental housing. Even when technically compliant with electrical standards, the need for landlord approval and certified installers increases cost and reduces accessibility. Non-invasive or reversible installation methods are therefore significantly more compatible with rental housing conditions.

In addition to general electrical safety requirements, light therapy devices are subject to regulations that specifically address optical radiation and its interaction with the human body. These regulations are particularly relevant for products emitting red and near-infrared light, as improper exposure can lead to thermal damage or other adverse biological effects. Within the European context, standards developed by the IEC, such as IEC 62471, provide guidance on the photobiological safety of lamps and lamp systems. Complementing these, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) publishes exposure guidelines that define safe limits for human exposure to visible and infrared radiation. Together, these frameworks ensure that compliance extends beyond electrical safety to include strict control over emitted radiation and its biological effects.

A key aspect of these regulations concerns quantitative exposure limits. According to ICNIRP guidelines on incoherent visible and infrared radiation, the maximum permissible exposure to protect the eye from thermal injury in the infrared range (approximately 780–3000 nm) is typically limited to a corneal irradiance of 100 W/m^2 for exposure durations exceeding 1000 seconds. For shorter exposures, higher irradiances may be permitted, but only within defined time–intensity relationships. For skin exposure, limits are generally expressed in terms of radiant exposure, with values on the order of several kJ/m^2 depending on wavelength and duration, to prevent excessive heating and burns. These limits are particularly relevant for devices intended for repeated or prolonged use, as cumulative exposure must remain within safe boundaries.

The ICNIRP statement on far infrared radiation further emphasizes the risk of thermal damage due to prolonged exposure. It highlights that, for wavelengths above approximately 1400 nm, absorption occurs primarily at the skin surface, increasing the risk of localized heating. As a result, exposure limits are designed to prevent skin temperatures from rising to levels that could cause pain or tissue damage. This reinforces the importance of carefully controlling both the intensity and duration of emitted radiation, particularly in enclosed environments where heat dissipation may be limited.

These regulatory limits have direct implications for product design. Devices must be engineered such that their maximum output, at the minimum user distance, does not exceed ICNIRP-defined exposure thresholds under any operating condition. This affects not only the selection and configuration of light sources, but also the implementation of control mechanisms such as timers, fixed distances, and output restrictions. In systems that allow user-adjustable settings, worst-case scenarios must be considered to ensure compliance across all modes of operation.

For Sunshower, these considerations are especially relevant given the intended use in a warm, humid, and spatially constrained shower environment. The combination of infrared radiation and ambient heat increases the importance of maintaining safe exposure levels. Integrating ICNIRP-based limits into both the hardware design and user interaction, through features such as controlled session durations and predefined output levels, ensures that the product remains safe while still delivering an effective therapeutic dose.

Lastly, the MDR (medical device regulation) is a regulation with implications for this project. Whether the Sunshower qualifies as a medical device is up for debate. However, the MDR is evolving to also include devices without an intended medical purpose. In Annex XVI of the MDR, groups of such devices are listed. On of the listed groups is described as:

High intensity electromagnetic radiation (e.g. infra-red, visible light and ultra-violet) emitting equipment intended for use on the human body, including coherent and non-coherent sources, monochromatic and broad spectrum, such as lasers and intense pulsed light equipment, for skin resurfacing, tattoo or hair removal or other skin treatment.

The Sunshower could fit this description. That would mean that it would have to meet the requirements of the MDR. One of the biggest implications of that would be that all devices under the MDR must be clinically tested and evaluated. As the process of developing and carrying out such research is costly and takes time, this would have big consequences for Sunshower.

2.6.2 Use context

Showers come in a lot of different shapes and sizes. Depending on the layout of the bathroom, a shower can have one, two or three walls surrounding it. As one of these walls typically holds the shower fixture, that leaves either zero, one or two walls to mount a Sunshower to (see figure 26).

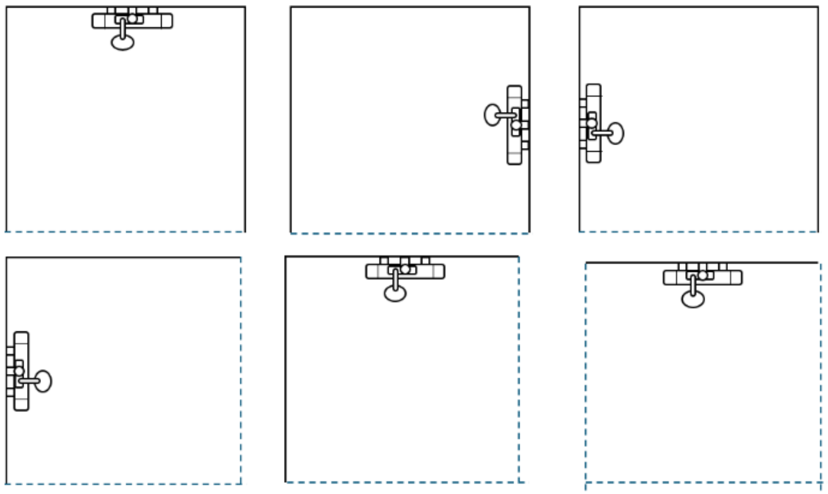


Figure 26: Possible shower lay-outs

In Dutch residential housing, showers are typically designed as compact, standardized units rather than generous wellness spaces. Common shower dimensions range from 80 × 80 cm to 100 × 100 cm, with rectangular walk-in showers often measuring 80 × 100 cm or 90 × 120 cm. In rental apartments, the minimum sizes (80 × 80 cm) are especially prevalent due to space constraints and cost efficiency. Ceiling heights in showers usually correspond to general room heights of 2.3–2.6 m.

These dimensions mean that any additional product installed within the shower area must fit within a small pocket without reducing user movement or obstructing existing fittings. Products such as the Sunshower, which are installed on shower walls and occupy vertical surface area, therefore directly compete with limited usable space. The most common existing fittings that the Sunshower has to compete with for this usable space are the shower fixture itself, shampoo niches and shower racks (figure 27).

Figure 27: A shower rack and a shampoo niche

Electrical installations in showers are regulated by strict zoning regulations due to the presence of water. Under NEN 1010, shower areas are divided into zones that determine what electrical equipment is allowed. In the first zone, Zone 0 (See figure 25), the interior of the shower tray or floor area. Only SELV (Safety Extra Low Voltage) (≤12 V AC / 30 V DC) equipment with IPX7 protection is allowed. As this zone covers only the lowest part of the shower, it is not restricting to the Sunshower itself. However, it might concern the power cord that runs to the product.

The ambient temperature in a shower can reach up to 35 degrees Celsius with a relative humidity of 100%. Although this is advantageous for the wellness experience, it does present challenges for the electronics within the product. The moisture in the air can cause erosion and short circuiting of electronics. Raised ambient temperature can lower the efficiency of electronic components.

2.6.3 Design Takeaways

The regulatory framework places strict, interconnected constraints on the Sunshower design. Electrical and safety standards such as NEN 1010, NEN-EN-IEC 60529, and NEN-EN-IEC 60335 require robust grounding, high water resistance (≥IPX5 in Zone 1), and safe surface temperatures. This drives a sealed, well-insulated design where thermal management must be achieved without compromising waterproofing, limiting options like active cooling.

Radiation-related standards, including NEN-EN-IEC 62471 and guidelines from ICNIRP, add constraints on light intensity and exposure. Compliance depends not only on output limits, but also on user interaction, requiring features such as timers and automatic shut-off to control exposure duration.

Practical use further narrows the design space. Strict installation rules and rental housing constraints discourage invasive or permanent solutions, favoring compact, easy-to-install, and potentially reversible designs. Combined with small shower dimensions and harsh conditions (heat and humidity), this leads to a clear direction: a compact, sealed, thermally efficient product that integrates safety into both its hardware and user interaction.

3. Defining phase

This chapter summarizes all the takeaways and conclusions that have been made during the analysis phase. The insights that were gained were transformed into a list of requirements and a set of main design drivers to guide the next phase in the project.

3.1 Compilation of Design Takeaways

This chapter summarizes the findings from previous analyses into a structured design framework for the redesign. It serves as a bridge between research and concept development, translating insights from regulations, technology, user needs, and market context into clear and actionable design requirements.

The visual summarizes these takeaways in a concise format, showing how different factors are interconnected and must be addressed together. By organizing them into thematic sections and coded elements, the framework provides both overview and traceability.

REGULATORY & SAFETY

RS1: Electrical safety (grounding, insulation)
RS2: Waterproof ≥ IPX5
RS3: Safe surface temperatures
RS4: Timers & auto shut-off
RS5: Safety in hardware + UX

TECHNOLOGY & ENGINEERING

TE1: LED wavelength control
TE2: Internal thermal control
TE3: Passive cooling
TE4: Compact architecture
TE5: Efficient integration

FORM FACTOR & INSTALLATION

FF1: Compact design
FF2: Easy installation
FF3: Modular/reversible
FF4: Heat & humidity resistant
FF5: Maximize exposure

PHOTOBIOMODULATION

PBM1: Dose 1–4 J/cm^2
PBM2: Irradiance 5–100 mW/cm^2
PBM3: Time 30–600 s
PBM4: Depth-based wavelength
PBM5: Overdose protection

USER EXPERIENCE

UX1: Intuitive use
UX2: Simple + personalized
UX3: Presets & guidance
UX4: Smart sensing
UX5: Fits shower routine

MARKET & POSITIONING

MP1: Differentiate via UX/design
MP2: Evidence-based claims
MP3: Build trust
MP4: Avoid exaggeration
MP5: Strong branding

PRODUCT ARCHITECTURE

PA1: Lightweight
PA2: Sealed design
PA3: Reduce size/weight
PA4: Easy assembly
PA5: Low energy/material use

Figure 28: Categorized compilation of design takeaways

3.2 List of Requirements

From the design takeaways of the analysis phase, requirements and wishes can be derived. In table 3, the most important requirements and the chapter they originate from are shown. In appendix J, the full list of requirements is shown in more detail.

Table 3: Simplified list of requirements

	Requirement theme	**Category**	**Source chapter**	**Associated Requirements**
1	The product uses LED technology to generate light	Technology	1.1	1.1-1.2
2	The product delivers a dose of light that is consistent with scientific literature	Output	2.1	2.1-2.7
3	The product radiates a light spectrum that is associated with the desired health benefits in scientific literature	Output	2.1	3.1-3.8
4	The product radiates half the body	Dimensions	1.1	4.1-4.4
5	The product is safe to use in regard to radiated output, electrical safety and generated heat	Safety	2.6	5.1-5.17
6	The product must be able to withstand the conditions of the shower environment	Environment	2.3	6.1-6.12
7	The design must adhere to the applicable regulations	Regulations	2.6	7.1-7.8
8	The design must fit into most showers	Dimensions	2.3	8.1-8.5
9	The product matches the Sunshower product portfolio and brand identity	Aesthetics	2.3	9.1-9.9
10	It must be clear to the user how a meaningful dose can be achieved	Interaction	2.5	10.1-10.6
11	The installation of the product does not require big changes to the bathroom	Installation	2.2	11.1-11.11
12	The product has a comfortable experience	Interaction	2.2	12.1-12.8

3.3 Main Design Drivers

Based on the findings in the analysis phase, 4 main drivers were identified. These 4 main drivers are the priority requirements for the new design and will inform design decisions in later phases of the project.

Compact and easy installation

The redesign should fit into most showers without having to do major renovations. This means that it should not get in the way of other shower accessories or obstruct the user in their typical shower rituals. The device should facilitate to be mounted flat on a wall to not compete for space with, for example, shower baskets. The redesign should aim to be as thin as possible so users can relax, wash and dry themselves without experiencing problems.

Safe and meaningful light

The light radiated by the redesign has the right wavelength and power to provide effective therapy, consistent with literature. This light is radiated on the targeted body parts at a comfortable distance. The power of the light is within the recommended and regulatory range to prevent damage to the skin and eyes.

Efficient use of energy

The total energy use does not require the device to be put on a separate electrical fuse. As little energy as possible is wasted on things other than effective therapy. The generation of heat is prevented as much as possible to protect internal components and to maintain the optical output of the LEDs. The light that is generated is transmitted to the user as much as possible.

Comfortable and confident experience

The experience of the redesigned Sunshower creates trust and comfort in the user. Design features and marketing emphasize effective therapy and the actions that are needed to obtain it. Nudges help users to stand at the correct distance, and a timer shows how much longer the session will take.

4. Developing phase

Building on the Discover phase, this chapter presents the development of design concepts for the redesigned Sunshower. Insights related to user needs, stakeholder input, and technical constraints informed the ideation process. Through sketching, multiple concepts were explored to translate these insights into tangible solutions, focusing on usability, integration of LEDs and user experience. This phase emphasizes the exploration of ideas through methods, allowing different directions to be evaluated. The presented concepts form the basis for selecting and refining a final design in the next chapter.

4.1 Developing product Concepts

This chapter focuses on turning the insights from the previous analysis phase into comparable concepts. Certain design decisions were made to create these concepts. The design drivers that were determined in the previous chapter were used to choose between several concepts.

4.1.1 Ideation starting point

Firstly, a 'Function Tree' (Figure 28) was created to translate the takeaways from the previous chapters into possible functions and components of the redesign. The EcoDesign Checklist from the Delft Design Guide (Van Boeijen et al., 2014) was used to make sure all categories of product functions were considered.

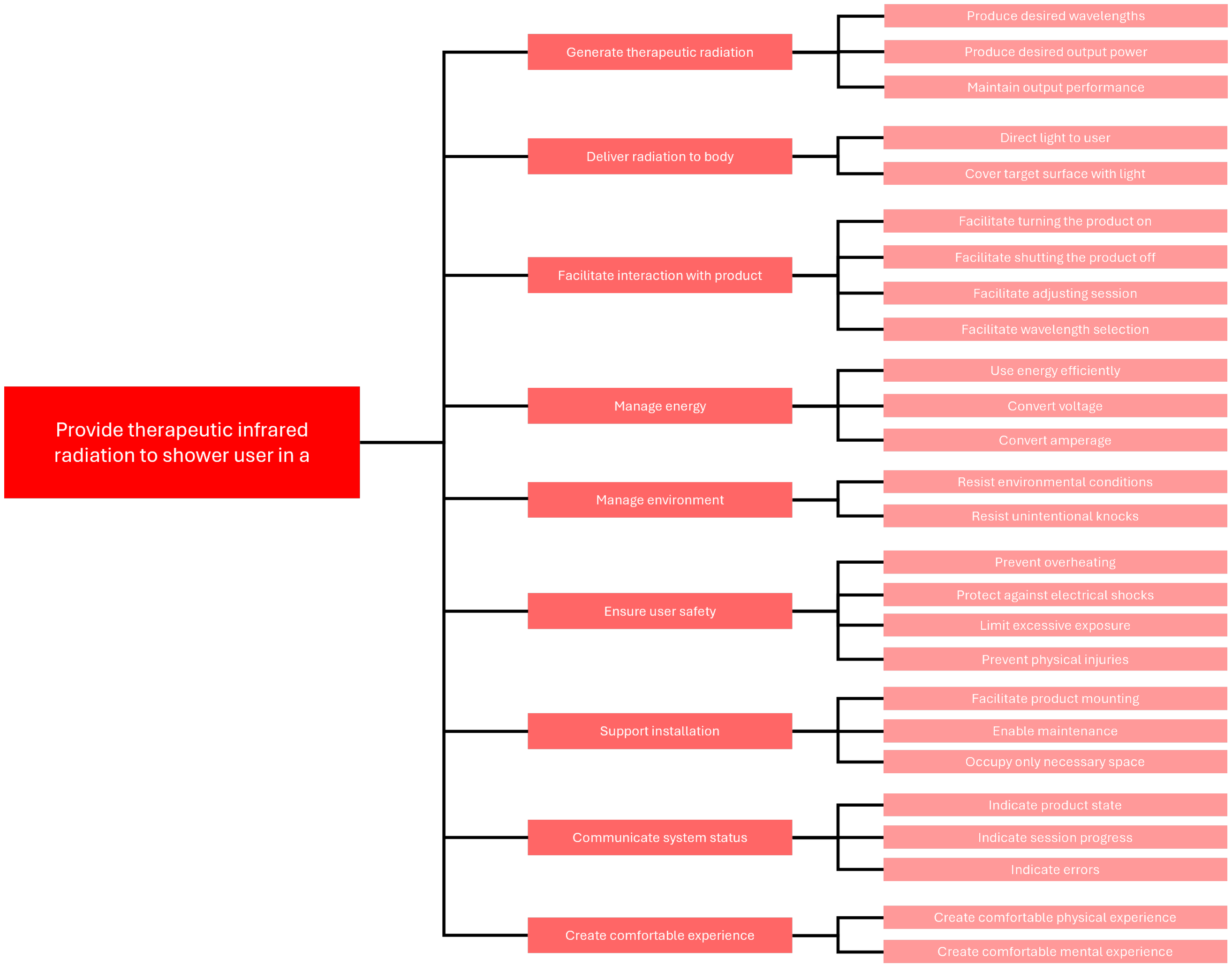


Figure 29: Function Tree

4.1.2 Product Architecture Concepts

Taking the concept developed previous to this project and the input from the function tree, ideas were generated for the product architecture of the redesign.

With these ideas, 3 product architectures were created (see Figure 30).

Product architecture 1: Sealed box

A fully sealed plastic housing protects the LED board from water exposure. Heat generated inside is passively transferred through the enclosure and front cover. This simple, waterproof design prioritizes safety and durability, though thermal performance depends on material conductivity and surface exposure.

Product architecture 2: Heat sink

This concept uses passive cooling with a metal heat sink integrated into the back wall. Heat from the LED board is conducted outward and dissipated via ribbed fins, maximizing surface area. This ensures efficient thermal management while maintaining a sealed, water-resistant design suitable for shower use.

Product architecture 3: Wind tunnel

This concept applies active cooling using a fan to create airflow through the housing. Cool air is drawn in while warm air is expelled, improving heat dissipation. Openings must be carefully designed to maintain water resistance, making this approach more complex but thermally effective.

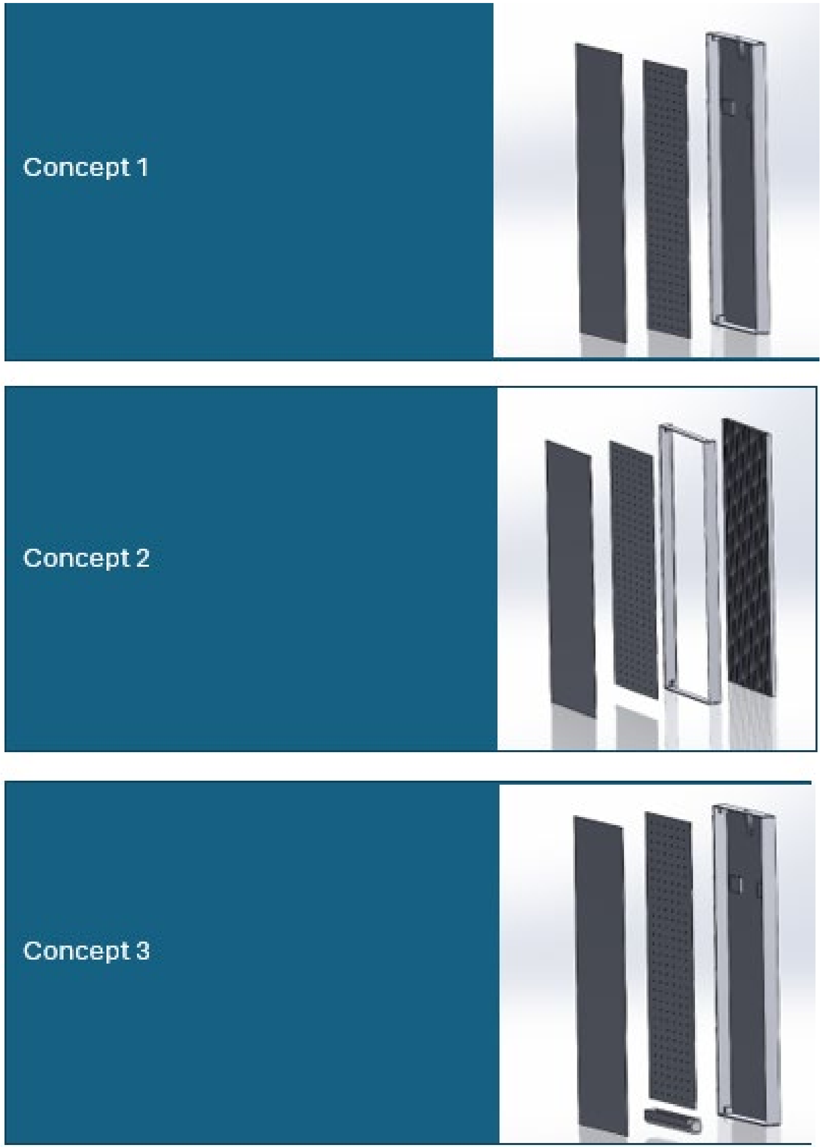
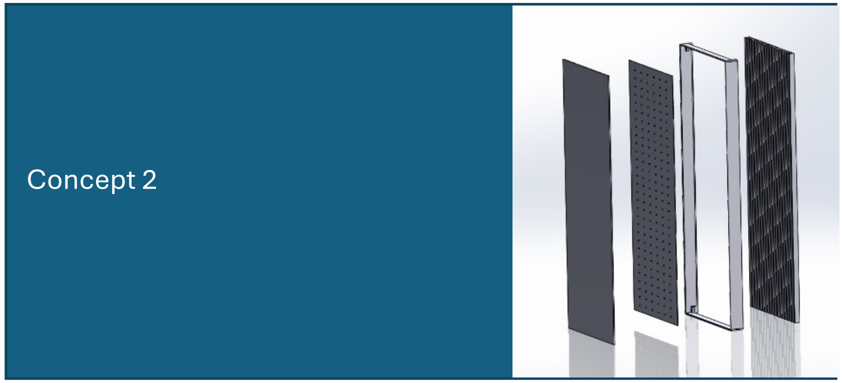


Figure 30: 3 product directions



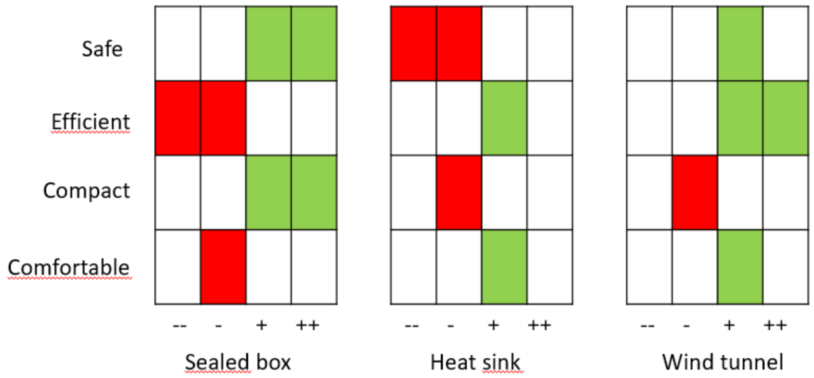


Figure 31: Harris profile of the product directions

To evaluate the 3 concepts, a Harris profile was used (Van Boeijen et al., 2014). The categories that the Harris profile compared the 3 concepts on were based on the 4 design drivers identified in chapter 3.3:

1. Safety of the product
2. Efficiency of the energy
3. Compactness of the device
4. Comfortable experience

The Harris profile shows that concept 3, the Wind Tunnel, has the best overall score and is therefore selected as the concept to continue with.

4.2 Conceptualization

This chapter shows how the concept chosen in the previous chapter is further developed into a product. In this process, the concept was divided into several different design components. These 8 components are described, visualized and connected to relevant requirements below.

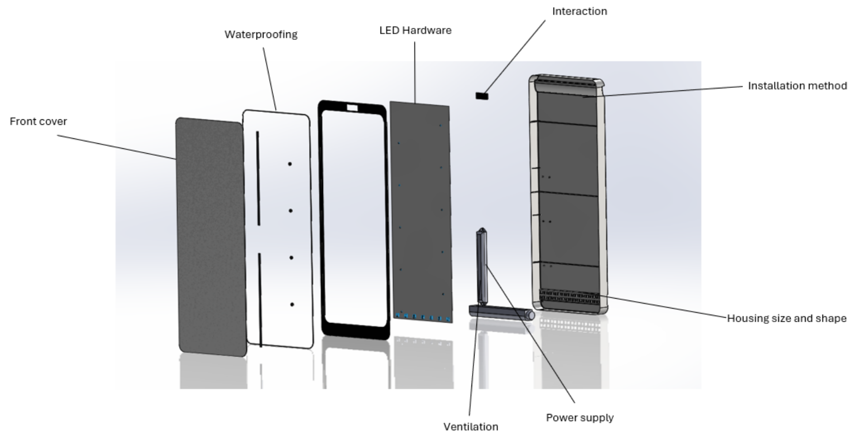


Figure 32: Design areas visualized as components

LED Hardware
The LED hardware contains the light sources responsible for therapeutic output. It must be thermally efficient, moisture-protected, and securely mounted. Proper layout ensures uniform light distribution while supporting effective heat transfer to maintain performance and longevity.

Front Cover
The front cover protects internal components while allowing optimal light transmission for effective photobiomodulation. It must be made from water-resistant, durable, and optically clear material that minimizes light loss and withstands heat, moisture, and frequent exposure to shower conditions.

Ventilation
Ventilation enables airflow through the device, supporting active cooling via the internal fan. Openings must be strategically placed to create an efficient air path, balancing heat dissipation with minimal exposure to water ingress.

Waterproofing
Waterproofing is critical in a shower environment. Seals, cable glands and protective prevent water from reaching sensitive components, especially around ventilation openings, ensuring safety, durability, and compliance with appropriate ingress protection standards.

Housing Size and Shape
The housing must accommodate all components while maintaining a compact, ergonomic form. Its shape should promote efficient airflow for cooling, fit comfortably within a shower space, and support ease of cleaning and aesthetic integration.

Installation Method
The installation method should allow secure mounting in wet environments, such as wall attachment or integration into existing fixtures. It must be stable, easy to install, and resistant to moisture-related degradation over time.

Interaction
User interaction should be simple and intuitive, potentially including waterproof buttons or touch controls. The interface must function reliably in wet conditions and allow users to operate the device safely and conveniently during shower use.

Power Supply
The power supply must be safe for wet environments, using low-voltage systems or sealed connections. It should ensure consistent performance while complying with electrical safety standards and protecting users from potential hazards.

4.2.1 LED hardware

The most vital part of any photobiomodulation device is the component that generates the light. In this project, the sources of light are LEDs. LED lamps come in several shapes and sizes that have their own characteristics. This allows them to be assembled in various ways.

Different ways of assembling large amounts of LEDs were explored and ideas were generated. In figure 34, sketches are shown of different kinds of LED arrays in different configurations. Inspiration for these ideas came from the case studies in the previous chapter and using 'Hoe kun je' (HKJ) and other methods from the Delft Design Guide (Van Boeijen et al., 2014).

With help from experts at Thal Technologies (Thal Technologies,2026), a company specialized in LED arrays, it was determined that SMD LEDs would be the best option for this redesign. Therefore, only SMD LEDs were considered for further development. The main reasons for this decision were the easy integration of SMD LEDs in large arrays and the possibilities for integrated lenses. Figure 33 shows the other considerations for this decision.

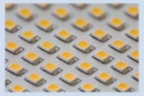
Type	SMD	COB	Through hole	LED strip
Reference picture				
Beam control	Wide options for lenses and domes	Needs external optics	Very wide beam	Unfocused
Efficiency	Good	Very good	Medium	medium
Power output	High	Very high	Low	Medium
Cost	Medium	Medium/high	Low	Low
Assembly	Very easy	Easy	Hard	Very easy

Figure 34: Comparison of several types of LEDs

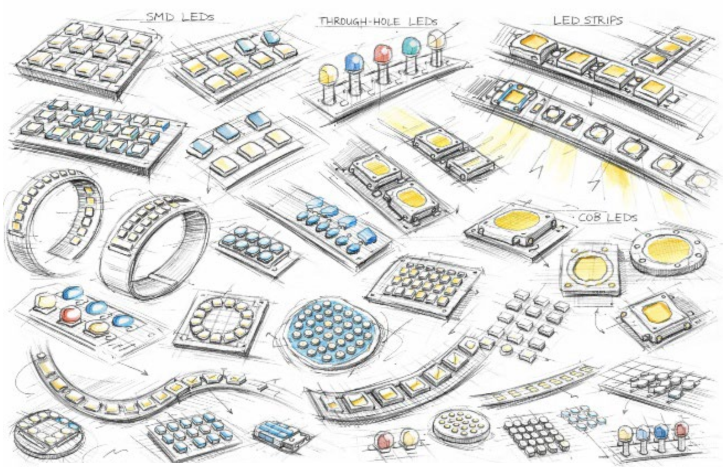


Figure 33: Sketches exploring different LED configuration types

Therapy target area

To determine the optical dimensions for the LED board, the common treatment locations for the desired health benefits have been mapped. The health benefits, that were determined in chapter 2.2, can be broken down into 4 groups. With colored spots and surfaces these 4 groups have been visualized on the male and female body in Figure 35.

To find these spots, a selection of sources was consulted.

For a broad and useful therapy, the redesign should cover as many of these spots as possible within the limits of the context and requirements.

The most important requirements to consider are:

- The redesign should fit in most showers
- The redesign should be efficient in its energy
- The redesign should be compact

For defining the dimensions of the box, data from the DINED anthropometric database was used. From this database, data of Dutch adults between the ages of 18 and 80 (measurements from 1982, 2003 and 2004) was used. In selecting the data to use, the common design limit of 95 percentile was used (Pheasant, 2003). Pheasant states that this design limit accounts for the middle 90% of the user population but that the consequences for the remaining 10% should be seriously considered. In the case of this redesign, a mismatch of the product width to the body width of the user, will cause the user to not receive effective therapy over the entire width of their body. As this consequence does not have serious implications for the health of the user and will only be “mildly inconvenient”, the 95 percentile is applicable.

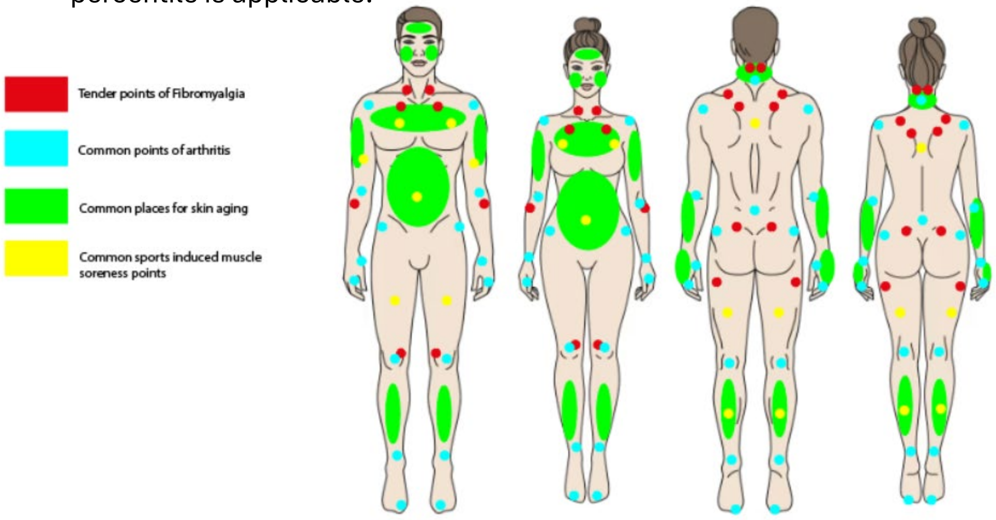


Figure 35: Relevant target points for light therapy

Following the data from DINED, an irradiation field of 45 x 100 cm would cover most of the spots identified in figure 35. This is visualized in figure 36.

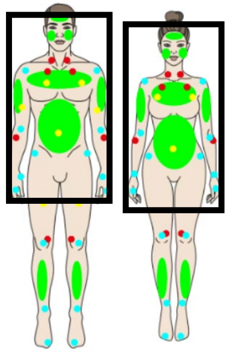


Figure 36: Outline of proposed LED board dimensions

Calculating needed LEDs

To be able to model and predict the needed amount of LEDs to cover this irradiation field in figure 36, a calculator was developed. This calculator takes the total irradiated power and combines it with the angular distribution of a certain LED to calculate the amount of power over a certain angle. Together with the distance from the target to the light source, the surface within this angle can be calculated. Dividing the total power in that angle by the surface area leads to an approximation of the irradiance that the LED has in that area (Figure 38).

The calculation follows the inverse-square law (Voudoukis & Oikonomidis, 2017), which dictates that the irradiance decreases in an inverse-square manner compared to the distance from the light source.

Now that the irradiance from a single LED on a surface is clear, the model can be used to approximate the combined irradiance of multiple LEDs placed close together Figure 37. When the irradiance values are color coded, the evenness of the irradiance over a larger surface becomes easy to see Figure 38. Faults in the distribution of the LEDs over the board can be easily spotted as lighter gaps using this color-coded model.

Combined with the desired irradiation surface from the previous subchapter, this calculator was used to determine the distribution of the LEDs. It was used to calculate how the lowest number of LEDs could achieve the desired irradiation level over the desired irradiation surface. This distribution is showed in Figure 39. The complete calculation can be found in Appendix H.

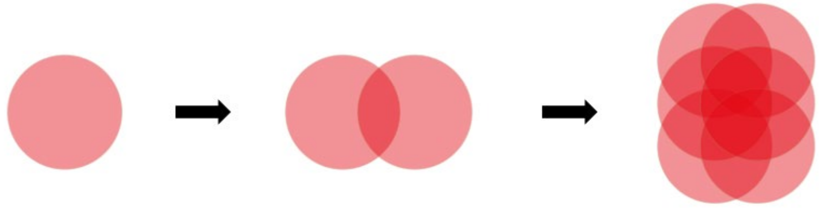


Figure 37: Cumulative irradiation effect of overlapping LED light

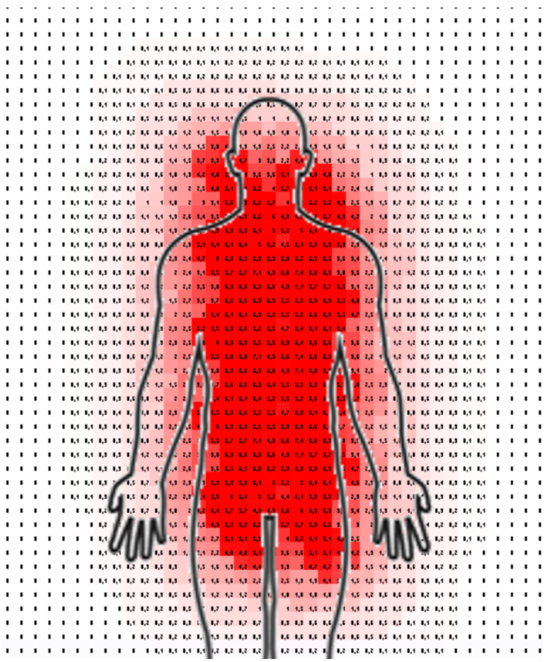


Figure 38: Color coded irradiation field calculation projected on human outline

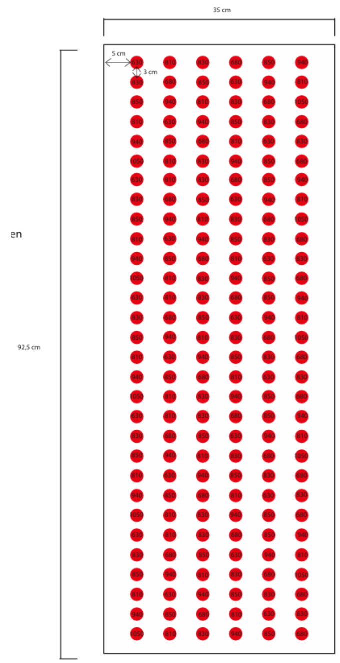


Figure 39: Proposed LED-board configuration

4.2.4 Housing shape

In this subchapter, ideas for the aesthetic appearance were generated. Mugge & Schoormans(2012) found that “novelty in a product appearance negatively affects their expectations of a product's usability at the point of sale”. Meaning that people will feel reluctant to buy a product that looks innovative and new, because it feels difficult to use.

Because the redesign in this project is quite novel in technology, the appearance of the product needs to be recognizable. Therefore, for the shape and look of the redesign, elements were chosen that closely resemble the look and feel of the current Sunshower.

Front view

In the sketches in Figure 40, different shapes and configurations were envisioned for the front view of the redesign. Shape 3 was selected for its similarity to the current Sunshower.

Side view

In figure 41, sketches are shown of 2 possible side view designs. Either the front cover is parallel with the housing or the front cover protrudes on all sides. Considering that the redesign is meant to be compact to facilitate usage in smaller showers(requirement 8), side view 2 was selected for further development

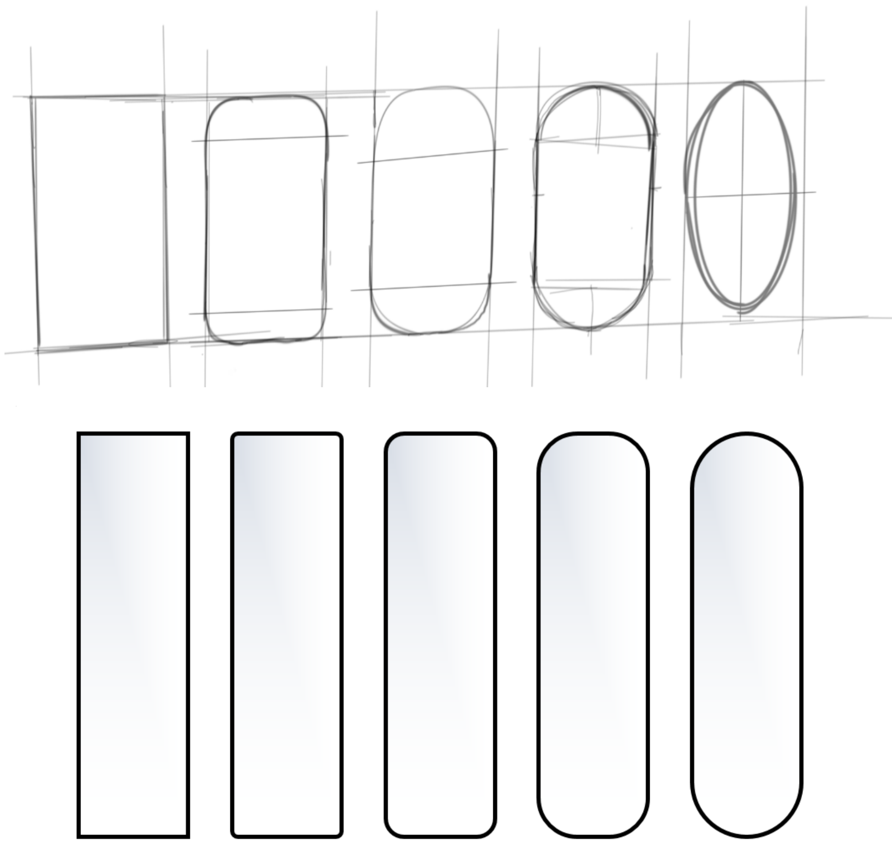


Figure 40: Sketches exploring different front view designs

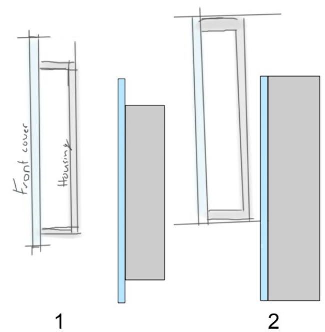


Figure 41: Sketches exploring different side view designs

4.2.5 Installation method

As the method of installation is a factor that makes the current Sunshower design less obtainable for certain customers, different methods should be considered. Whether the device is built in or on the wall with the current design, wall penetration is necessary. This is suboptimal for people who wish not to make big changes to their bathroom. For people in rental houses, it is often prohibited to drill into a wall. Therefore, ideas were generated that could eliminate the need for wall penetration in the installation of the Sunshower.

In Figure 44, these ideas are shown. When these ideas were weighed with the design drivers in mind, it was concluded that none of these categories can meet the requirements due to regulations of the NEN1010 (Chapter 2.6). This regulation states that the devices in zone 1 of a bathroom must be permanently and securely fixed, eliminating any concepts that are not screwed into the wall.

To not reinvent the wheel, the current Sunshower installation system was analyzed again to see how it could be improved. In Figure 42, the current mounting plate and mounting bracket are shown. The mounting plate is screwed into the wall and the mounting bracket is attached to the device. Then the bracket can be placed into the plate to create a secure connection.

Figure 43: Current Sunshower mounting bracket

In interviews with current users and service technicians, a technique was mentioned to make the installation less invasive. In some cases where drilling into the tiles was not desired, the screw holes were drilled into the tile joints. This way, when the Sunshower was removed, the holes were way less noticeable and easier to refill. Therefore, to facilitate this technique, the mounting plate is modified (see figure 45). With longer slots for the mounting screws, the user has more freedom as to where to put the screws in the wall.

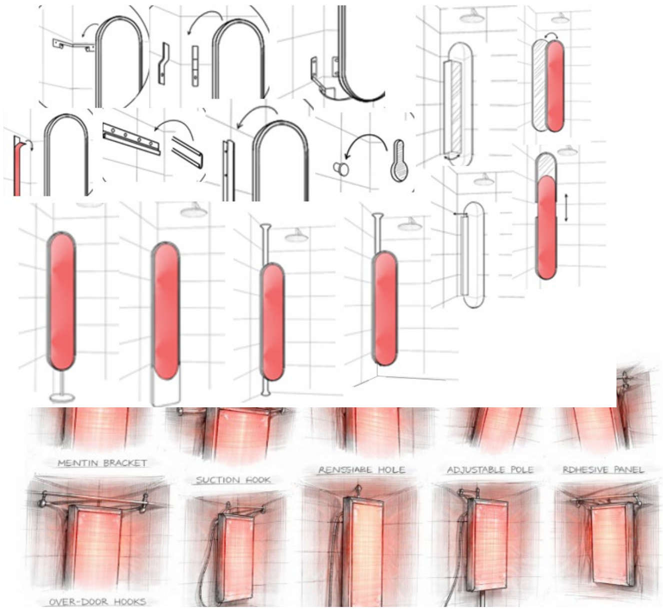


Figure 44: Sketches of mounting mechanisms

Figure 42: AI enhanced sketches of mounting mechanisms

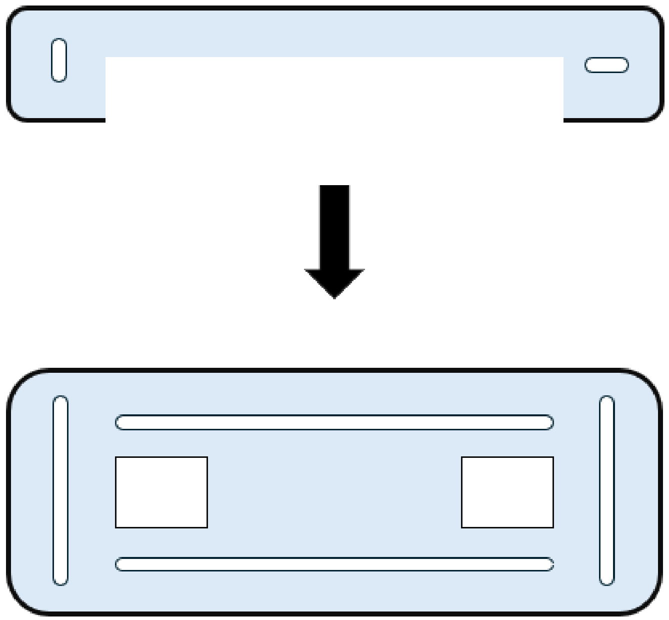


Figure 45: Redesigned mounting bracket

4.2.6 Thermal Management

Even though LED technology does not generate the amount of heat that halogen does, the heat of the electronics should be managed. The selected concept uses a fan in combination with ventilation openings to move air through the housing.

Cooling fan

There are several types of fans that have different characteristics. In Table 4, some common types of fans are listed with their pros and cons. For the envisioned housing shape, one of the fan types stands out. To cool the entire width of the LED board, the airflow should be distributed evenly over the width of the housing. Additionally, the air should be sucked in from the back of the housing,

which is perpendicular to the airflow. The tangential fan can do both of these things and therefore is the most obvious choice.

Table 4: Comparison of different fan types

Fan type	Axial fan	Radial	Tangential
Reference picture			
Airstream direction	Parallel	Perpendicular	Perpendicular
Width of airstream	Narrow	Narrow	Very wide
Noise level	Medium	High	Low
Power level	Medium	High	Medium

Air circulation

From the analysis of the thermal management of the current Sunshower it became clear that the redesign should have an air inlet in the lower part of the housing and an outlet in the upper part of the housing. This way, warm air can easily move out of the product and is prevented from accumulating within the housing.

4.2.7 Front cover

The purpose of the front cover is to protect the internal components of the product from water, while allowing radiation/light to pass through. Additionally, the front cover should prevent the user from looking into the product for aesthetic purposes.

The degree to which materials transmit light can depend heavily on the wavelength of the light. Therefore, light transmitting materials usually have a spectrum of transmission that shows the percentage of transmission for every wavelength between ~100 and 3000 nm.

Material

In the current design, the front cover is made of sandblasted borosilicate float glass. This material looks and feels very luxurious and measurements show it has a light transmission around 80%.

Another possible material that is often used with LEDs are acrylic sheets. These sheets are available in a variety of colors and finishes. Excellent resistance against moisture makes it a good fit for the Sunshower context. These sheets can have light transmissions of upwards of 90% while not being see through. Additionally, this material is generally much cheaper than glass and be shaped more easily.

Figure 46 compares the current glass material to several types of acrylic sheets. Comparing the materials on light transmission will lead to the most energy efficient product. Together with the aesthetics, these are the most important characteristics for the front cover. Following the comparison, the frost white and frost grey Perspex sheets are the chosen as the most optimal materials. Their high transmission on the functional wavelengths ensures the efficiency of the design, while the neutral colors make it easy to implement them in a lot of bathrooms. As these materials have a very comparable light transmission spectrum and identical mechanical specs, the only thing that sets them apart is the look.

During user testing (Appendix I) there was no clear favorite between these two colors. Several people mentioned that they liked white for its lightness and ability to blend into their bathroom. However, equally as much people mentioned liking the dark grey color for its neutrality and compatibility with their bathrooms. This means it boils down to personal preference and bathroom design. Offering both colors would enhance the chances of the product fitting into the potential users bathroom, aligning with requirement 8.

	Borosilicate glass	Perspex 962 Black IR	Perspex Frost Stone Grey 9T21	Perspex Frost Perfect Plum 8T15	Perspex Kersrood 4403	Perspex Frost Helder LT85%
Picture						
Red light transmission	High	Low	Medium	Medium	Medium	Medium
Infrared light transmission	Medium	Very high	High	High	Medium	High
Aesthetics	High quality	Mirror effect	Dark and Neutral	Does not fit in a lot of bathrooms	Mirror effect	Light and neutral

Figure 46: Comparison of front cover materials

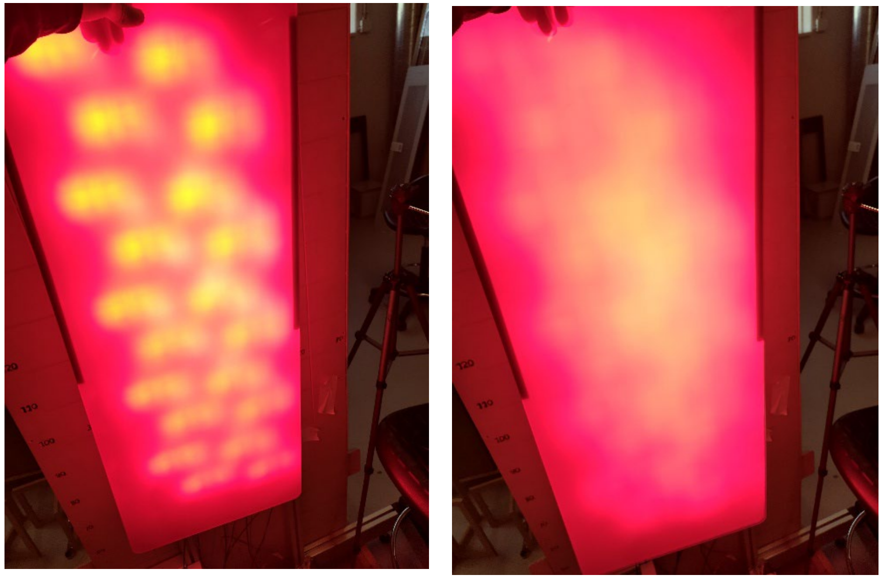


Figure 49: Chosen Perspex sheets before LED panel

Figure 48: Glass pane with metal strips attached to it

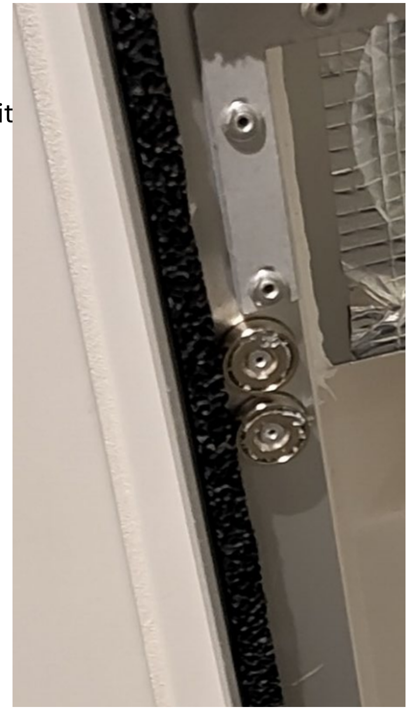


Figure 47: Magnets mounted to the housing

Connection

To connect the front cover to the housing there are several methods that can be used. It is important that the connection is waterproof and can be easily undone when maintenance is needed. In the Sunshower Square line, the glass pane is connected to the housing through metal strips and magnets (see Figure 47). This method is low cost, allows easy maintenance and puts less forces on the front cover itself. The magnetic force of the magnets pulls the front cover into a rubber profile, facilitating water protection.

Testing this connection method revealed that water could still get into the top of the product in extreme circumstances (Figure 50). However,

Figure 50: Waterproofing test

4.2.8 Interaction

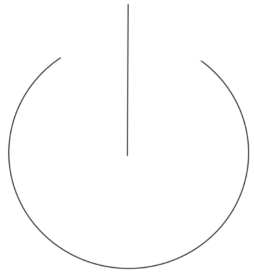
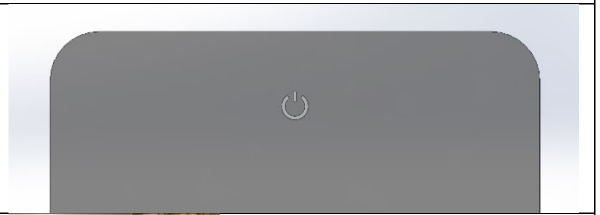
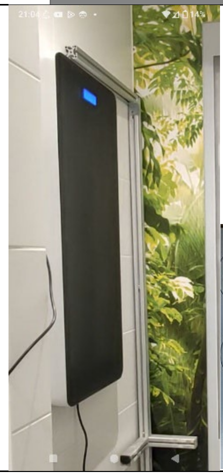
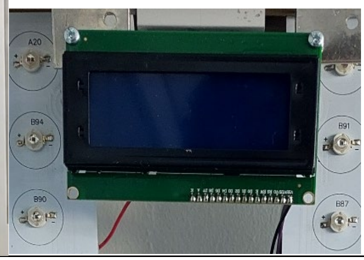
An important function of the product is to guide users in receiving a useful therapy and make the experience comfortable. Providing the user with information about the session, such as the remaining session time, can help ensure a useful dose. Additionally, the user has to be in the right distance range from the product to prevent over- or underdosing.

The interaction of the device with the user consists of 3 parts:

- Turning the product on/off (On/Off button)
- Communicating how much time remains for the session (Progress Bar)
- Communicating if the user is at the right distance. (Distance feedback)

For each of these directions, ideas were generated using the HKJ method, which can be seen in figure 51,52 and 53. With the requirements in mind, several of these ideas were chosen to be the most promising ideas and mockups of these ideas were created. Using these mockups, feedback sessions with participants were held. With the feedback from these sessions (Table 6, 7 and 8) power button 1, progress bar 3, and distance feedback 1 were selected.

Table 5: Evolution of models

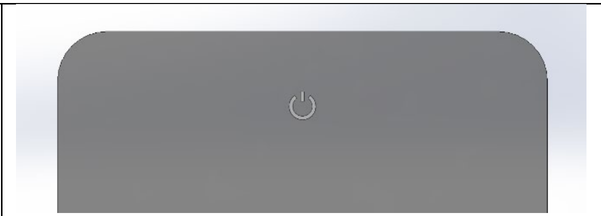
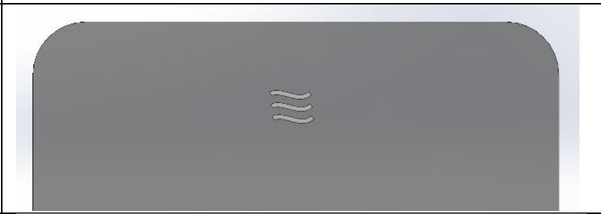
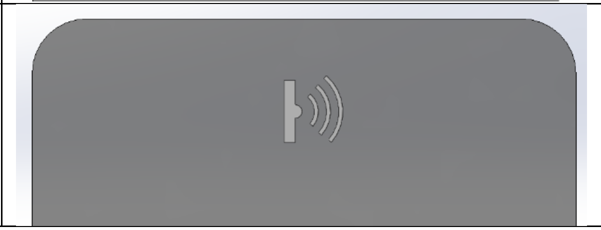
Evolution	**Picture**
Sketch	
Mockup	
Prototype	 

Turning the product on and off

Power button 1 is an international symbol that the participants recognized instantly and understood how to use it. Other symbols relating to infrared or radiation were seen as warning symbols or a way to wirelessly connect to the device like Bluetooth or WiFi.

Figure 51: Sketches of ideas for On/Off buttons

Table 6: On/Off button concepts

1		On/Off button	All participants instantly recognized the symbol and the majority (5) instantly pressed it to see if it would do anything.
2		Infrared wave symbol	Was familiar to the Sunshower users, others had associations with cooling or heating
3		Infrared ray symbol	Was mistaken for a WiFi or Bluetooth signal, the participants did not feel inclined to press the button

Communicating how much time remains for the session

A progress bar has several components that can change the way it is perceived. Firstly, the way that the progress bar counts can have a big impact on the experience. One of the design drivers derived from the analysis states that the redesign should have a comfortable and confident experience. Tan en Nov (2026) found that 'Elapsed time displays' (timer counting up) caused a less frustrating and more pleasant experience as opposed to 'Remaining time displays' (timer counting down). A timer counting down can lay the focus on monitoring the therapeutic progress. Whereas a countdown can lead to the user waiting until the session is over. Therefore, a progress bar that counts up is more in line with the goals of this product.

Progress bar 3 was preferred by the majority of participants for its clear depiction of the minutes that were left. With a gradual bar like progress bar 1 it was sometimes hard to estimate the time left. A participant mentioned that during their morning shower, they do not have a lot of time and like knowing the amount of time left. Another comment mentioned that as they have other activities to do while in the shower like brush teeth, wash, shave or rinse, they like knowing how much time is left to know what activities are still possible.

The timer was very difficult to read accurately. Through the front cover, the numbers got somewhat blurry and participants felt that with the addition of water it would be completely unreadable. Especially for people wearing glasses, which are not worn in the shower, an easily visible progress bar is necessary.

Table 7: Session status communication concepts

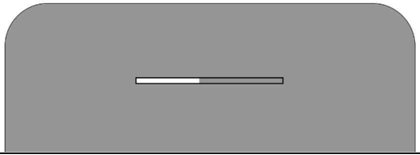
Prototype number	Picture	Description	Remarks
1		Gradual progress bar	A gradual timer could add to a relaxing experience, not being focused on precise timing
2		A timer	A timer is familiar to users and gives them an exact number of how long they have left, very informative.
3		Progress bar with blocks for minutes	Blocks are the middle way, not as precise as the timer, but more indicative than the gradual bar.

Figure 52: Ideation progress bar

Communicating that the user is at the right distance

An added element is distance feedback to the Sunshower interaction. The distance between the user and the device is important for the effectiveness of the therapy and making the user aware of it could help their confidence in the therapy. Therefore, it is useful to provide feedback to the user regarding their distance to the device.

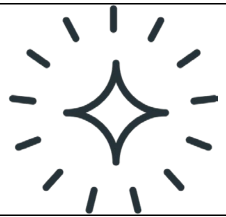
Important for this feature is that it informs the user clearly while not negatively impacting the experience of the shower session. Too little feedback could result in a therapeutically ineffective session or possibly inhibitory effects. Too much feedback could result in users feeling frustrated or restricted in their movement.

Several options were considered for the feedback mechanism. In Figure 53, the several design directions and concepts for feedback mechanisms are shown. The directions 'audible feedback' and 'feedback through existing display' were most in line with the requirements and wishes. Several concepts were developed and eventually 2 were tested during user testing.

In this user testing, the audible feedback option was reviewed by the majority of participants to be very easy to notice. However, repeated feedback of this design was considered annoying and obtrusive. A participant mentioned that repeating beeps of the device could also bother other housemates.

The blinking feedback through the existing display was deemed less obtrusive. Initially the assumption was that this form of feedback is not noticeable enough. However, observing the participants showed that when properly informed, people were keen to check whether they were standing at the correct distance from the device.

Table 8: Distance feedback concepts

Prototype number	Picture	Description	Remarks
1		Blinking of the display	The blinking is a subtle way of letting the user know if the right distance is being held, the user does have to look at the display
2		A soft beeping sound	The beeping sound is very clear to the user as it does not matter how the user is turned or whether their eyes are closed. The sound may however be annoying to the user or people outside of the bathroom depending on the loudness and pitch

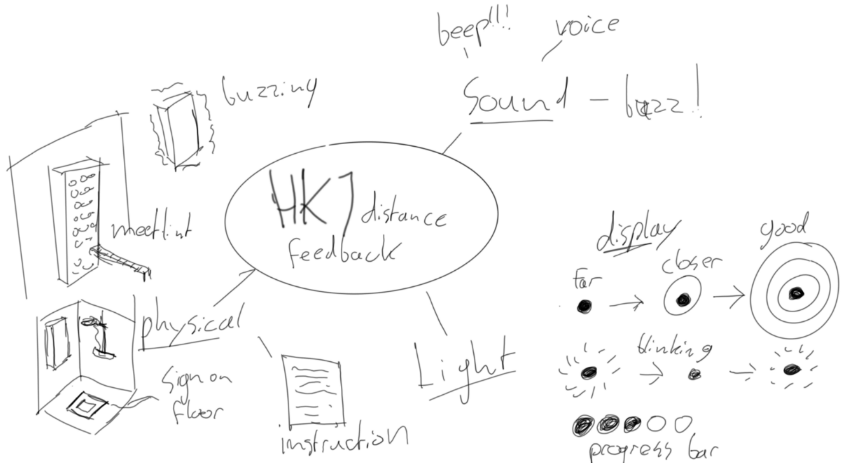
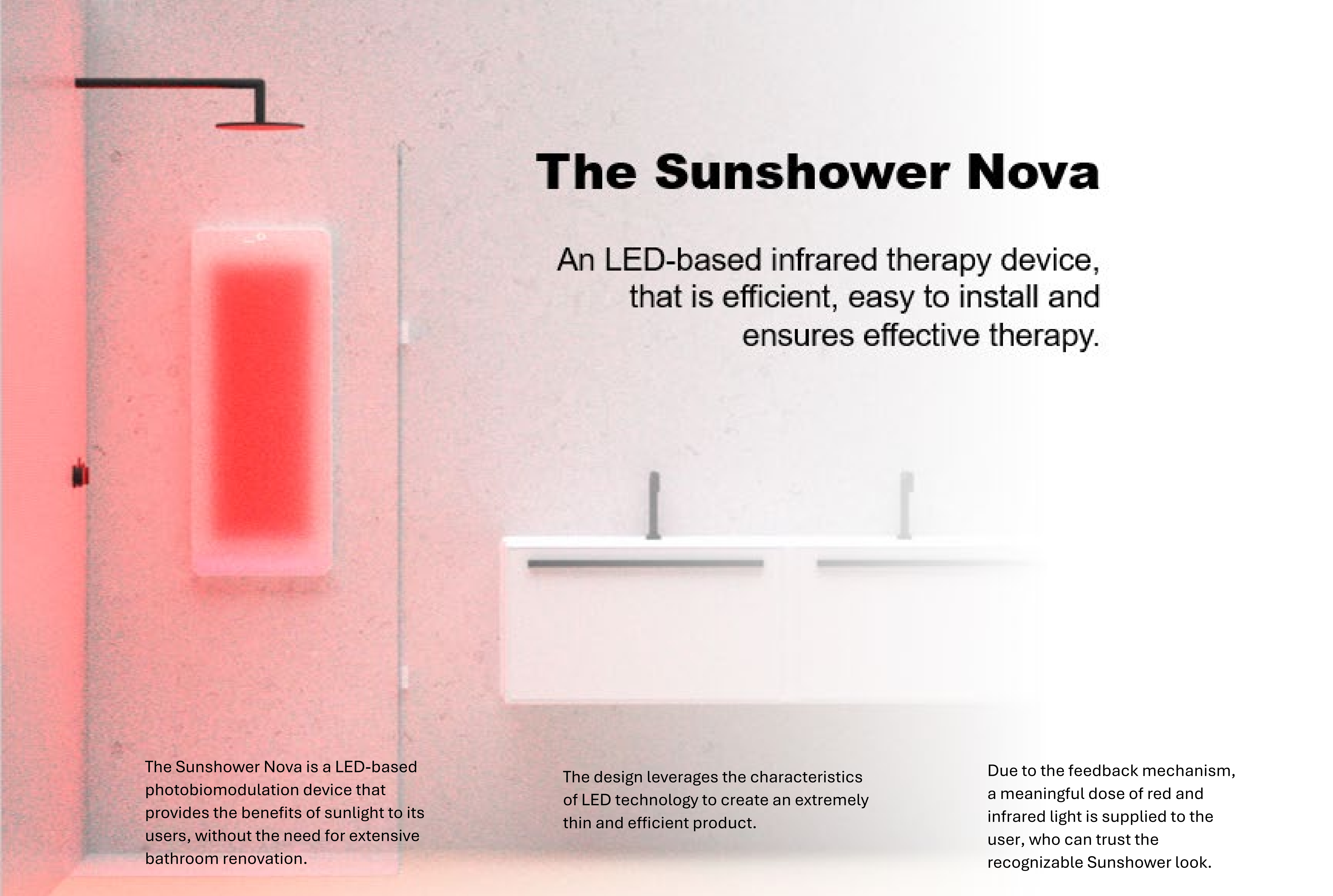


Figure 53: Ideation sketches distance feedback

5.Delivering the Sunshower Redesign

In this chapter, the final redesign is presented. Details of the redesign are explained based on the design drivers that were determined in chapter 3. Additionally, the most important components of the design are highlighted.



The Sunshower Nova

An LED-based infrared therapy device, that is efficient, easy to install and ensures effective therapy.

The Sunshower Nova is a LED-based photobiomodulation device that provides the benefits of sunlight to its users, without the need for extensive bathroom renovation.

The design leverages the characteristics of LED technology to create an extremely thin and efficient product.

Due to the feedback mechanism, a meaningful dose of red and infrared light is supplied to the user, who can trust the recognizable Sunshower look.

Figure 54: Textured render of the redesign in context

5.1 Final design overview

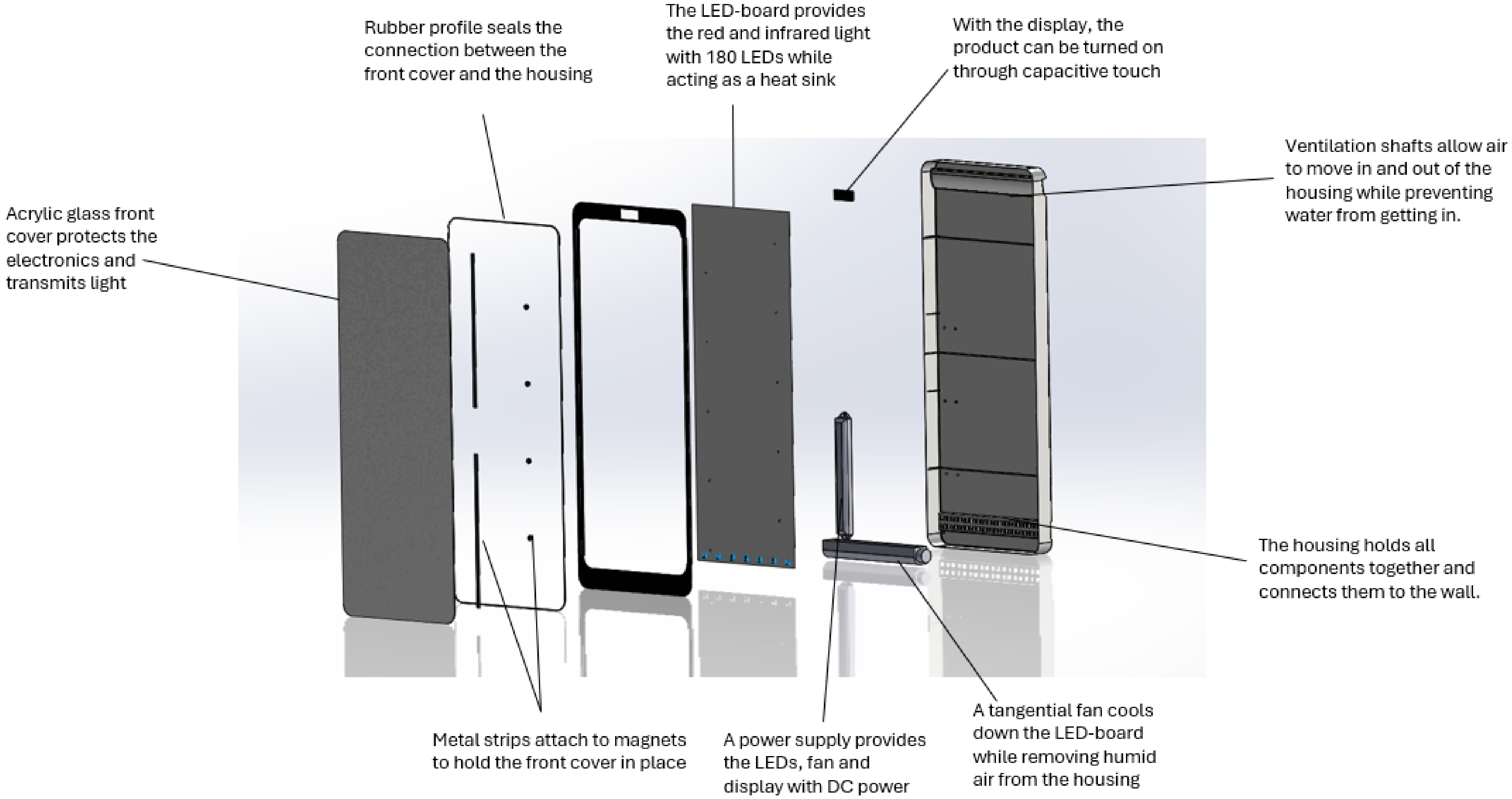


Figure 55: Annotated exploded view of the redesign

Figure 56: Render of redesign in context

Figure 57: Render of redesign in context while turned on

5.1.1 A safe and meaningful dose

The light that is emitted by the Sunshower Nova is designed to provide the user with benefits for their skin, muscles, joints and overall energy. The lower wavelengths of the irradiated light help the skin stay flexible and strong, while reducing wrinkles. The higher wavelengths that reach deeper into the skin can reduce inflammation and pain in muscles and joints. Lastly, a combination of these wavelengths can improve heart rate variability (HRV), which is associated with a mix of health benefits.

With a total 25 mW/cm2, the dose delivered to the user during the standard 10 minute session is consistent with scientific research and well below the limits for risk of eye and skin damage.

Due to the recessed location of the air inlet, water is prevented from dripping or splashing into the ventilation openings.

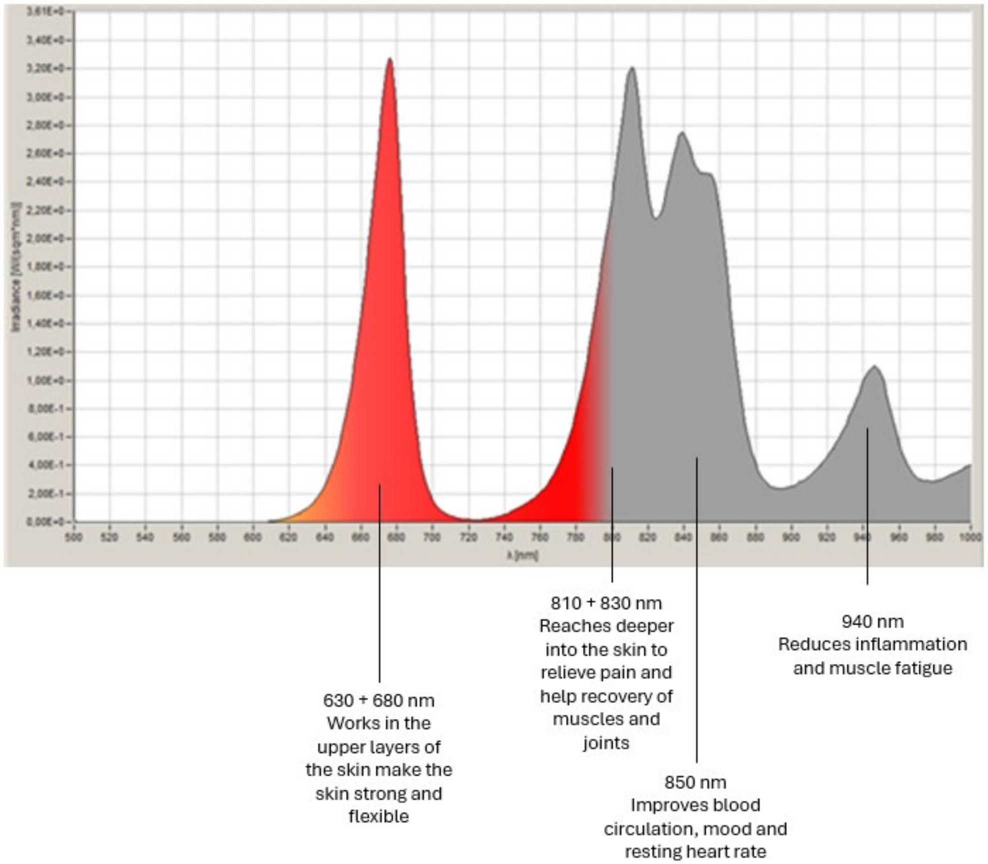


Figure 58: Annotated irradiation spectrum of the final design

5.1.2 Compact and easy installation

The redesigned housing facilitates the mounting of the LED board and the associated electronics while ensuring that they are protected from water.

With only 5 cm protruding from the wall, the Sunshower nova is the thinnest Sunshower to date. Users can freely move and carry out their shower rituals without being obstructed by the device. As the LED-board measures only about 0,5 cm, the depth of the housing is mostly dominated by the size of singular components like the fan and the power supplies for the LEDs.

The housing can be mounted completely flush against the wall with the recessed mounting cavity. In this cavity, a steel mounting bracket is placed which can be connected to the mounting bracket on the wall to ensure rigid installation, which will be explained in detail in chapter 5.2.5.

Tactically placed ventilation openings in the bottom and top of the housing allow air to be moved through the device for cooling. The openings face the wall to prevent splashing water from entering. By being positioned at an angle with a sharp edge, water dripping down the back of the housing cannot drip into the device.

On the front side of the housing, the front cover is pressed against a silicone profile to create a waterproof seal. Magnets screwed to the housing pull on the metal strips that are glued to the front cover.

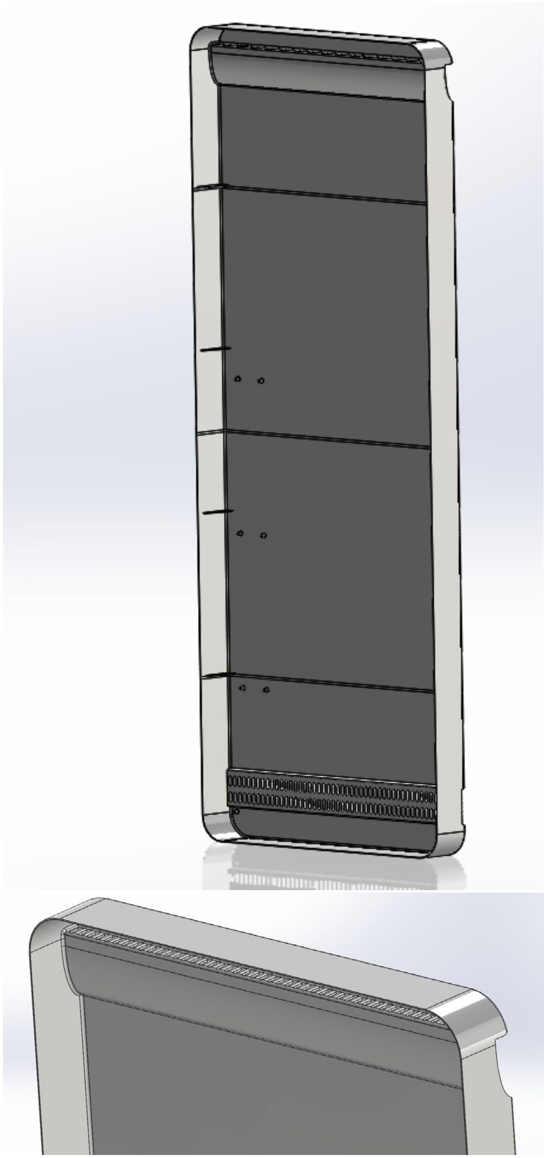


Figure 59: Overview and close-up of redesigned housing

5.1.3 Efficient energy use

By using LEDs, relatively little energy is lost on heat or unnecessary wavelengths. This lowers the electricity usage from 2000 W to about 380 W. This is a significant reduction that eliminates the need for the Sunshower to be put on a separate electrical fuse.

By eliminating features that are no longer necessary with LEDs, less energy is wasted. In the absence of extremely high temperatures, a second front cover is no longer needed. Therefore, less light is blocked on the way out of the device.

The front cover that is still needed was changed from sandblasted glass to a special grade of plexiglass that has excellent transmission. This allows even more light to transmit to the user, lowering the needed power of the lamps.

The metal core PCB that the LEDs are mounted on, also functions as a heat sink. This means that when the LEDs heat up, this heat is quickly dissipated to maintain the efficiency of the lamps.

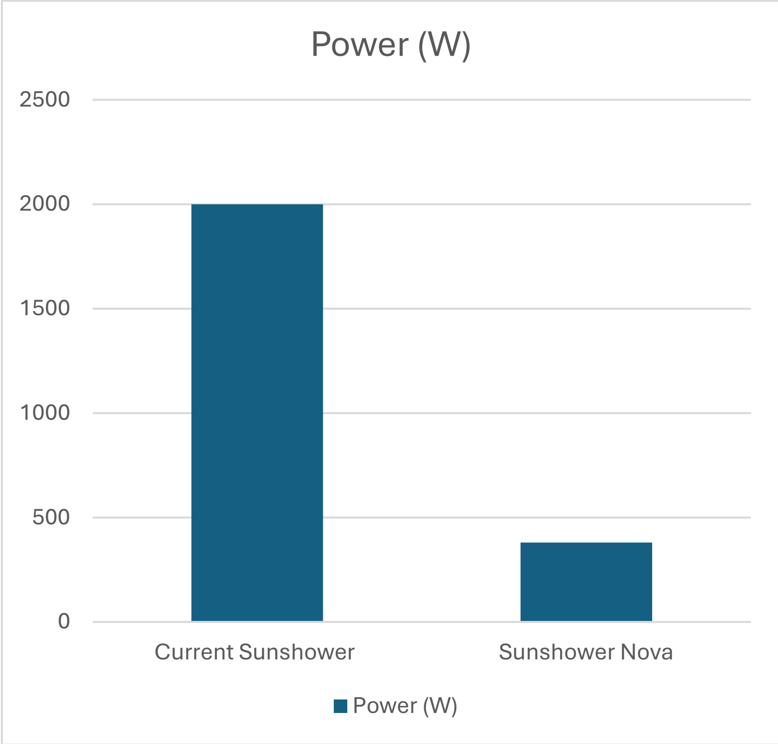


Figure 60: Graph comparing energy usage of the current and redesigned Sunshower

5.1.4 Trust in a comfortable experience

With recognizable features from the known Sunshower and clinical research to back up the therapeutic effect of the device, the user can comfortably use the Sunshower Nova.

The therapy boosts the health of the user while they simply go about their shower session. The device ensures an effective session by interacting with the user. If the user is out of position, the device will provide the user with feedback.

The device can be turned on when a user starts showering, by the simple touch of the power button. After 10 minutes, when the effective therapeutic dose has been reached, the Sunshower 2.0 will automatically turn off. To make sure an effective therapeutic dose is provided for the user, the device informs the user whether they are within the recommended distance range.

An infrared distance sensor will inform the device of the distance that the user is at. With this information, it can
be determined whether distance feedback should be activated or not.

Together, these features can support the user in trusting the efficacy of the device. The feedback systems ensure that the user knows that the therapy is being delivered in an effective manner. Next to that, the comfortable wellness experience that Sunshower values is still being achieved by communicating with the user in a clear and non-intrusive way.

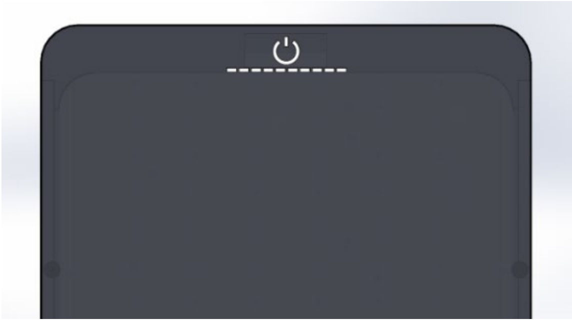


Figure 61: Front view of the interactive display

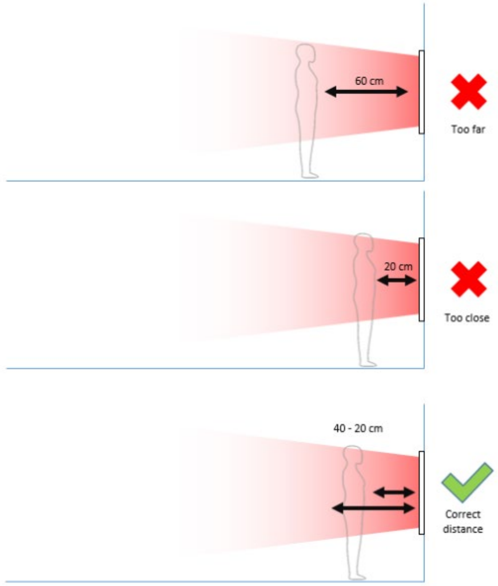


Figure 62: Guide for recommended distance range

5.2 Design Detailing

In this chapter, the details of the designed components will be elaborated upon. These details have been designed to facilitate the functions and experiences that were named in previous chapters.

5.2.1 Front cover

To protect the inner electronics and allow as much light as possible to transmit, the front cover is placed on the open end of the housing. This 100 x 40 cm acrylic plate covers almost the entire front surface of the product.

Due to the transmission spectrum of the sheet, the internal components are hidden from the sight of the user. However, upwards of 90% of the light emitted by the LEDs is transmitted through the sheet.

Perspex has a good resistance to water and can perform well in the lower ambient temperatures created by the LED-components. Clearance between the front panel and the outside edge of the housing accommodate the expansion of the sheet due to water absorption and temperature rise. The magnetic connection allows the expansion to happen without warping or mechanical stresses on the sheet.

Chamfered edges on the front panel to prevent sharp edges cutting users, installers or production crew. Additionally, this ensures a clean finish that looks and feels luxurious and professional. The front covers are available in 2 colors, white or dark grey, allowing the user to pick the color that best suits their bathroom.

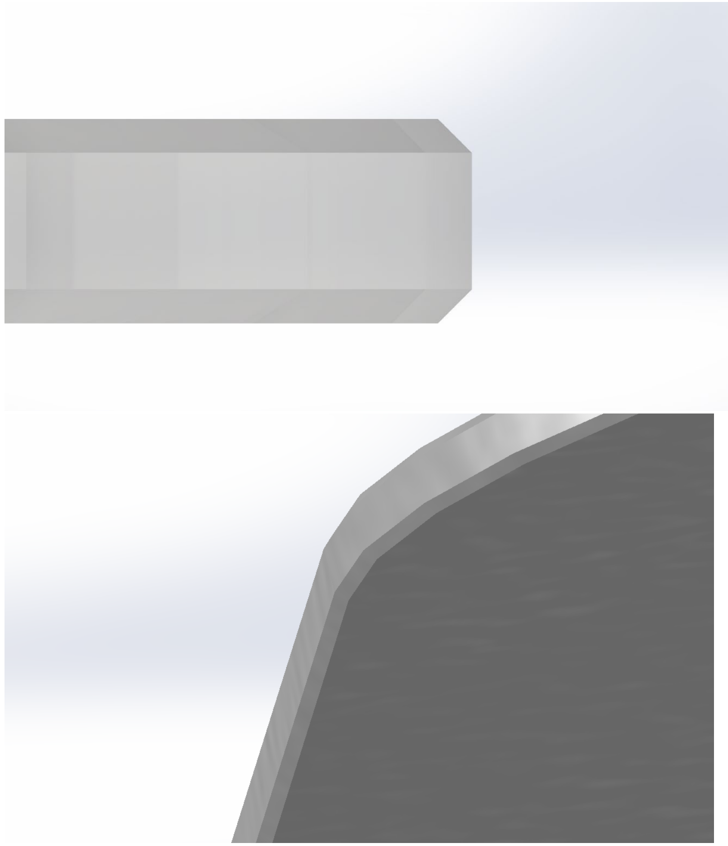


Figure 63: Chamfered edge of the front cover

5.2.2 Housing

Due to the completely different characteristics of LEDs compared to halogen lamps, there were opportunities in redesigning the housing of the Sunshower. One of the main problems with mounting the current Sunshower on the wall is the depth of the product. When built into the wall, the Sunshower sticks out approximately 3 cm. However, when the current design is mounted flat on the wall, the entire product measures about 14 centimetres from the wall.

The need for a reflector and a secondary glass panel leads to the housing of the current Sunshower to be relatively deep. In the redesign, the need for these components is eliminated. Without these components, the depth of the housing can be reduced significantly. As the LED-board measures only about 0,5 cm, the depth of the housing is mostly dominated by the size of singular components like the fan and the power supplies for the LEDs. This allows the housing to be only 5 cm in depth, which makes it the thinnest Sunshower ever.

The housing is a PBT injection molded shell of 100 x 40 cm. The design is made with a slight draft angle to facilitate the part coming out of the injection mold. Ribs have been added to connect the back surface to the sides of the housing. This ensures that the sides will not bend or warp, which would effect the waterproofing of the design. On the back surface of the housing, threaded bosses have been placed to accommodate the installation of the fan, LED- board and the display.

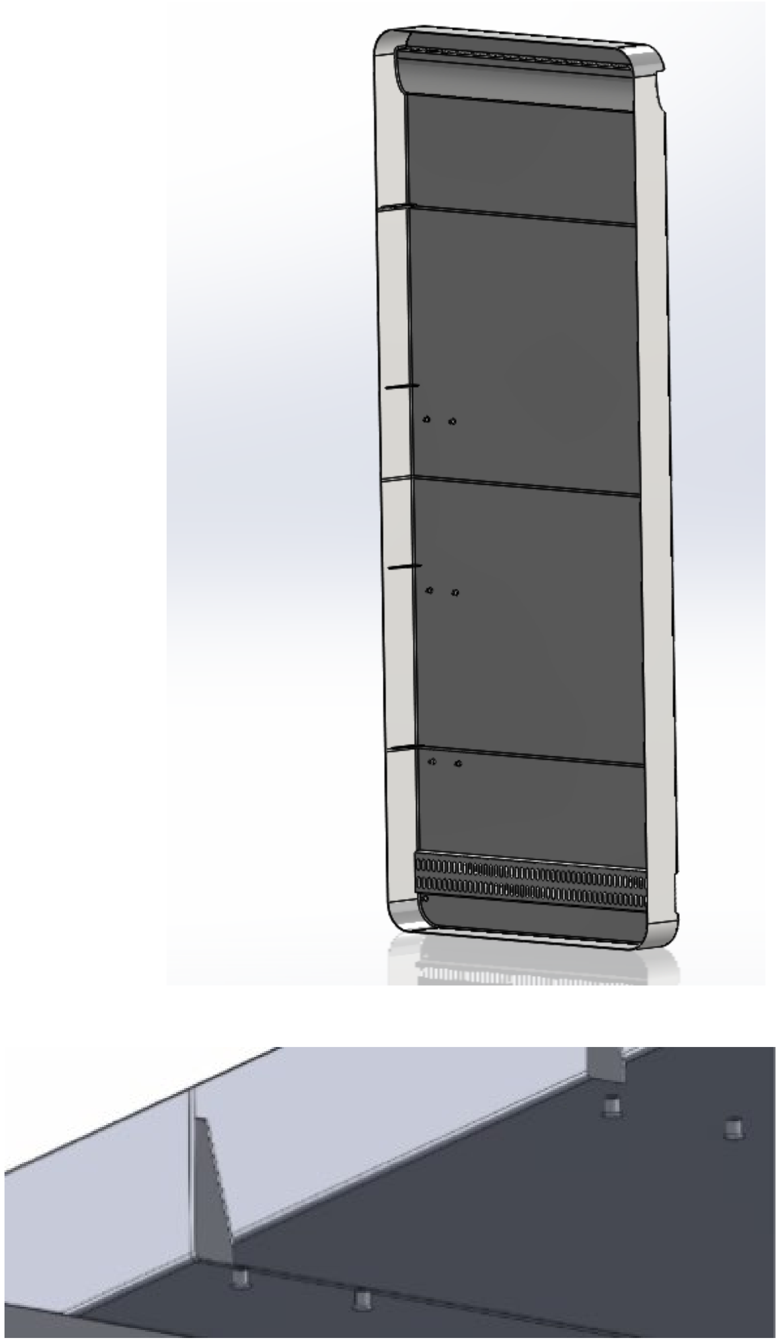


Figure 64: Overview and close up of redesigned housing

5.2.3 Electronics

The electronics represent the functional elements in this design, consisting of the LED-board, power supply, fan and the display.

The LED-board is a metal core PCB made of 1,5 mm of aluminium with a thin dielectric layer, copper traces and a solder mask. This core allows generated heat to be dissipated while the mask insulates the board electrically but not thermally.

On this board, a total of 180 LEDs divided over 7 types of LEDs that are spaced equally. These 7 types of LEDs each have their own electrical string and connector at the base of the PCB to accommodate their specific electrical needs. Figure 66 shows an overview of the different LEDs and their placement.

The power supply is a seperate pcb, enclosed in an IP67 rated aluminum housing. This PCB takes the input AC mains power and converts it to 7 seperate DC output channels with a constant current. The power supply also protects the product against issues like overvoltage, inrush current and temperature rises. The power supply is controlled through the display.

The display consists of a thin plate with a capacitive touch sensor, which is backlit by white LEDs to create the button design Figure 66. This system is identical to the current Sunshower.

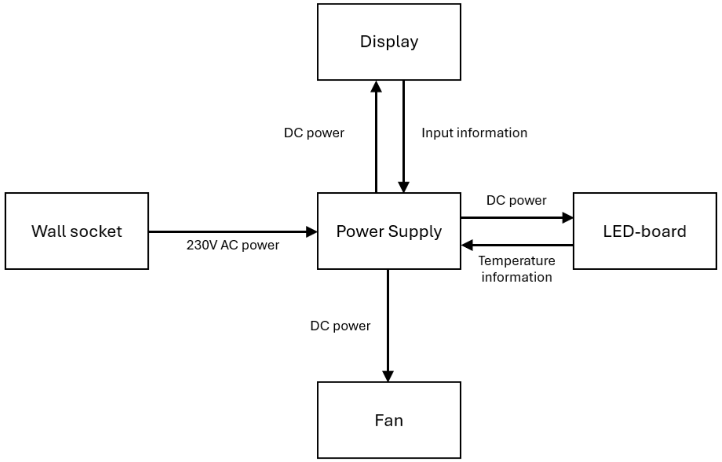


Figure 65: Function tree of electrical system

Figure 66: Backlit display

5.2.4 Interaction

The interaction display of the redesign is very similar to that of the current Sunshower. A thin PCB plate with a capacitive touch sensor and cutouts for the progress bar and on/off button is connected to the front cover with an adhesive layer. This adhesive layer is heat and moisture resistant and makes sure the display stays flush with the front cover to ensure good functioning of the capacitive touch sensor.

Mounted to the back of this display plate is another thin PCB plate that has white LEDs connected to it. In between these plates are separators that make sure the light of the LEDs only shines through the right cutout.

Next to the display front, the infrared distance sensor is mounted. This wide angle infrared sensor receives the infrared light that reflects of the users body. With this information, the sensor can decide whether to start blinking the display to alert the user. By mounting it at the same height as the display plate, the connection with the front cover is ensured.

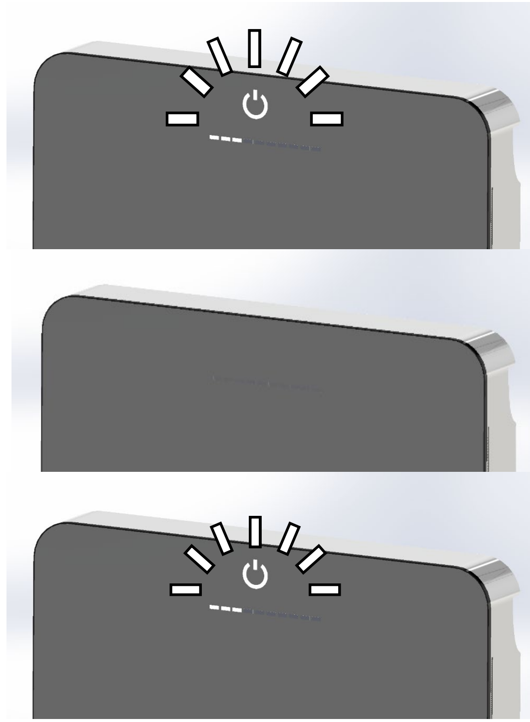


Figure 67: Visualization of the distance feedback interaction

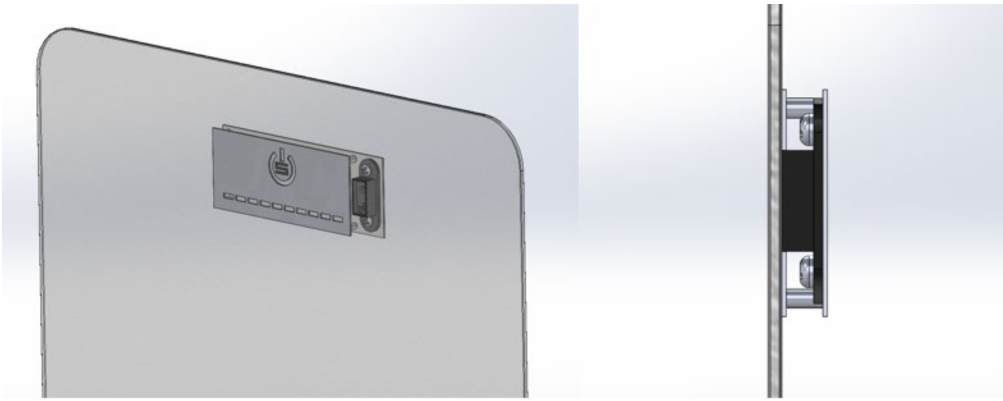


Figure 69: Front and side view of the display-to-front cover connection

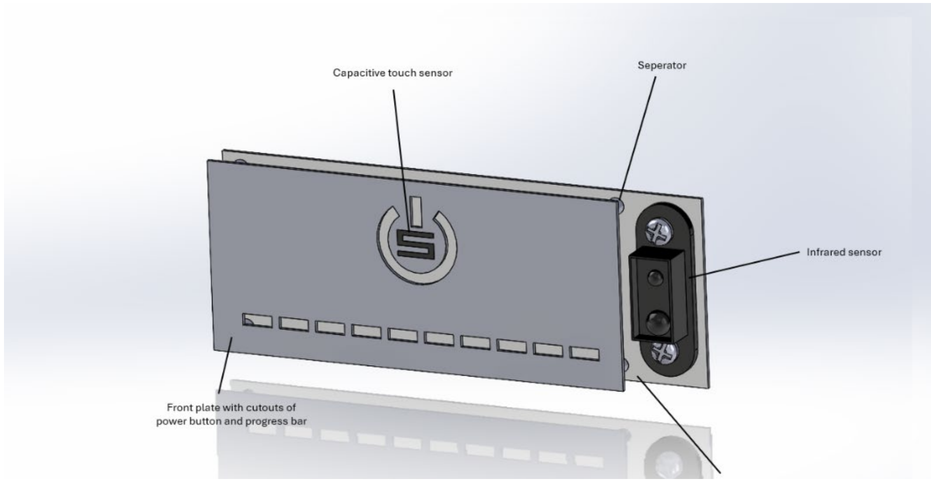


Figure 68: Annotated model of the display

5.2.5 Installation

To enable the invisible rear installation of the redesign, the installation consists of 2 parts: a wall bracket and an installation plate.

The installation plate is connected to the body using screws Figure 71. This stainless steel plate has a straight edge to fit into the wall bracket. The material properties of the AISI 304 steel ensure a rigid and strong connection of the housing to the wall bracket

The wall bracket is also made of AISI 304 stainless steel sheet metal. It is fixed to the wall as shown in figure 72. The wide screw slots allow more flexibility in where the screws will be drilled into the wall. This way, the user has more freedom to choose the least intrusive place to make holes in their wall. To still ensure a safe and stable installation, the user will be instructed to use at least 2 screws and place them on opposite sides of the wall bracket.

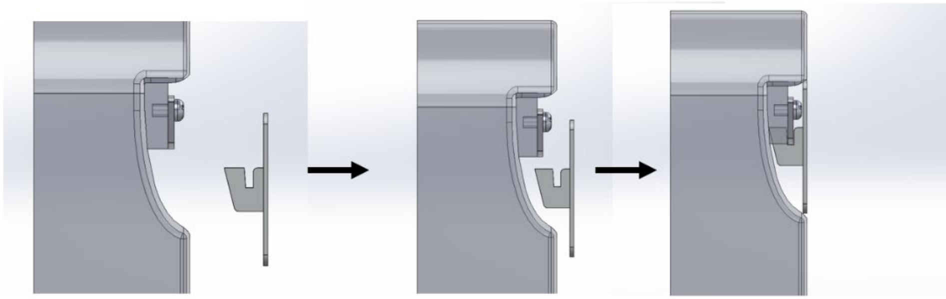


Figure 70: Mounting instruction

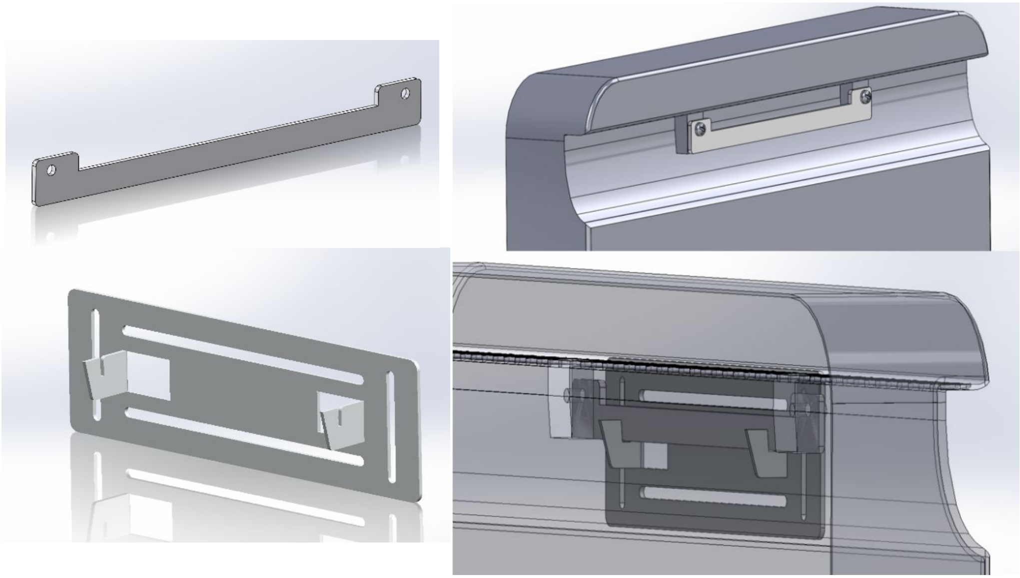


Figure 71: Mounting bracket/plate system

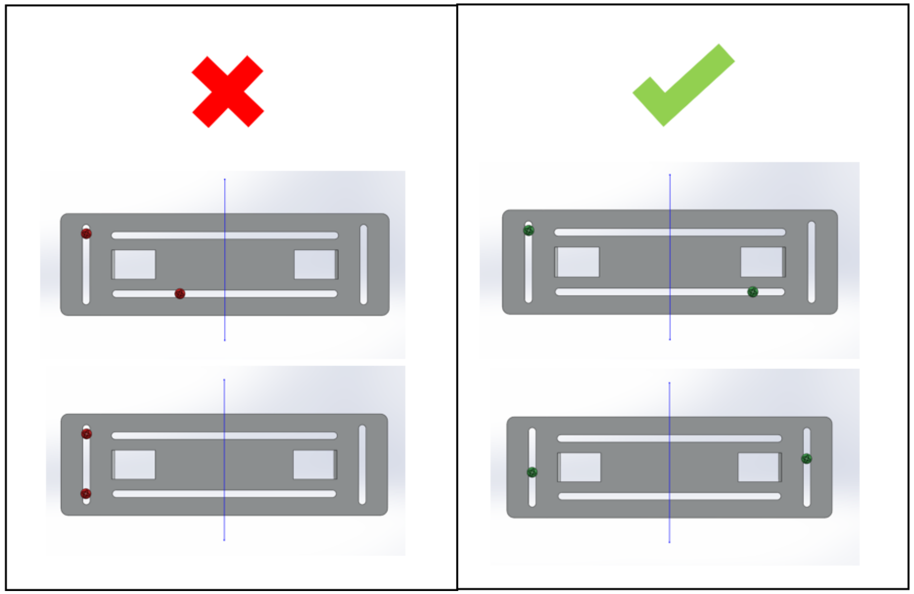


Figure 72: Instruction manual for correct installation of the bracket

6.Validation

To verify whether the intended technical and experiential qualities of the design are being achieved with the proposed design, several tests are carried out. These tests will evaluate whether the assumptions, decisions and calculations made during the design process were correct.

In this chapter, several methods will be used to evaluate the cost price, carbon footprint, radiation output, energy usage, user experience and interaction.

To conduct these tests, 2 prototypes were built. The first prototype was constructed with the purpose of evaluating the aesthetics, user experience and interaction of the design. The second prototype was made to verify the energy usage and radiation output of the proposed design.

6.1 User Testing

To evaluate how the proposed design is being perceived by the target group, user tests were carried out. In total, 15 people were interviewed and asked to carry out several actions relating to the design and its context of use. This process took place in a test setup that was created to be as close to the real use context as possible.

A testing plan (see Appendix K) was developed with the roadmap described in ‘Usability Testing Essentials’ (Barnum, 2020). The individual testing results can be found in Appendix I.

Figure 73: Anonymised pictures of user testing

Results

The user tests yielded some interesting insights. The

First Impression

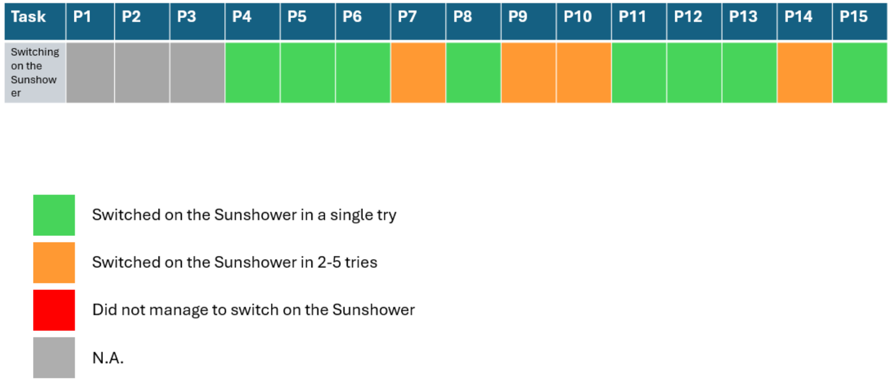


Figure 74: Task completion of turning on the device per participant

The prototype made a generally positive first impression. Most participants described the design as **modern, sleek, and minimalist**, appreciating its compact form factor and the fact that it occupies little space. Several participants mentioned that the product would fit well within a contemporary bathroom environment.

However, a recurring observation was that the all-black appearance caused the device to blend into darker surroundings and get associated with phones or tv's. In addition, several participants indicated that the product's function was not immediately apparent from its appearance alone.

Button Visibility and Interaction

The power button was generally easy to locate and operate. Most participants found the front placement intuitive and appreciated the simplicity of the interaction.

Several participants suggested that they expected the button would be positioned on the side of the product. However, once the button was lit up, the placement and the use of the button were instantly recognized

Lighting Experience

The lighting was one of the most positively evaluated aspects of the prototype. Participants consistently described the light as soft, comfortable, and non-intrusive. The indirect illumination created a pleasant atmosphere. However, the instant turning on of the light led to some negative reactions. Some users were startled or simply uncomfortable when the light switched on instantly instead of gradually.

Many participants reported that the lighting enhanced the overall experience by creating a relaxing, spa-like ambiance. Several even associated the lighting with feelings of wellness and luxury.

Although the light was perceived as pleasant, participants generally reported only a limited sensation of warmth. While this did not negatively affect the overall experience, several participants expected a stronger warming effect based on the concept.

Overall Experience

Overall, participants responded positively to the prototype. The combination of the product's aesthetic design and ambient lighting contributed to a comfortable and relaxing experience.

Several participants indicated that the experience would become even more immersive if the warming sensation were more noticeable. Despite this, the device was generally perceived as pleasant and easy to use.

Distance Feedback

The automatic distance feedback was well understood by nearly all participants. The blinking light effectively communicated whether users were positioned at the correct distance from the device. The beeping feedback was generally perceived as annoying and intrusive.

Participants considered the feedback intuitive and useful, as it helped them naturally adjust their position without requiring additional instructions. Some participants suggested that the transition between feedback states could be slightly smoother or more responsive, although this was considered a minor improvement.

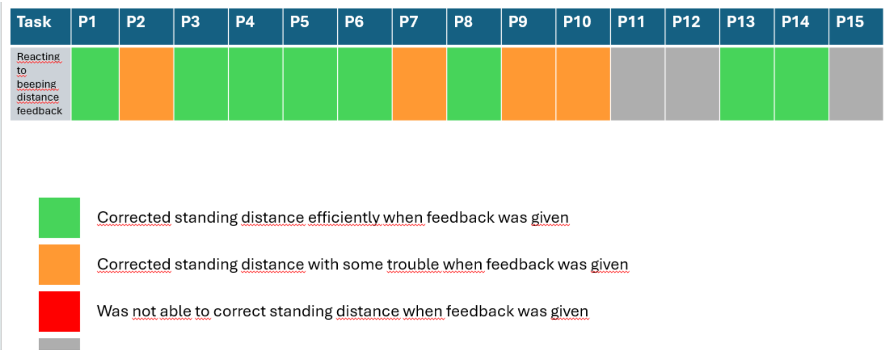


Figure 75: Task completion per participant

Freedom of Movement

Most participants reported that they did not feel restricted while using the prototype. They were able to perform normal shower movements comfortably, and the device did not interfere with their activities.

Some participants noted that maintaining the optimal distance required a slight awareness of their position. However, this was generally not experienced as inconvenient, particularly because the distance feedback provided clear guidance.

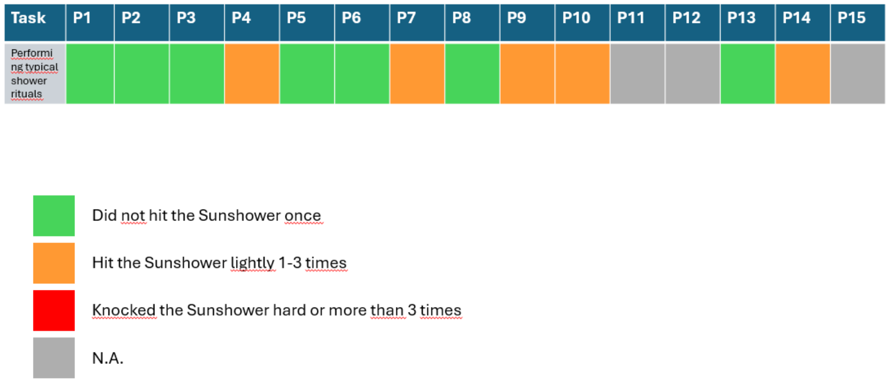


Figure 76: Task completion per participant

Conclusion

Overall, the usability test demonstrated that the prototype was well received by participants. The modern appearance, intuitive interaction, and calming lighting experience were identified as its strongest qualities. The distance feedback system was considered effective and easy to interpret, supporting users in maintaining the correct position during use.

The primary opportunities for improvement concern easing in the light intensity, making the device's function more immediately understandable, and improving the visibility of the power button. Addressing these aspects could further enhance the overall user experience and strengthen the connection between user expectations and the intended product experience.

6.2 Carbon Footprint

To compare the carbon footprint of the Sunshower Nova and the current Sunshower, a fast-track LCA was conducted for both products. Compared to the LCA in chapter 2.3, the weight of the carbon footprint has shifted towards the materials and manufacturing as can be seen in figure 77. This can simply be explained by the increase in electronics in the design. Due to the large amount of LEDs and the power supply which both contain heavy metals, the initial carbon footprint has become higher. However, the energy consumption of the Redesign is 5 times lower than the current design. When the carbon footprint of both designs are plotted over time, the impact of the redesign becomes immediately clear. In Figure 78, it can be seen that the carbon footprint of the redesign starts out higher, but that the carbon footprint of the current design becomes higher after about 150 sessions.

As this break-even point is expected to be achieved within a single year, the conclusion can be made that according to this parameter the redesign is more sustainable than the current Sunshower.

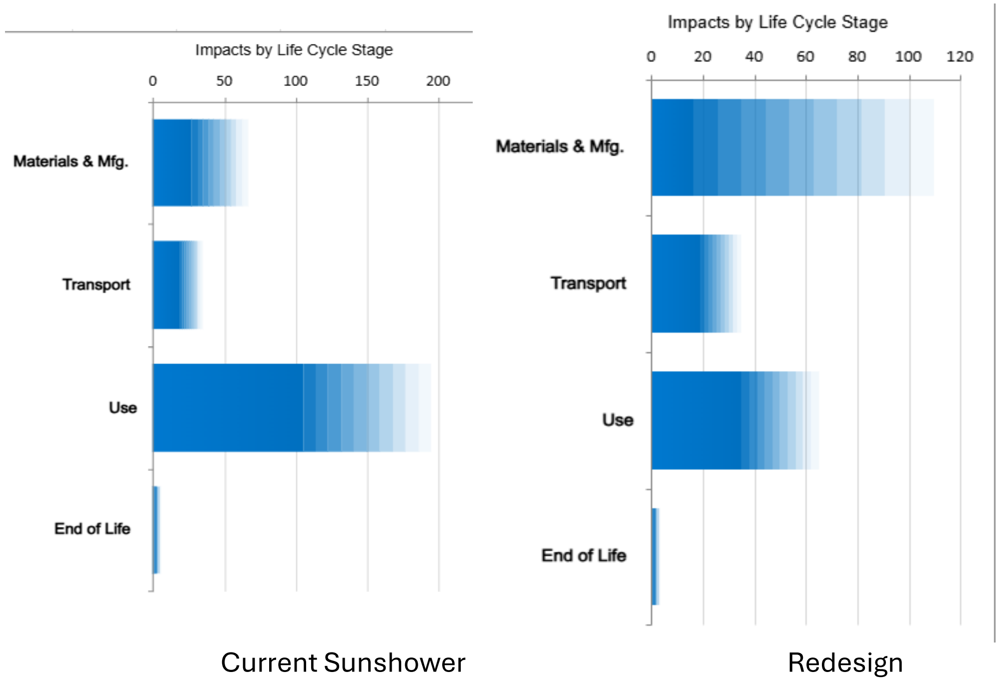


Figure 77: Side-by-side comparison of the LCA of the current and redesigned Sunshower

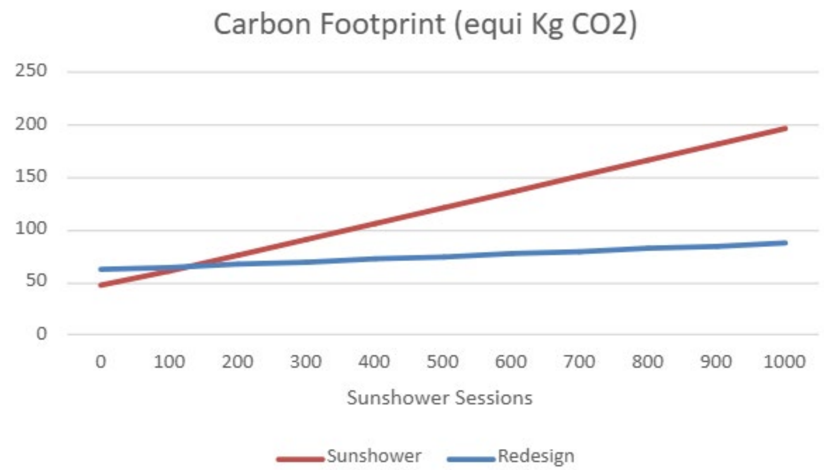


Figure 78: Comparison of the carbon footprint of both designs over time

6.3 Radiation Output

To validate whether the calculated LED power actually leads to the desired irradiation, a spectroradiometer is used to measure the actual output of the LED board. With this spectroradiometer, the Jeti Specbos 1211, the exact irradiation per wavelength can be measured. The limitation of this spectroradiometer is that it only measures up to 1000 nm, therefore the 1050 nm LED output can not be validated.

The measuring setups in figure 79 were used to measure the total irradiation, the shape of the spectrum and the reach of the light emitted by the board. These setups were located in a dark room and a baseline measurement was done to prevent unwanted impacts on the measurement.

Evaluating the calculations

In table 9, the most important measurements are shown. It can be seen that the irradiation at these points is almost exactly the same as the calculated value. This is kind of an unexpected outcome due to the many variables such as measuring distance, LED production variability and measurement inaccuracies where something could be off. However, the closeness of these values does validate the correctness of the calculation model.

Table 9: Comparison of calculated and measured irradiation at important points

	Calculated Value	Measured Value
Point 5 top	24	26
Point 5 middle	28	25
Point 5 bottom	27	28

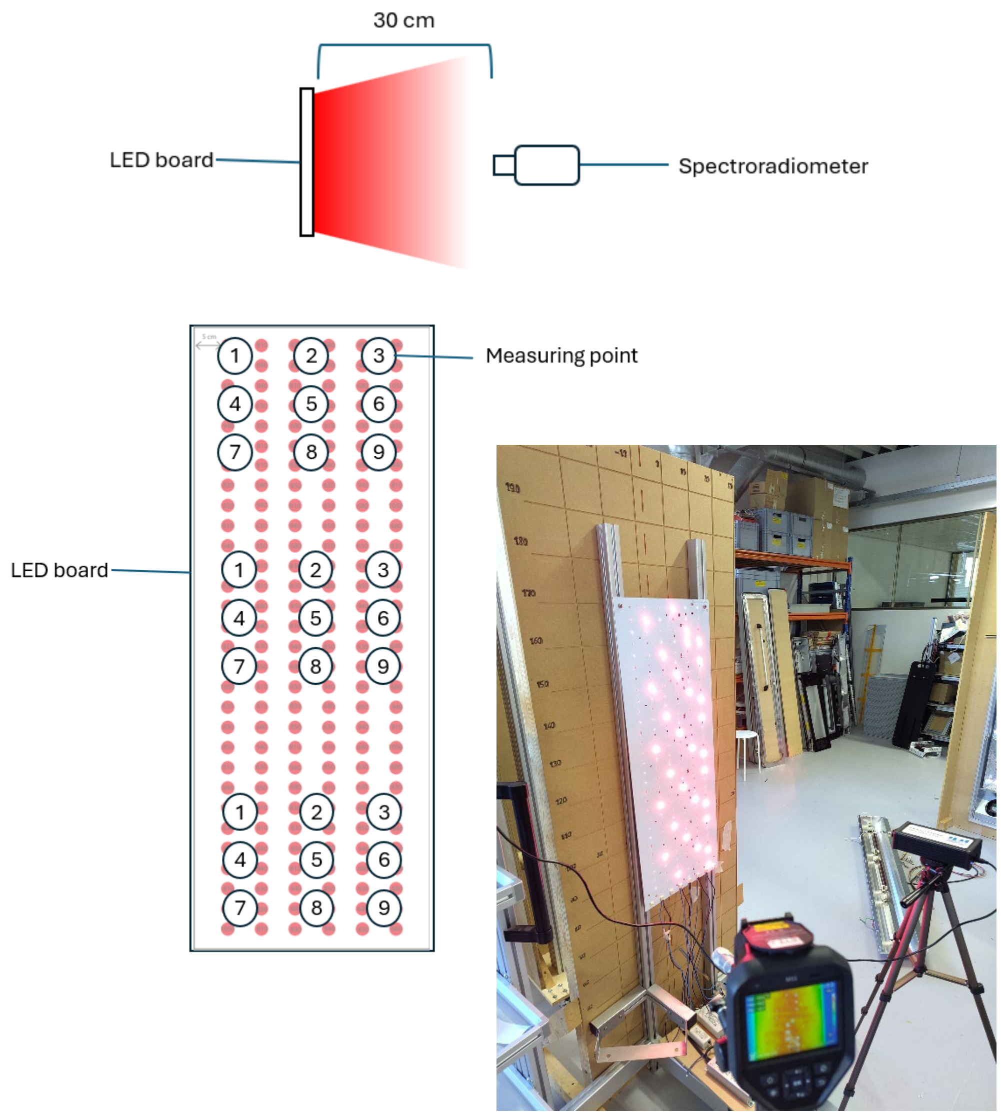


Figure 79: Irradiation measuring setup

Evaluating the spectral distribution

In Figure 80, the calculated spectrum and the measured spectrum are showed. The spectra look quite similar. The first two peaks for 630 and 680 nm are almost identical. The middle peak surrounding 810,830 and 850 nm seems to show a little difference on the right side. This could mean that the 850 nm LED produces less output than expected.

This trend seems to continue with the 940 nm peak, which is less than half of the calculated size. Due to the limitations in measuring equipment the peak of 1050 can not be compared. However it is to be expected that this peak will also be lower than its calculated counterpart.

As it is known that higher wavelengths are more difficult and energy intensive to produce, a conclusion here could be that the efficiency of LEDs with higher wavelengths is easier disrupted.

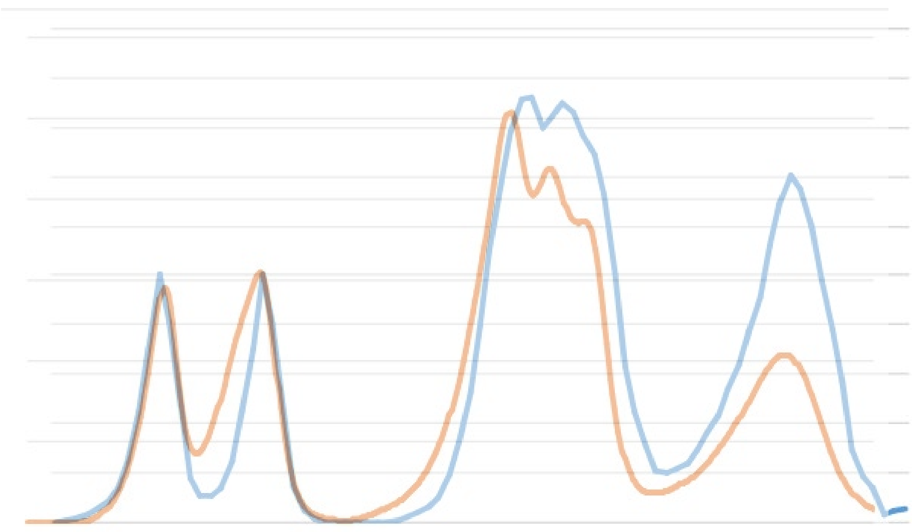


Figure 80: Relative spectral distribution comparison of the calculated (blue) and measured (Orange) spectra

6.4 Cost estimation

Table 10: BOM with cost estimation

Part Number	Part name	Assembly	Part cost (€)	Quantity	Total Cost	Source of price estimation
1	Housing shell	Housing	16.15	1	16.15	Calculation based on current shell
2	Housing top	Housing	4	1	4	Online quote
3	Front cover	Front cover	11.85	1	11.85	Quote from manufacturer (EBRI Plastics
4	Magnets	Front cover	0.30	8	2.4	Current Sunshower BOM
5	Metal strips	Front cover	0.35	6	2.1	Current Sunshower BOM
6	Silicone profile	Housing	1.470 / meter	2.8 meter	4.12	Current Sunshower BOM
7	LED board	Electronics	250.00	1	250.00	Quote from manufacturer (Thal technologies)
8	Power supply	Electronics	60	1	60	Estimation from Manufacturer (Thal Technologies)
9	Tangential Fan	Electronics	17.977	1	17.977	Quote from reseller (Conrad)
10	Display	Electronics	27.254	1	27.254	Current Sunshower BOM
11	Wiring	Electronics	6.56	1	6.56	Current Sunshower BOM
	Material Purchasing				~ 400	
	Material + 10% margin		10%	1	40	Current Sunshower BOM
	Labor		37,50	1	37,50	Current Sunshower BOM
	Interest material		1%	1	4	Current Sunshower BOM
	Rejection		2%	1	8	Current Sunshower BOM
					~ 490	

To be able to evaluate the viability of this design, it is important to have a general idea about what the product might cost to make. In this stage of the design it is difficult to get an exact price of what all components will cost. By estimating costs from known prices of existing components and getting quotes from suppliers/ manufacturers a rough cost price can be realized.

For the purpose of this cost price estimation, a production batch of 7000 units was used. This batch size was derived from a comparable product design project within Sunshower.

As can be seen in table 10, the cost price is now estimated at roughly 500 euros. This cost price is close to the cost price of the current Sunshower Medium. That means that the current redesign, would have approximately the same price as the current Sunshower. This does not align with the subgoal of making the redesign more attainable by lowering the purchase price.

However, the comparison of these two products is not a fair one as they have completely different levels of development. Even though there are likely costs for the redesign that are yet unforeseen, the product also is not optimized for cost yet. On top of that, the current Sunshower is produced in larger production batches, which typically lowers the cost per unit.

Given these implications, the fact that the estimated cost price is of the same order of magnitude as the current design suggests that the redesign could be viable.

6.5 Energy usage

The proposed lowering of energy usage is a large part of the value proposition. It makes the design easier to install in homes and significantly lowers the carbon footprint. Therefore, it is important to validate whether the design actually has the proposed energy usage. Using the functional prototype made by Thal Technologies, the energy usage can be simply measured using a multimeter plug.

As can be seen in figure 80, the setup contains the LED-board, 7 power supplies and a ventilator. In this setup the wattage of the display is not present. Since a very comparable display is used in the current Sunshower, the energy usage is already known and does not need validation. This value will be added to the measured wattage of this prototype.

In this setup, the prototype measures a total of 390,5 Watts. This is very close to the calculated wattage of the design. The difference between the two values can be explained by production inefficiencies of the LEDs. These LEDs can use about 10% more or less voltage than the typical value, as described in the datasheet (Appendix H).

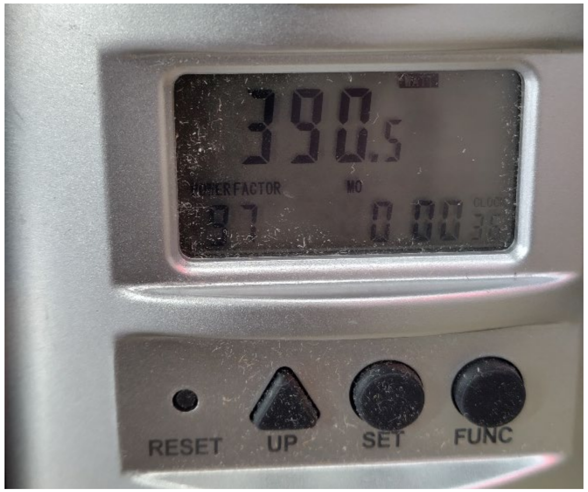


Figure 82: Multimeter measurement of LED board Wattage

Figure 81: LED board testing setup

7. Discussion

This thesis explored how infrared wellness technology can be redesigned through the integration of scientific research, engineering validation, user experience, and sustainability considerations. The project aimed not only to create a conceptual redesign for the Sunshower, but also to investigate whether a more evidence-based and efficient LED-based alternative could realistically be developed within the context of a shower environment. By combining literature research, technical calculations, prototyping, user evaluation, and Life Cycle Assessment methods, the project demonstrates both the opportunities and challenges involved in developing a next-generation infrared wellness product.

One of the most important outcomes of this project is the successful validation of the LED-based irradiation calculations through physical prototyping and testing. A significant part of the research focused on translating photobiomodulation literature into practical design parameters such as wavelength selection, irradiance, and dose. These theoretical values were subsequently used to design and manufacture a functional LED board prototype. The measured irradiance values of this prototype corresponded closely to the calculated values, indicating that the methodology used to predict the optical performance was largely reliable. Small deviations between calculated and measured output could be explained by several factors, including tolerances specified by the LED manufacturer, minor inaccuracies in the positioning of the measuring equipment, and limitations of the measuring device itself. Nevertheless, the results demonstrate that it is possible to translate scientific principles regarding photobiomodulation into a technically functional and measurable product concept.

The realization of a professionally manufactured prototype also represented an important step within the design process. Compared to lower-fidelity mock-ups, the manufactured LED board provided a much more realistic representation of how such a system could function in a final product. This allowed for more meaningful testing of light distribution, thermal behavior, and system integration. In this sense, the project moved beyond conceptual speculation and demonstrated the feasibility of integrating LED photobiomodulation technology into a shower-based wellness product.

In addition to the functional prototype, the project also emphasized the importance of visual and experiential prototyping. The second prototype focused on achieving a high level of visual fidelity in order to evaluate the aesthetic qualities and perceived user experience of the redesign. Earlier research within the thesis showed that users associate the Sunshower experience not only with therapeutic effects, but also with luxury, relaxation, and visual atmosphere. The visual prototype therefore played an important role in evaluating whether the redesigned product maintained these experiential qualities while transitioning away from traditional halogen technology. Participant feedback generated through this prototype provided valuable insights into the perception of form, lighting, and integration within the bathroom context. This demonstrated the value of combining technical validation with user-centered design evaluation within the development process.

Another important contribution of this project lies in its attempt to position the redesign within a more scientifically substantiated framework. Analysis of the competitive landscape revealed that many existing LED photobiomodulation products rely heavily on broad marketing claims while offering limited transparency regarding effective dose, wavelength selection, or clinical substantiation. This project therefore aimed to establish a clearer connection between scientific literature and product development decisions. While the project does not clinically validate therapeutic outcomes, it does contribute a substantial step toward a more evidence-based approach to infrared wellness product design.

It is important to note that not all aspects of the redesign were developed to the same level of detail. Within the scope of this thesis, the primary focus was placed on the development and validation of the infrared LED system and the accompanying calculation model. This decision was made because LED-based photobiomodulation technology represented an area in which limited knowledge and development experience was available within Sunshower itself. In contrast, aspects such as waterproofing, thermal management, and aesthetic product integration build upon existing expertise already present within the company through years of experience in developing shower-integrated wellness products. As a result, these aspects were explored more conceptually within the redesign process, while the technical development effort concentrated on the LED architecture, optical calculations, and validation of therapeutic light output. This focus allowed the project to contribute new technical knowledge in an area considered strategically relevant for the future development of Sunshower products.

The sustainability analysis further broadened the scope of the project by evaluating the environmental implications of redesigning the Sunshower. The Life Cycle Assessment demonstrated that the use phase dominates the environmental impact of the current product, highlighting the importance of reducing energy consumption through more efficient technologies such as LEDs. At the same time, the LCA process also revealed the limitations and uncertainties involved in conducting sustainability assessments during early-stage product development. Obtaining accurate data for electronic components, manufacturing processes, and material compositions proved difficult, while the quality and specificity of available datasets strongly influenced the reliability of the results. As a consequence, the LCA remained relatively general in nature and was most effective as a comparative tool rather than an exact environmental calculation. Nevertheless, the analysis succeeded in identifying key impact areas and demonstrated how sustainability considerations can be integrated into the design process from an early stage.

Overall, this thesis demonstrates how research-driven design methods can be used to develop a technically validated, experientially refined, and more sustainability-conscious infrared wellness product. By combining scientific research, engineering validation, user evaluation, and sustainability analysis, the project provides a foundation for future development of LED-based photobiomodulation products within the shower environment.

8. Recommendations

Due to the limited time of this master thesis project and the broad nature of this project, the degree to which this design was worked out was also limited. There are still a lot of challenges that need to be addressed to make this design into a product that is ready for the market. Some examples of these challenges are:

- A clinical trial on therapeutic effects and risks of the proposed radiated light output in accordance with the MDR. A scientific study like this will provide Sunshower with proof of the therapeutic functions of the product, which will help greatly in appealing it to the target users and complying with regulations.

- Optimizing the LED-board for production. As the LED board was mainly designed with light output in mind, it has not been optimized for mass production. This led to a price of 250 euros per board, which is quite a large portion of the total cost price of the design. Together with experts from Thal Technology, a new iteration should be done to see how the size, components and layout of the board can be changed to keep a good light output but lower production time and cost.

- Validation and further development of the ventilation system. Despite simulations and calculations, it is difficult to say whether the proposed design for the ventilation system will work as intended. It should be tested whether air pockets are formed in the airflow, if the airflow is sufficient to cool the LED-board and if the ventilation openings do not let in water. Moreover, the amount of sound resulting from sucking in air through the ventilation holes should be tested.

- Moisture resistance of internal components. Even when the ventilation works optimally, humid air will still end up in the product. Even though the power supply and led board have been designed to handle these levels of moisture, the connectors on the boards and wires in between them need more development and testing to reach the same IP rating.

- Installation without the need for wall penetration. This project aimed to lower the barrier for potential users to install a Sunshower. Especially in rental housing, creating holes in the shower wall is undesired. Within the available regulation documentation on installation of products in zone 1 of bathrooms, unfortunately no useable solution was found to eliminate this problem. In future iterations, through contacts with regulation experts and authorities, nuances in this regulation can be found to come to a solution that does not require wall penetration and still pass regulation.

9. Personal Reflection

During this period, I learned a great deal about what it means to work in a more professional environment, especially in collaboration with others and in communication with experts and suppliers. One of the most valuable aspects of my experience was gaining confidence in practical work and stepping outside my comfort zone. These moments helped me develop not only technical skills, but also a better understanding of how projects move forward in real-world settings.

At the same time, I noticed an important area for improvement in my way of working, particularly in documenting and writing down my findings. This became especially clear when I failed the green light meeting twice. Although I had been actively engaged in practical tasks and had gathered useful insights, I did not manage to translate this progress into clear written documentation. As a result, my work was not fully visible to others, even though I had made meaningful progress.

I also became more aware of how perfectionism influenced my workflow. I often felt the need for my writing to be complete and well-structured from the start, which sometimes led me to postpone beginning the report. Instead of allowing myself to produce rough drafts and improve them over time, I would delay writing until deadlines became pressing. This created unnecessary stress and made the final stages of the process more difficult than they needed to be.

Despite these challenges, I see this period as a very valuable learning experience. Working with others, especially professionals in the field, helped me understand how important communication and documentation are in a team environment. I also learned how much can be gained from simply engaging in the process, even when things feel uncertain or outside my comfort zone.

Overall, I am taking away both technical and personal growth from this experience. Moving forward, I want to focus on improving my documentation habits by starting earlier, writing in iterations, and being less focused on perfection in the first draft. By doing this, I believe I can better combine my practical learning with clear communication, which will strengthen both my individual performance and my contribution to future projects.

10. References

Alfredsen, L. (2020). Insufficient Sun Exposure Has Become a Real Public Health Problem. Int. J. Environ. Res. Public Health.

De Boer et. al (2024) Effect of Repeated Low-Dose UVR Exposure on Skin Inflammation Threshold, Skin Biomarkers, and Vitamin D in Healthy Adults

Anders, J. J., Lanzafame, R. J., & Arany, P. R. (2015). Low-Level Light/Laser therapy versus photobiomodulation therapy. *Photomedicine And Laser Surgery*, *33*(4), 183–184. https://doi.org/10.1089/pho.2015.9848

Chopra, S., Morrissette, K., Fan, E., Hendren, S., & Pavlis, M. (2025). Photobiomodulation and Photodynamic Therapy Using Red LED Light in Dermatology: A Narrative Review. *Bratislavské LekáRske Listy/Bratislava Medical Journal*, *126*(9), 2041–2053. https://doi.org/10.1007/s44411-025-00272-9

Dompe, C., Moncrieff, L., Matys, J., Grzech-Leśniak, K., Kocherova, I., Bryja, A., Bruska, M., Dominiak, M., Mozdziak, P., Skiba, T., Shibli, J., Volponi, A. A., Kempisty, B., & Dyszkiewicz-Konwińska, M. (2020). Photobiomodulation—Underlying Mechanism and Clinical Applications. *Journal Of Clinical Medicine*, *9*(6), 1724. https://doi.org/10.3390/jcm9061724

Ferlito, J. V., Ferlito, M. V., Leal-Junior, E. C. P., Tomazoni, S. S., & De Marchi, T. (2021). Comparison between cryotherapy and photobiomodulation in muscle recovery: a systematic review and meta-analysis. *Lasers in Medical Science*, *37*(3), 1375–1388. https://doi.org/10.1007/s10103-021-03442-7

Hamblin, M. R., & 02139, H. D. O. H. S. A. T. C. M., USA. (2017). Mechanisms and applications of the anti-inflammatory effects of photobiomodulation. *AIMS Biophysics*, *4*(3), 337–361. https://doi.org/10.3934/biophy.2017.3.337

Heiskanen, V., & Hamblin, M. R. (2018). Photobiomodulation: lasers vs. light emitting diodes? *Photochemical & Photobiological Sciences*, *17*(8), 1003–1017. https://doi.org/10.1039/c8pp00176f

Makrantonaki, E., & Zouboulis, C. C. (2007). Molecular Mechanisms of Skin Aging. *Annals Of The New York Academy Of Sciences*, *1119*(1), 40–50. https://doi.org/10.1196/annals.1404.027

Mester, A., & Mester, A. (2017). The History of Photobiomodulation: Endre Mester (1903–1984). *Photomedicine And Laser Surgery*, *35*(8), 393–394. https://doi.org/10.1089/pho.2017.4332

Mgwenya, T. N., Abrahamse, H., & Houreld, N. N. (2024). Photobiomodulation studies on diabetic wound healing: An insight into the inflammatory pathway in diabetic wound healing. *Wound Repair And Regeneration*, *33*(1), e13239. https://doi.org/10.1111/wrr.13239

Montazeri, K., Farhadi, M., Fekrazad, R., Chaibakhsh, S., & Mahmoudian, S. (2022). Photobiomodulation therapy in mood disorders: a systematic review. *Lasers in Medical Science*, *37*(9), 3343–3351. https://doi.org/10.1007/s10103-022-03641-w

Mota, L. R., Da Silva Duarte, I., Galache, T. R., Pretti, K. M. D. S., Neto, O. C., Motta, L. J., Horliana, A. C. R. T., De Fátima Teixeira Da Silva, D., & Pavani, C. (2023). Photobiomodulation Reduces Periocular Wrinkle Volume by 30%: A Randomized Controlled Trial. *Photobiomodulation Photomedicine And Laser Surgery*, *41*(2), 48–56. https://doi.org/10.1089/photob.2022.0114

Mugge, R., & Schoormans, J. P. (2012). Product design and apparent usability. The influence of novelty in product appearance. Applied Ergonomics, 43(6), 1081–1088. https://doi.org/10.1016/j.apergo.2012.03.009

Shen, C. Z., & Zhao, A. T. (2025). The Influence of Popular Media on Public Interest in Red-Light Therapy: Longitudinal Trend Analysis. JMIR Dermatology, 8, e69796. https://doi.org/10.2196/69796

Van Boeijen, A., Daalhuizen, J., Van Der Schoor, R., & Zijlstra, J. (2014). Delft Design Guide: Design Strategies and Methods. https://orbit.dtu.dk/en/publications/delft-design-guide(1c5397a8-c7b8-4c04-9f9f-1d96c6c74e7c).html

Vassão, P. G., Toma, R. L., Antunes, H. K. M., Tucci, H. T., & Renno, A. C. M. (2015). Effects of photobiomodulation on the fatigue level in elderly women: an isokinetic dynamometry evaluation. *Lasers in Medical Science*, *31*(2), 275–282. https://doi.org/10.1007/s10103-015-1858-7

Voudoukis, N., & Oikonomidis, S. (2017). Inverse Square Law for Light and Radiation: A Unifying Educational Approach. European Journal Of Engineering And Technology Research, 2(11), 23–27. https://doi.org/10.24018/ejeng.2017.2.11.517

Wolfe, F., Smythe, H. A., Yunus, M. B., Bennett, R. M., Bombardier, C., Goldenberg, D. L., Tugwell, P., Campbell, S. M., Abeles, M., Clark, P., Fam, A. G., Farber, S. J., Fiechtner, J. J., Franklin, C. M., Gatter, R. A., Hamaty, D., Lessard, J., Lichtbroun, A. S., Masi, A. T., . . . Sheon, R. P. (1990). The american college of rheumatology 1990 criteria for the classification of fibromyalgia. *Arthritis & Rheumatism*, *33*(2), 160–172. https://doi.org/10.1002/art.1780330203

World Association for Photobiomodulation Therapy (WALT). (2022). [Recommended anti-inflammatory dosage for photobiomodulation (PBM/ Low Level Laser Therapy)]. https://waltpbm.org/wp-content/uploads/2022/11/Dosage-recommendation-904nm-REVISED-OCTOBER-2022.pdf

Yadav, A., & Gupta, A. (2016). Noninvasive red and near-infrared wavelength-induced photobiomodulation: promoting impaired cutaneous wound healing. *Photodermatology Photoimmunology & Photomedicine*, *33*(1), 4–13. https://doi.org/10.1111/phpp.12282

NEN normen