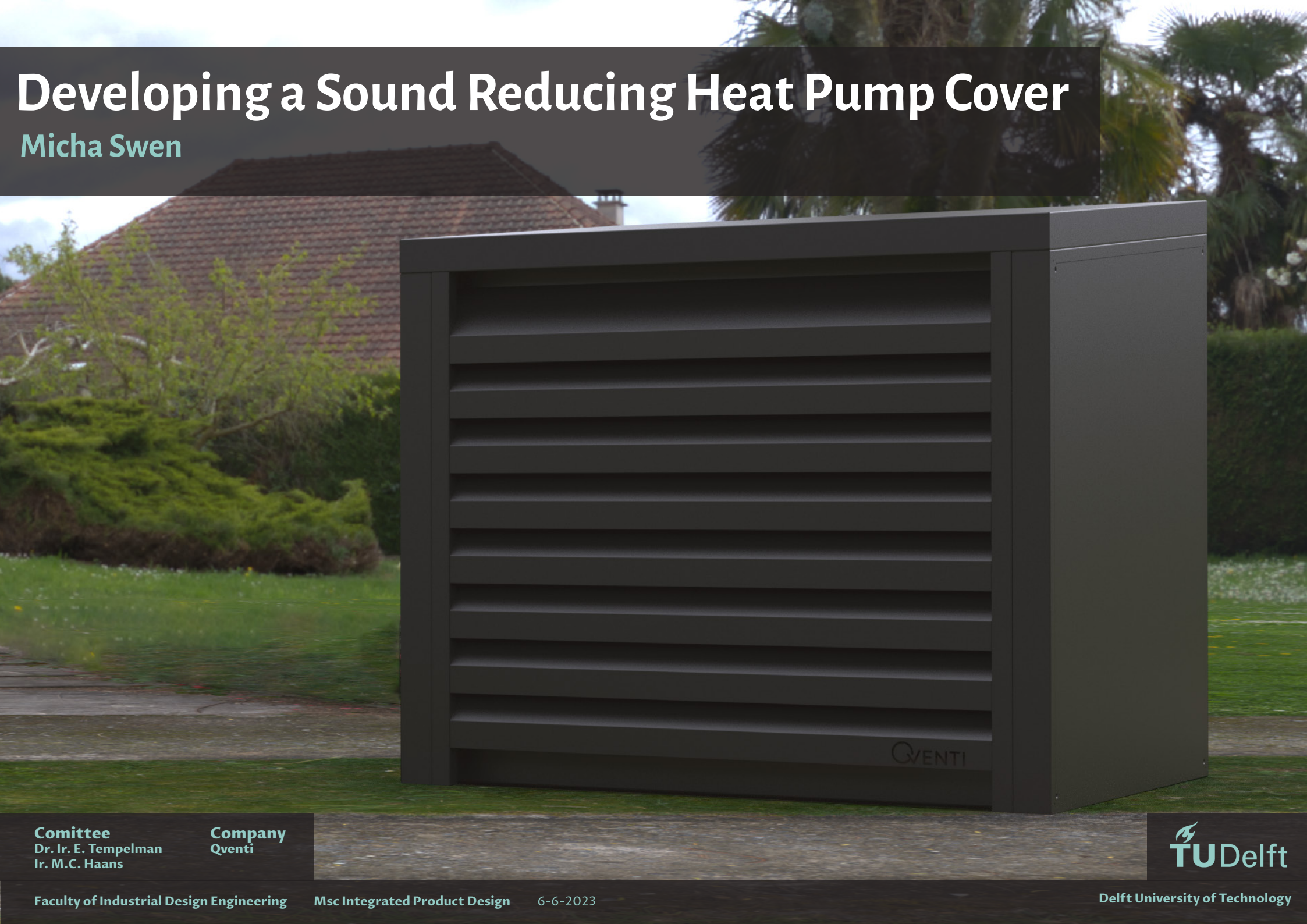
Developing a Sound Reducing Heat Pump Cover

Micha Swen



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Msc Integrated Product Design
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Delft University of Technology

Executive summary

The heat pump market is growing rapidly and new noise legislation creates issues for many people living in terraced housing and apartments. The assignment was to develop a sound reducing heat pump cover for Qventi. It should reduce the sound sufficiently, while being aesthetically pleasing and easy to assemble. It should also be smaller, lighter and sold for a lower price than the main competitors.

Through market analysis, it was found that 10-15dB reduction was needed to stay within legal limits and data was gathered about the types of heat pumps and sound reducing covers. Through interviews, installers were found to value ease of delivery, ease of installation and ease of quoting. There are researching users, who research and install by themselves, and there are outsourcing users, who leave everything to the installer.

An anechoic chamber was used to test an aesthetic cover of Qventi with varying configurations of foam. This had no noticeable effect on the sound level of the heat pump. However, the key heat pump frequencies were found, which led to the optimal foam thickness and sheet metal thickness for the final design.

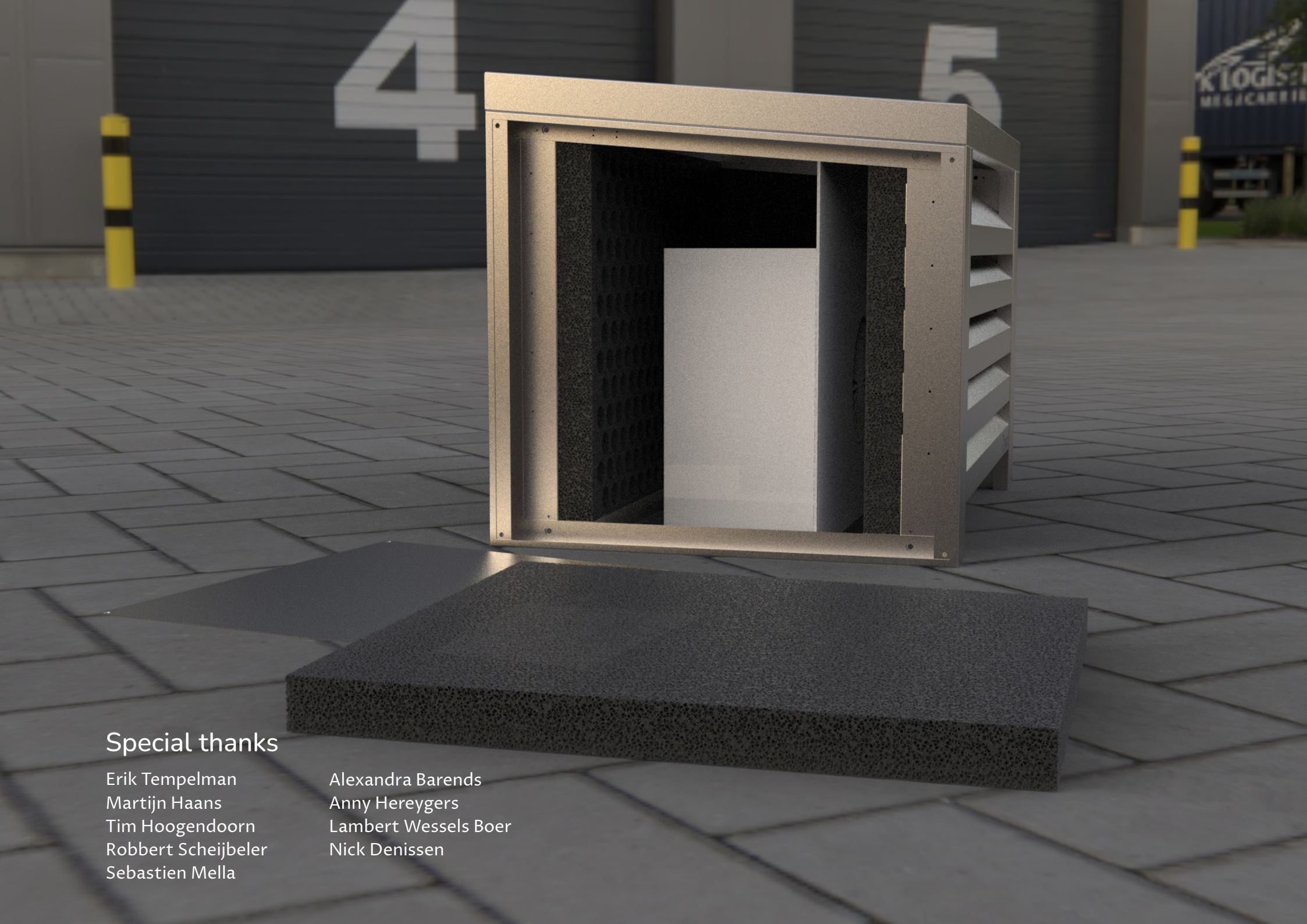
Through nine iterations, the final design was reached. It consists of five sheet metal panels, with clamped-in foam. A recirculation plate splits the inner area into two compartments, preventing the recirculation of air. Anti-vibration foam is placed underneath the heat pump to prevent contact sound.

The model was optimised for assembly by reducing the part count and pre-assembling the panels. Two doors were created on the side panels for easy maintenance access. The roof panel slots into place using a hidden locking mechanism.

Magnelis was chosen as a metal for its high corrosion resistance, long lifespan, recyclability and low CO2 footprint. For the foam, stratocell whisper was chosen for its sound reduction capabilities, low weight, moisture resistance and long lifespan.

Qventi will sell a range of sizes, with the option of custom sizing using a configure to order workflow, where models, technical drawings and quotes are automatically generated based on the specific case of the user. The first model Qventi will bring to the market will be priced at €2065,- for consumers. It is lighter, lower cost, more compact and easier to install than its competitors.

Through an evaluation with users and installers, the hush was found to be more aesthetically pleasing than the rest of the market. Mainly because of the hidden screw holes and the sleek, clean and robust design.



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Vaillant
QVENTI

Problem definition

This chapter describes all there is to know about the premise of the project. It will describe the initial assignment, the context around the project and who are involved.


QVENTI
DC INVERTER
R32
QVENTI

Assignment

As part of the energy transition, heat pumps have taken a rise in popularity, selling an estimated 100.000 heat pumps in the Netherlands in 2022, which is an increase of 37% since the year before (Dutch New Energy Research, 2023). Unfortunately, heat pumps can be quite noisy, sometimes reaching sound levels of 65 dB(A), which can be seen in Appendix 2. For many people this is a significant problem, especially in apartments and terraced houses. Besides this, a new dutch law since 2021 dictates that the maximum allowed sound level at the edge of the property is 40dB during the day and 45dB at night (Geluidsmetingwarmtepomp, 2021).

Qventi is a company formed in 2020 and is owned by the parent company Findyourgroup. Qventi specialises in selling air conditioning and covers to both businesses and consumers. The casings are aluminium exteriors that are mounted around the outside unit of a heat pump or air conditioning. Their primary goal is to make the look more appealing.

However, as these casing are purely aesthetic and do not reduce the sound in any way, the goal of this project is to develop a new sound reducing cover for Qventi. This new product must fit to the needs of installers, for example by ensuring an easy installation process. It must also fit to the wishes of the end users, by making the cover pleasant to look at, compact and available for a reasonable price.

Qventi wants to become the biggest brand in covers for airconditioning and heat pumps. Also being able to provide sound reducing covers would help them to reach more different customers, greatly increasing the speed of their growth.

Compared to the original project brief which can be found in Appendix 1, the focus shifted from heat pumps and air conditioning to just heat pumps, because it was found that air conditioning rarely leads to significant noise disturbance.

Context

This project was set up by Qventi to capitalise on a business opportunity they noticed in the market. Through their work experience of visiting conferences and talking with installers they noticed an opportunity for sound reducing heat pump covers. As they had their hands full and were still quite a small company, Qventi decided to set it up as a graduation opportunity at the Delft University of Technology.

Before starting this project, Qventi had no prior experience in products that reduce sound, so they were looking for someone who was interested in diving into this topic and to develop a new sound reducing cover that fits with the Qventi brand.


QVENTI


QVENTI


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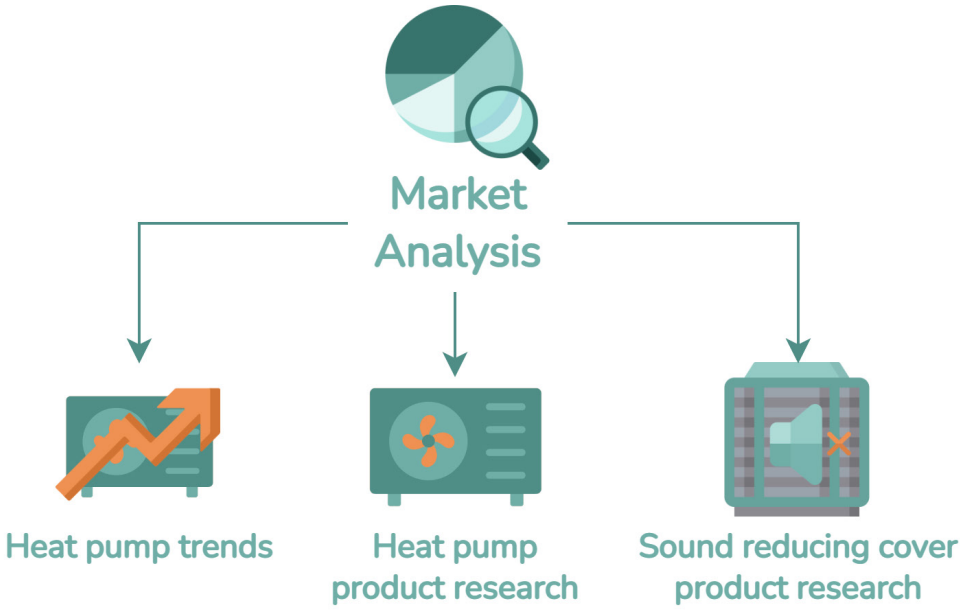
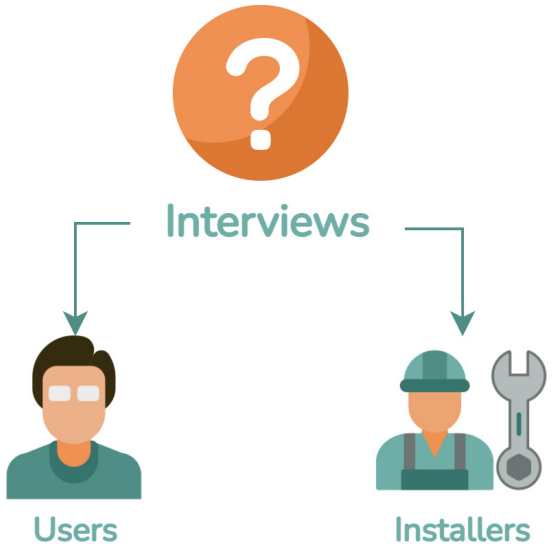
Energolux
Energolux
Midea
SHYROCK

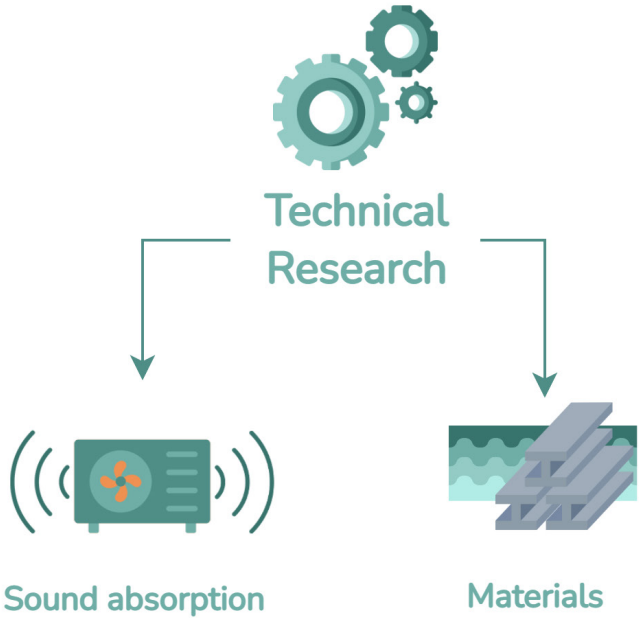
Analysis

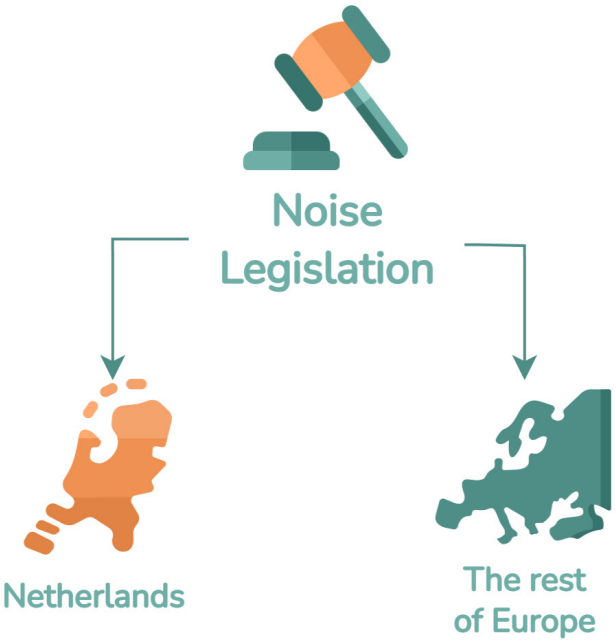
How would you want a heat pump cover to look like?
How many people have issues with noise disturbance?
How do you effectively decrease the sound level of a heat pump?
When does an installer love working with your product?
Is it feasible to make a cover with customised dimensions?

These and other questions will be answered in the coming chapter to lay a foundation upon which the design will be built.


Market Analysis
Heat pump trends
Heat pump product research
Sound reducing cover product research


Interviews
Users
Installers


Technical Research
Sound absorption
Materials


Noise Legislation
Netherlands
The rest of Europe

Exploration

At the start of the analysis phase, a scope was defined. This scope contains the subjects that would be beneficial to understand the context of the product and to lay a foundation whereupon to build the design. This scope can be summarised into the four following fields.

Market Analysis

The goal of this field is to gain a thorough understanding of the market as it is now and where it is going. Firstly, this includes a thorough analysis of currently existing heat pumps as well as sound reducing covers. Secondly, the heat pump trend analysis helps to understand the scale of the market that the product will be operating in and also how the future will look like.

Interviews

There are two main groups of people whose needs are crucial to understand. There are the users who purchase sound reducing covers and sometimes install them. And there are installers, who give advice to users about noise problems and install sound reducing covers themselves. This chapter describes how these groups were interviewed and summarises the most important insights.

Technical Research

This is the field that contains everything somewhat technical. Firstly, the different elements of effective sound absorption of heat pumps. Secondly, a list of promising materials to use in the eventual design.

Noise Legislation

A new Dutch legislation from April 2021 introduced strict limits on noise disturbance. This chapter will go in depth into the specifics of this legislation and how it is applied. Finally the Dutch legislation will be compared to the rest of Europe.

Heat pump trend analysis

Introduction

A trend analysis was conducted in order to gain an understanding of the current heat pump market. The goal was also to gain insight into the different consumer segments and to get an idea of the market scale for sound reducing covers.

Method

Online literature research was conducted, searching for trend reports, sales numbers and other figures. The goal was to find data on the amount of heat pump sales in the Netherlands, the consumer segments and customer satisfaction related to noise disturbance.

Results

In 2022, close to 100.000 heat pumps were installed in the Netherlands, shown in Figure 1. This is an increase of 37% compared to 2021 (Dutch New Energy Research, 2023). In comparison, there were 440.000 installations of central heating boilers in 2022, however, this only warranted a 2% increase compared to 2021 (NOS, 2023).

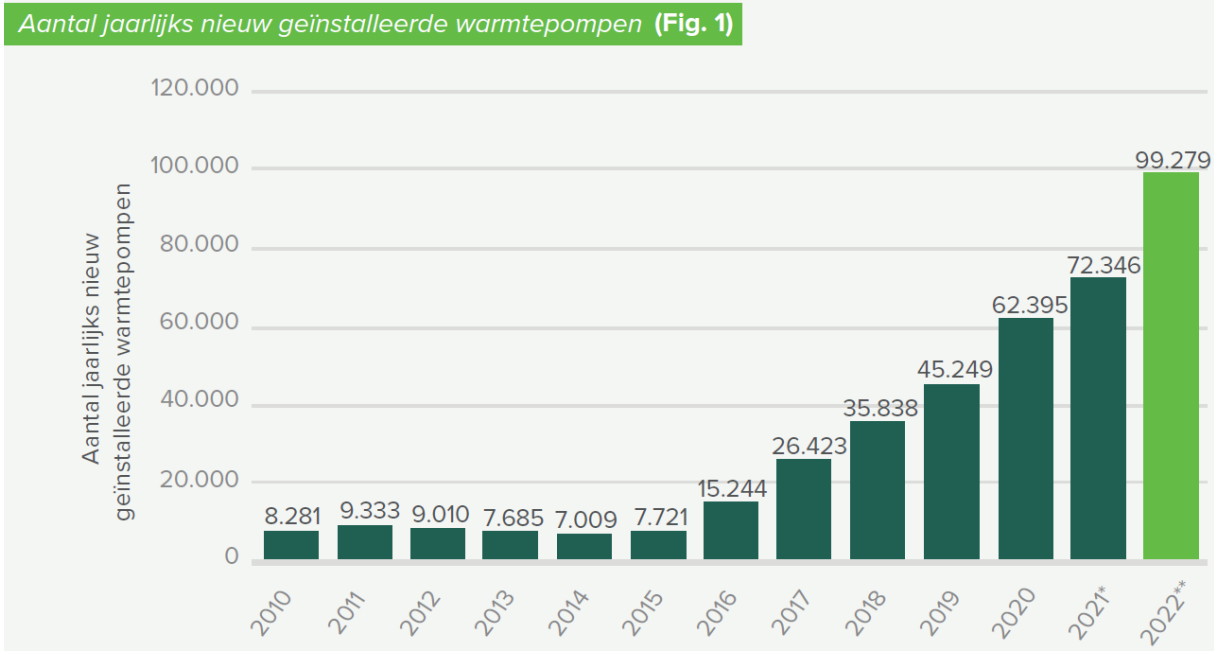


Figure 1: Yearly installed heat pumps in the Netherlands (Dutch New Energy Research, 2023)

When looking at consumer segments, displayed in Figure 2, it can be seen that the growth in the residential segment is immense compared to utility. In 2010, the utility segment comprised around 11% of total heat pump installations. In 2021, this share decreased to just 3% due to the large growth in residential heat pump sales. (Dutch New Energy Research, 2023)

Furthermore, it is of interest to note that heat pump installations take place more often in less densely populated areas, which is shown in Figure 3. Note however, that less densely populated areas will have a lower chance of noise disturbance, as the houses are often further apart and the gardens are larger. (Dutch New Energy Research, 2023)

Figure 2: Yearly heat pumps installed in residential and utility buildings in the Netherlands (Dutch New Energy Research, 2023)

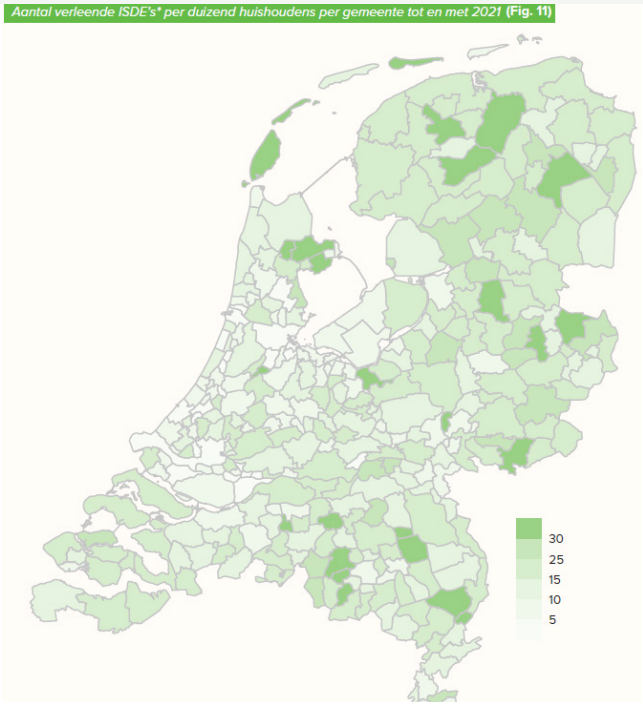


Figure 3: Amount of granted subsidies per 1000 inhabitants per municipality (Dutch New Energy Research, 2023)

The heat pump market can be divided into three main types of heat pumps. There are ‘air to air’ and ‘air to water’ heat pumps. These heat pumps often have an outside unit. Then there are Ground source heat pumps, which do not have an outside unit and thus are not within the scope of the new sound reducing cover. Figure 4 shows the yearly sales of air to air and ground source heat pumps as well as their growth rates compared to the year before. Note that the air to air numbers are missing. This is because their subsidies are grouped with air conditioning. (Dutch New Energy Research, 2023)

From the total of 200.000 air to air subsidies, Qventi estimates 20.000 are heat pumps. So in total, roughly 75% of heat pumps sold in the Netherlands are potentially fit for a sound reducing cover.

Verdeling van het aantal verleende ISDE’s per type warmtepomp **(Fig. 4)**

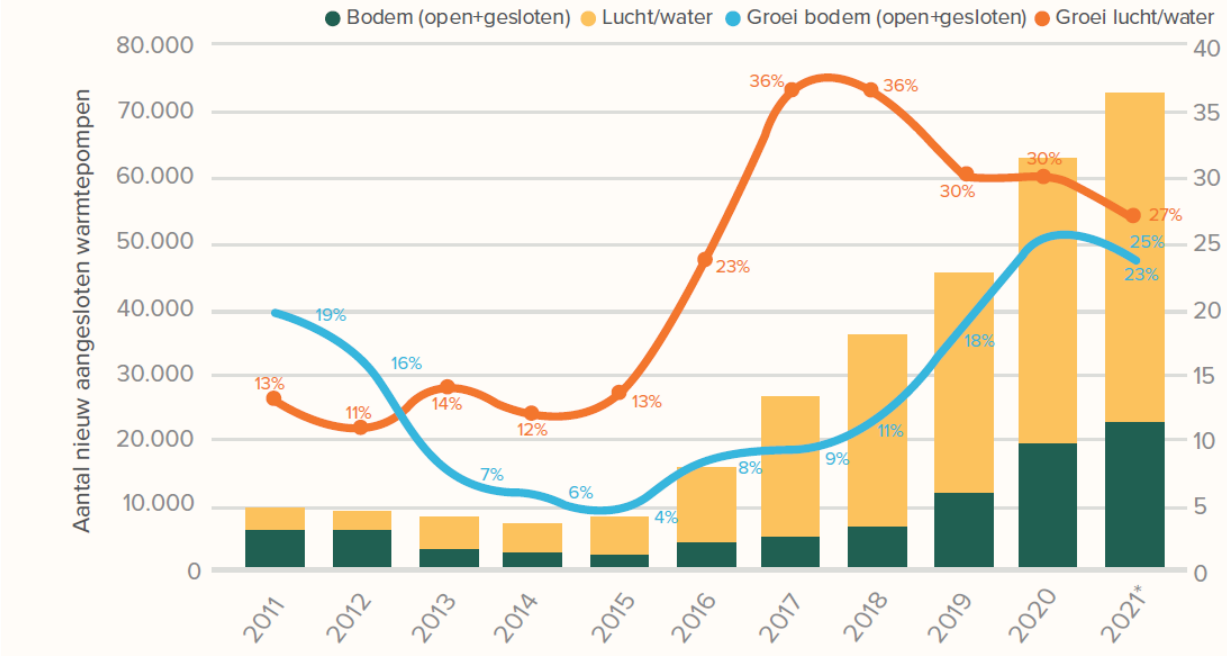


Figure 4: Yearly granted subsidies of ground source and air to water heat pumps (Dutch New Energy Research, 2023)

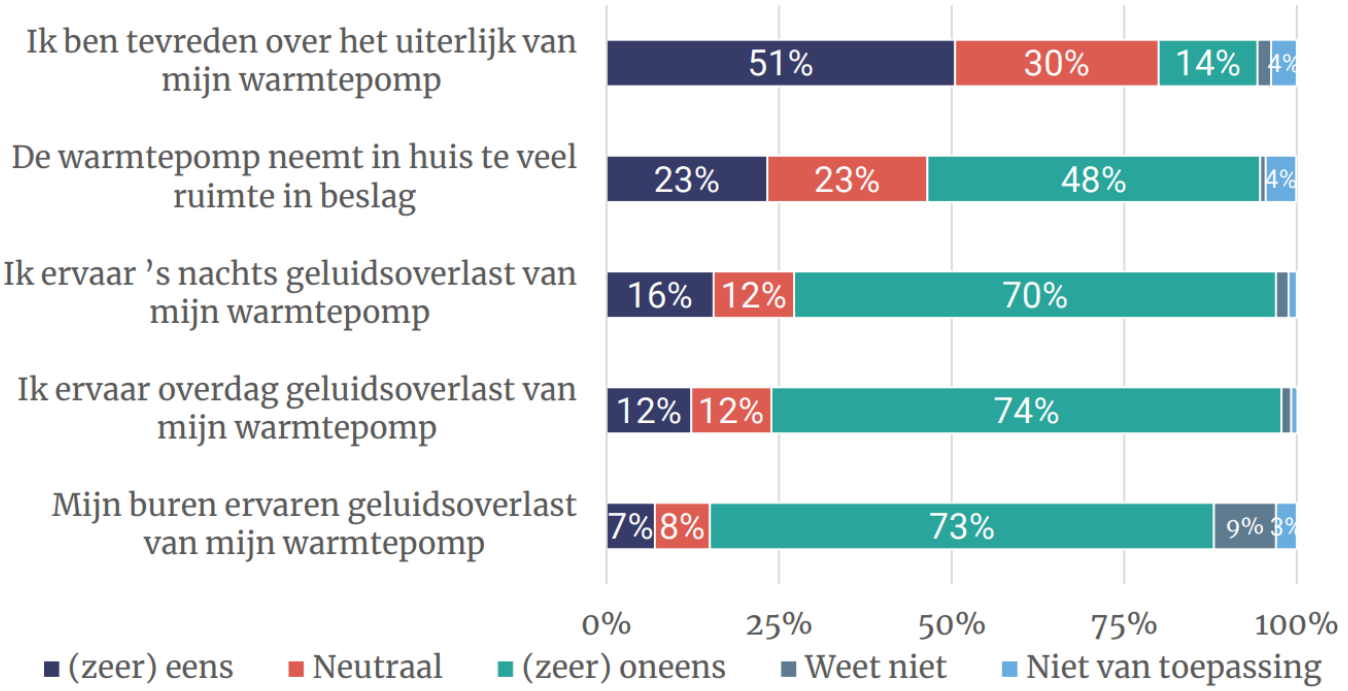


Figure 5: Survey results of a research on heat pump customer satisfaction (I&O research, 2021)

As of the end of 2022, there are a total ~450.000 installed heat pumps in the Netherlands (Dutch New Energy Research, 2023). In a survey of 995 Dutch people, it was found that . 16% experience noise disturbance at night, 12% during the day, and 7% of people's neighbours experience noise disturbance, this is shown in Figure 5 (I&O research, 2021). Taking a rough average of 12% of the 450.000 total installations, this would result in about 54.000 potential customers for a sound reducing cover.

To map out the newest trends in heat pump product development, the largest heat pump fair in the Benelux was visited (Green Heating Solutions, 2023). Figure 6 shows a collage of this visit.

A major trend that was identified was that heat pump manufacturers are increasing the size of their outside unit to reduce the sound level. It could also be seen that brands are paying more attention to the aesthetics of their outside unit, utilising darker colours such as grey and black, using more rounded design details and more unique grate patterns. Finally, a last trend that was found was the increasing popularity of roof-mounted heat pumps. Figure 7 shows an example. The advantage of a roof mount is that it does not take up space from the garden and that the sound levels are less bothersome as the heat pumps are further away.

These trends are all dangerous for the existence of sound reducing covers, as heat pumps are becoming more aesthetically pleasing and quieter without the need of a cover. While the amount of aesthetic and quiet heat pumps is still relatively low, these trends need to be monitored carefully to ensure the future viability of sound reducing covers.

Conclusion

The heat pump market in the Netherlands is growing rapidly with a growth of 37% in the past year. Practically all installations are made in the residential segment, which means Qventi should fully focus their effort there. Looking at heat pump types, roughly 75% of heat pumps sold in 2021 have the potential to have an outside unit. About 12% of people have issues with noise disturbance, which gives an estimated 54.000 potential customers for a sound reducing cover.

Trends were identified indicating that heat pumps are becoming more quiet, more aesthetically pleasing and installed on the roof more. These trends threaten the existence of sound reducing covers and need to be paid close attention to.

Unfortunately, no sales data was found on sales of specific heat pump brands. There was also no data found on the amount of heat pumps with and without outside units.

Figure 6: Heat pumps displayed at the Green Heating Solutions fair

Figure 7: Example of a roof mounted heat pump (Ubbink, n.d.)







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LG
THERMA V

POOLWORLD

IMMERGAS

VIESMANN


Heat pump product research

Introduction

In order to gain an understanding of the heat pumps that will be designed for, a product research was conducted. The goal was to gain insight into common product characteristics that are important for designing a sound reducing cover, such as the airflow direction, sound level, size and price.

Method

As no data on exact sales figures was available, eight models that were selected by the consumentenbond were analysed (Van der Wilt, 2022).

This list was then checked with the project manager of technology, safety and environment from the 'NVKL' or dutch association of heat pumps and air conditioning (Groot Zwaaftink, 2022) and the two bosses of installation company Denissen (Denissen & Denissen, 2022) to see if the list was complete and contained the most important popular heat pumps. Through this check a ninth heat pump was added to the list. The data was then collected in a spreadsheet and analysed through graphs. The full spreadsheet can be found in Appendix 2.

Results

Firstly, looking at the models in Figure 8, it can be seen that they all employ a back to front airflow. Secondly, looking at the prices in Figure 9, it is apparent that 50% of the analysed heat pumps fall between 6400 and 8000 euros, with a median of 7250. Compared to the traditional central heating boilers this is quite a lot, as those typically fall between 2200 and 3500 euros (Denissen & Denissen, 2022). The most expensive heat pump goes as high as 15900 euros, which can be explained by the fact that the Nibe heat pump takes 8kW, which places it in a higher calibre than the rest.

Figure 10 shows the difference in size. It can be seen that the depth and length are relatively similar across the board, while the height differs a lot more. The height boxplot shows that 50% of the heat pumps are quite similar in height, but there are some outliers, being vastly different in size.

Figure 8: The nine heatpumps that were analysed

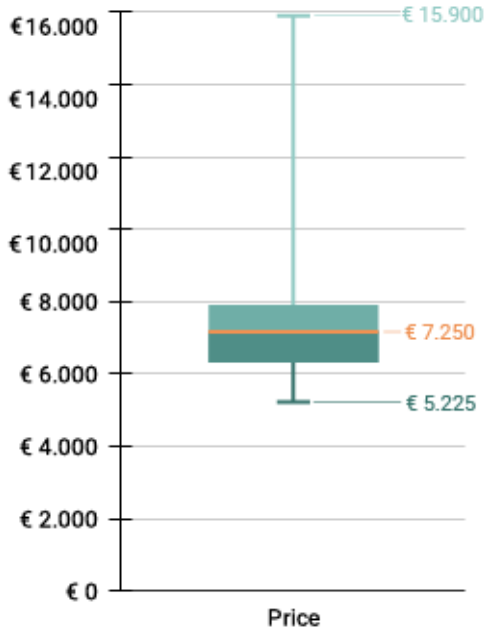


Figure 9: Box plot of price distribution including sales tax and installation costs

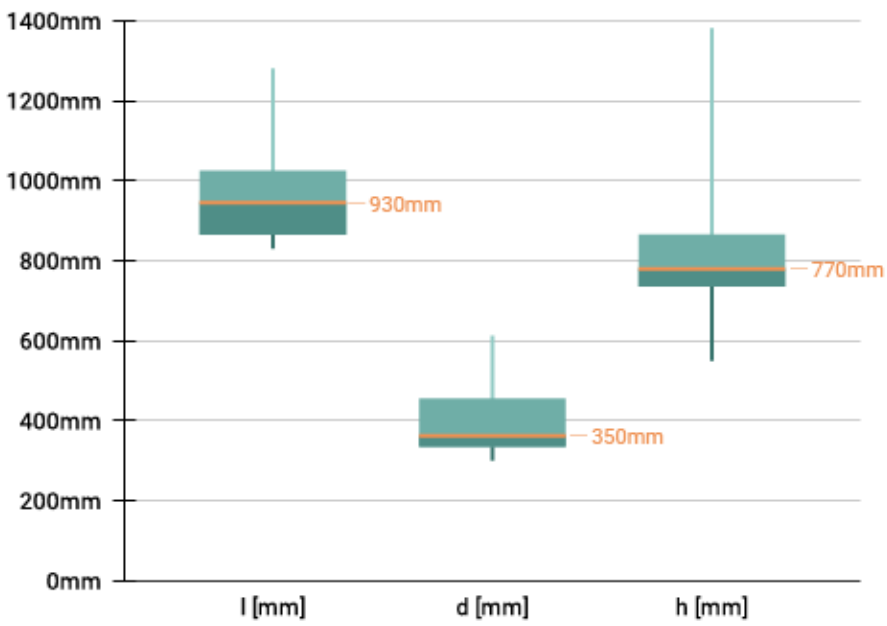


Figure 10: Box plot length, depth and height of the outside units in mm

Looking at Figure 11, these outliers in size are clear as well. The Nibe and Bosch heat pumps have two to three times as much volume as the others.
Finally, Figure 12 shows the sound levels of the heat pumps. Across the heat pumps that were analysed, there is an average sound production of 59 dB(A).

An interesting observation can be made when comparing this graph to Figure 11. The Nibe and Bosch models are some of the quietest outside units, even though they are 8 and 5kW respectively. This is related to their size. The heat pumps need a certain amount of airflow. Increasing the size allows for a larger fan which decreases the required rotations per minute. This greatly reduces the sound and is a technique employed more and more in newer models.

Conclusion

To summarise, the only airflow that needs to be designed for is a back to front airflow.

The price of heat pumps is still about 2-3 times more expensive than central heating units. Since this is a lot more than what people are used to, it is important that the cost of a sound reducing cover is kept as low as possible.

There is now a base understanding of the sizes and sound production of heat pumps in the market today.

It must however be kept in mind that only nine heat pumps were analysed. To get a proper assessment of the product range more research will have to be conducted.

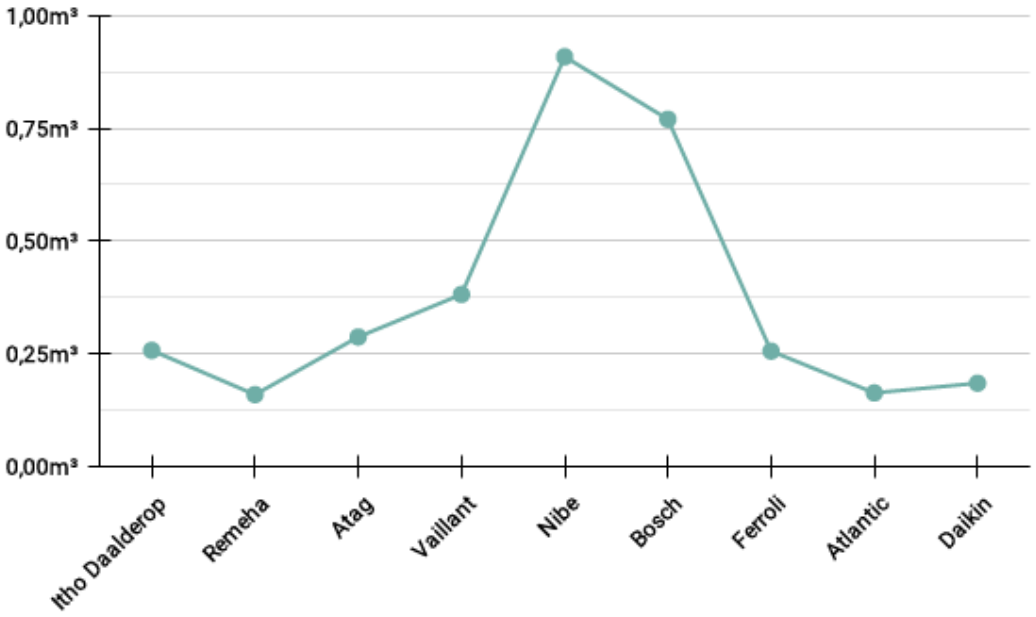


Figure 11: Total volume of the outside units in m³

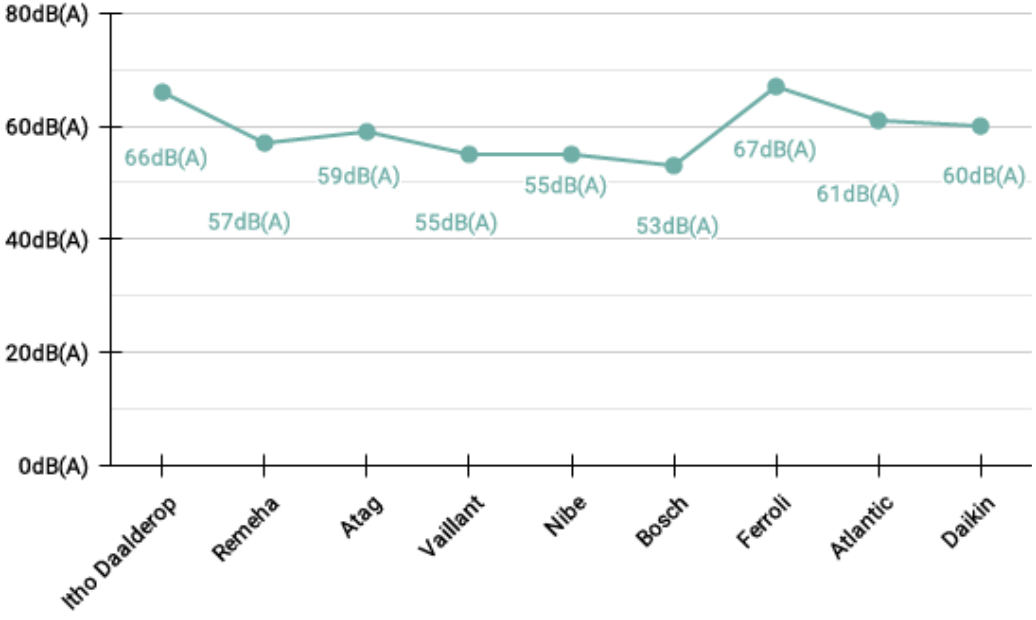


Figure 12: Sound levels of the outside units in dB(A)

Sound reducing covers product research

Introduction

The goal of this research was to analyse the current sound reducing cover market. Specifically to find out how the different models that are currently on the market work, their prices, sizes, weights and how much sound they reduce.

Method

A list was made of nine heat pump covers with sound reducing capabilities. In order to check the completeness of this list the product manager of technology, safety and environment of the NVKL was asked for the most popular brands in the Netherlands as of today. She clarified that the brand 'Merford' is the current market leader in the Netherlands without a lot of competition (Groot Zwaaftink, 2022). Merford shares this view (Vreede, 2022).

For this reason extra close attention will be paid to Merford in the product research. The brand 'Reducd' will also be analysed further, as they are a Dutch company with a specific focus on a short installation time, an aspect of the design which is of great importance to Qventi.

Because all brands have multiple sizes available, the dimensions of a dc inverter of Qventi were chosen, to then match the cover size to the inverter. In practice, this meant that the smallest size of the brands was often chosen.

After comprising a datasheet, the data was analysed through graphs. The full spreadsheet is displayed in Appendix 3.

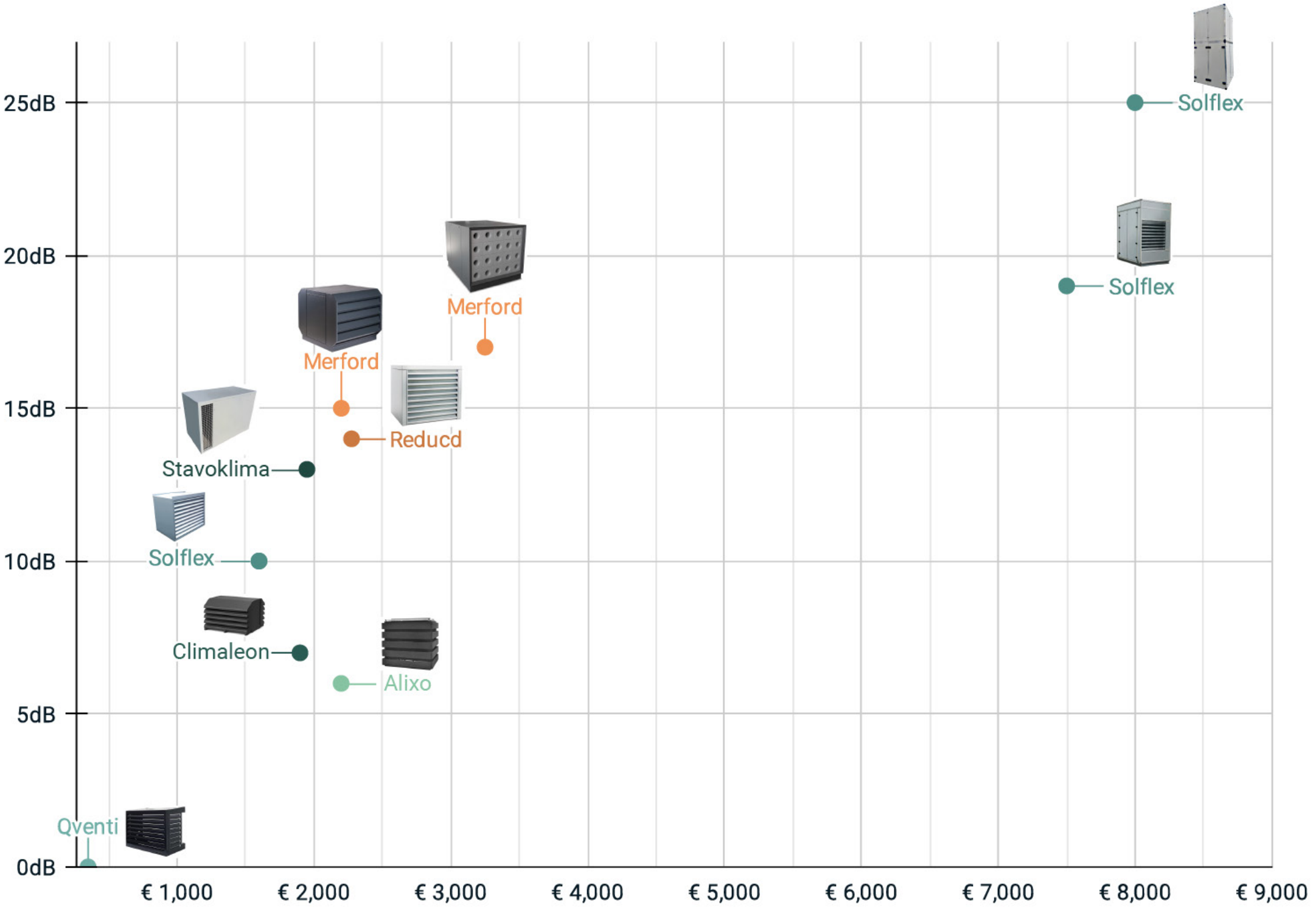
Results

Figure 13 displays the nine analysed covers with the addition of the Qventi aesthetic cover. The two extra important brands, Merford and Reducd, are displayed in orange.

From the graph it can be seen that the price point of the important brands starts at €2200,- for a minimum sound reduction of 14dB.

For the Qventi sound reducing cover it will be important to best reducd and merford. Either by providing more sound reduction for the same price, or by providing the same reduction for cheaper.

Figure 13: Price vs sound reduction. The most important brands are highlithed in orange.


25dB
20dB
15dB
10dB
5dB
0dB
€ 1,000
€ 2,000
€ 3,000
€ 4,000
€ 5,000
€ 6,000
€ 7,000
€ 8,000
€ 9,000
Solflex
Solflex
Merford
Merford
Reducd
Stavoklima
Solflex
Climaleon
Alixo
Qventi

In Figure 14 the extra volume and weight are displayed of the selected models. ‘Extra volume’ refers to the difference between the inside and outside dimensions of the cover. It gives an indication of the compactness.

As for weight, a lower weight is naturally more desirable as it is easier to manufacture, transport and install. However, the cover still needs to have enough weight to reduce the sound of the heat pump. For the readability of the graph, the two large solflex models are left out, as they are around 650kg and 5m^3 extra volume.

It can be seen that Reducd is the most compact model and is quite a lot better than the models of Merford. This is because the lamella design that Merford employs takes up a lot more depth than Reducd. However, it is a lot more heavy

It is also interesting to note that the Alixo model is extremely light, but the most space inefficient of all models. This is due to the fact that it is mostly made of thick expanded polypropylene instead of heavy galvanised steel.

Qventi’s current aesthetic cover is of course extremely compact, as there is no clamped in foam.

For Qventi it will be ideal if the new cover is more compact and lighter than Reducd while still having the same sound reduction capabilities.

Figure 14: Weight vs extra volume. Extra volume is the difference between inside and outside dimensions. Important brands are highlighted in orange

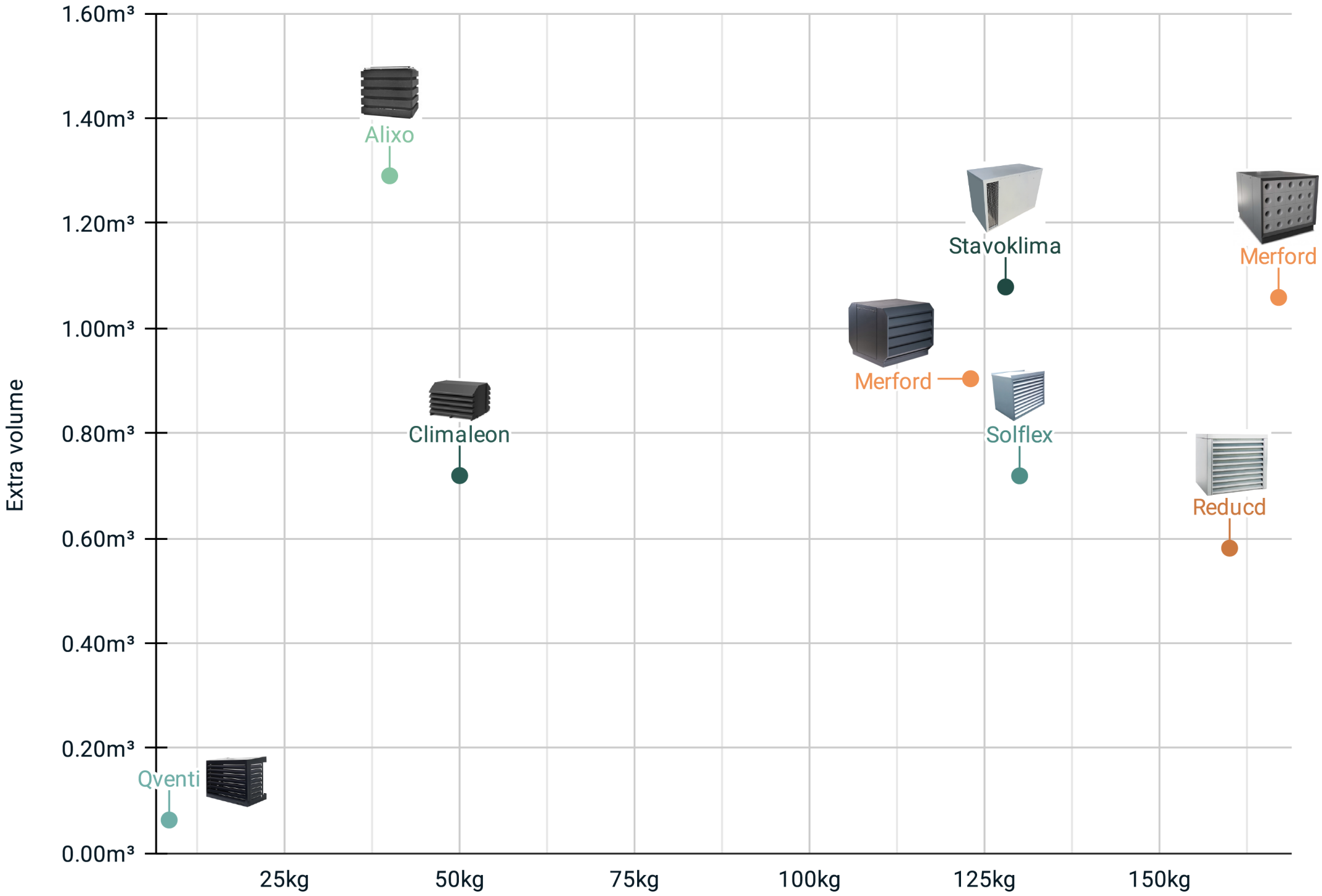

Extra volume
1.60m³
1.40m³
1.20m³
1.00m³
0.80m³
0.60m³
0.40m³
0.20m³
0.00m³
25kg
50kg
75kg
100kg
125kg
150kg
Alixo
Climaleon
Qventi
Stavoklima
Merford
Solflex
Merford
Reducd

Figure 15 shows a table containing some extra information of the two most important brands, Reducd and Merford.

The installation time of Merford is advertised to be two hours by two people, but is quite a bit longer in reality. This is due to the fact that no pre-assembly is done. All lamellas need to be individually screwed together, which also raises the part count and assembly time by a lot, as can be seen in Figure 16.

Reducd has a very flushed out assembly requiring only twelve screws. However, in order to create a hole for the cables of the heat pump, a drill, rivet gun and angle grinder are needed, which makes the process needlessly complex. This is displayed in Figure 17.

The goal for Qventi will be to create an assembly that is even more simple than Reducd and does not require specialised tools.

Conclusion

The market of sound reducing covers in the Netherlands is dominated by Merford, whose smallest model reduces 15dB for €2200,-. Their main competition Reducd is in a similar position. Reducd has a better installation process than Merford, but still requires specialised tools to assemble. Reducd is the most compact on the market.

Besides Reducd and Merford, there exists a high segment of ~20dB for ~€7500,- and a lower segment of 7dB for €1900,-

The new cover of Qventi will aim to sell for a lower price than €2200,- with the same sound reduction of 14dB, while being more compact than Reducd and while weighing less. The new cover will also not require specialised tools and aim to be faster to assemble than Reducd.

	Merford Dice-05	Reducd S
dB reduction	15dB	14dB
Price	€ 2,200	€ 2,275
Weight	123kg	160kg
Extra Volume	0.90m³	0.58m³
Metal part count	27	5
Screws	(up to) 100	12
Nuts	(up to) 100	0
Other parts	(up to) 55	6
Special tools required	×	Rivet gun, angle grinder
Installation steps	22	9
Advertised install time	2 people 2 hours	1 person 1 hour
Actual install time (based on reviews)	"8 hours" (Van Tilborg, 2021)	"a few hours" (Van Osch, 2022)

Figure 15: Comparison between the smallest Merford and Reducd model

Figure 16: Having to attach lamellas individually, combined with a high part count, makes Merford's assembly lengthy

Figure 17: If a cable hole is needed, a drill, angle grinder and rivet gun are required to install the cover of Reducd

Interviews

Introduction

To get an overview of the wants and needs of users and installers, interviews were conducted. The goal was to understand what is important to both users and installers when purchasing a sound reducing cover. Furthermore, to find out what covers that currently exist are considered (not) aesthetically pleasing and for what reason.

Method

Three users were selected that own a home and have had a heat pump installed in the past five years. For the installers, the two owners of an installation company were approached.

The interview with users consisted of two parts. To start, they were asked about their current heat pump and how they came to the model they have installed, as well as discussing the aspects of a sound reducing cover that are important for them, such as aesthetics, weight, price and size.

The second part consisted of a review of the aesthetics of existing sound reducing covers. Here, sets of three covers were shown and the users were asked to point out which ones they liked and which ones they did not like, while describing why they thought that way.

The installers were first asked about their prior experience with installations and covers. Then they were asked what is important to them while selecting a brand of sound reducing covers to sell to customers.

Results - Installers

Nick and Lambert are owners of installation company Denissen, displayed in Figure 18. They are located in Riel, from where they work on many facets of installations, such as heat pumps, sanitation, plumbing and roofing.
The houses they work on are mostly detached houses.

Nick and Lambert told us that noise problems from heat pumps mostly occur in apartments and terraced housing, as detached houses often have a lot more space for their heat pumps, meaning noise is less of an issue. They were also asked what was important to them while selecting a brand of covers to work with.

Figure 18: Lambert Wessels Boer (left) and Nick Denissen (right) are the owners of installation company Denissen

The first thing they mentioned was ease of delivery. If they can order from an existing wholesaler that is already delivering to them daily, that has their preference. Secondly they talked about the ease of installation and repair. The product has to have a streamlined, intuitive assembly process and a good manual, including a QR code to a video manual.

Another thing that is important to them is the ease of quoting. When making a quote, they want to immediately know the right cover size by looking up the model so it can be added to the quote as easily as possible.
They also mentioned that it should be easy to fit inside of a van and should be easy to transport.

Nick and Lambert also thought that a price of €2000,- will be hard to sell on top of a €7000,- heat pump installation, and that with this price point sound reducing covers might be better suited as a 'problem solver', to be placed when users experience noise issues with their heat pump. (Denissen & Wessels Boer, 2022)

For Qventi it will be important to optimise the assembly process, make it easy to see what model is needed and to make a clear video manual.

Results - Users

Two types of user groups were identified. Firstly there are the outsourcing users, who leave everything to the installer. Secondly, there are researching users. These users will research by themselves to select the exact product they want and also install it themselves wherever possible.

Alexandra is an outsourcing user. Figure 19 displays her living context. If her heat pump would make too much noise, she would ask her installer what she would need to make it quieter. She would also never install a cover herself. If it were placed in her garden however, she would want the cover to fit well aesthetically. She wants the design to be sleek and blend into the environment of her garden properly.

Anny and Pieter are researching users whose living context can be seen in Figure 20. Pieter is an ex mechanical engineer and a very technical person.

If Anny and Pieter would have a heat pump that makes too much noise, they would ask knowledgeable relatives and would research online. Specifically they would look into the functionality: Are the claims that the product makes true? What research and independent testing has been done? How easy is it to repair? They would also pay attention to the aesthetics. They would want a sleek design with straight angles and no 'weird' shapes, like circles or ovals. If possible, they would definitely install it themselves.

Figure 21 shows what users thought of the aesthetics of different currently existing covers. It can be seen that they did not like big shapes, seeing screw holes, machine-like exteriors and they did like sleek, straight designs that blend into the environment or more 'designy' covers.

Figure 19: Alexandra's Neighborhood. Her heat pump is outlined in red.

Conclusion

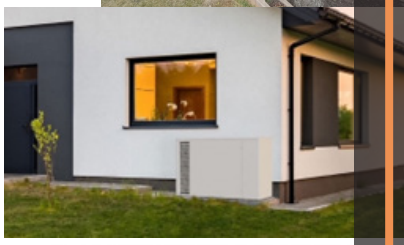
For installers, it is important that the cover is easy to order, quote, repair and assemble. To reach outsourcing users it is important that their installer likes working with the product and that the user still has input on the aesthetics of the design.

To reach researching users it is important to be communicative about independent testing that has been done to prove the functionality, and to make it easy to assemble for users. This means the heat pump should not have to be disconnected in order to install the cover.

Aesthetically, the design will be sleek, compact, with straight angles, blended into the environment and with a small detail scale.
The design will not be machine-like, and show no visible screw holes.

Figure 20: The Neighbourhood of Anny and Pieter. Their ground source heat pump is displayed bottom left.

Prettiest of all
Sleek



Blends in nicely
Proper

Kind of sleek
Could be more playful
Designy

Quite big
Aggressive
Air intake is gaudy

Like an old radiator
Hard to keep clean
Ugly grates

Holes are visible
Grate and corners are ugly
Rough
Like a machine
Cheap

Completely horrible
Like a blast furnace
Fierce

Figure 21: Review of existing covers from ugly (bottom) to pretty (top)

Pretty

Ugly

Technical research

Introduction
The goal of this research is to gain an understanding of how the sound of heat pumps can be reduced. Another goal is to comprise a list of promising materials that could be used for the sound reducing cover.

Method
This research was conducted through a combination of online literature research and an acoustic consultancy with an expert in the field of sound reduction and foams.

Results
In an acoustic consultancy with Vreede (2022) the different aspects of reducing sound of heat pumps were discussed. Figure 22 shows an overview of these aspects. Two categories were found. Sound travelling through the air, which needs to be reduced by a combination of sound reducing foams and heavy weight, which is most often done by using a cover of heavy steel.

The second category is contact sound. The vibrations of the heat pump can be passed on through the surface it is standing on, carrying the sound underneath the cover. This is especially significant when the heat pump is placed on top of a (wooden)roof.

Figure 23 displays a collection of promising sound reducing materials. Akotherm is used in the DICE model of Merford. It is a polystyrene wool, made from recycled PET bottles. It is not weather resistant, so proper care should be taken that it does not get wet. Stratocell whisper consists of expanded LDPE. It is water resistant, fire retardant, lightweight and extremely durable. An added benefit is that it is a bad thermal insulator, contrary to most sound reducing foams. This means the heat pump stays cool as it can dissipate its heat effectively. Expanded cork, natural rubber, biofoam and flax are all bio based renewable materials.

These materials have the advantage that their embodied CO2 emissions are rather low. The disadvantage however is that they do not reduce sound as effectively as materials like whisper.

Figure 24 shows promising metals. The metal used must be quite heavy to reduce sound effectively. Sendzimir is a more traditional type of galvanised steel and slightly more low cost, while magnelis is of a slightly higher cost with high corrosion resistance, lower CO2 footprint and with self-healing properties.

In Figure 25 regufoam is displayed. This high density polyurethane foam has been designed specifically to isolate vibrations and is currently used by Merford.

Conclusion
Reducing the sound of a heat pump consists of sound reducing foam, weight and anti-vibration foam. A selection of promising materials was made.

Figure 22: A diagram explaining the reduction of heat pump sound

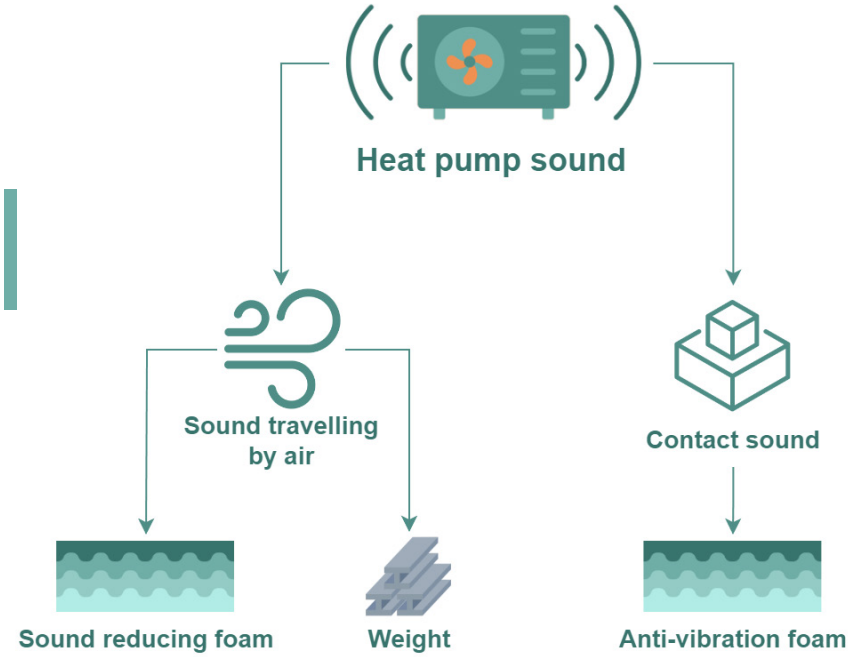


Figure 23: Sound reducing foams

Figure 25: Anti-vibration foam

Figure 24: Promising types of metal

Legislation

Introduction

The goal of this research is to understand the current noise legislation in the Netherlands. How it works, how it is enforced and for whom it is difficult to adhere to it. Finally, the noise legislation in other countries of Europe is briefly reviewed.

Method

Information about legislation was gathered through online literature research, and by speaking with Groot Zwaaftink (2022). She is the project manager of technology, safety and environment from the 'NVKL' or Dutch association of heat pumps and air conditioning, where she helped develop the current noise legislation in the Netherlands. Groot Zwaaftink was interviewed on the development of the policy and how people make sure to adhere to it.

Results

In the Netherlands, there is a noise limit of 45dB during the day (7:00-19:00) and 40dB during the night (19:00-7:00). This value is measured at the property border. For heat pumps on the ground this means a measurement from the property fence, and for roof mounts from the nearest window.

Groot Zwaaftink indicated that the legislation is mostly problematic for terraced housing and apartments.

When someone suspects that their neighbour has sound levels above the limit, they can put in a complaint with the municipality. The heat pump owner will then pay for an acoustic advisor to perform measurements.

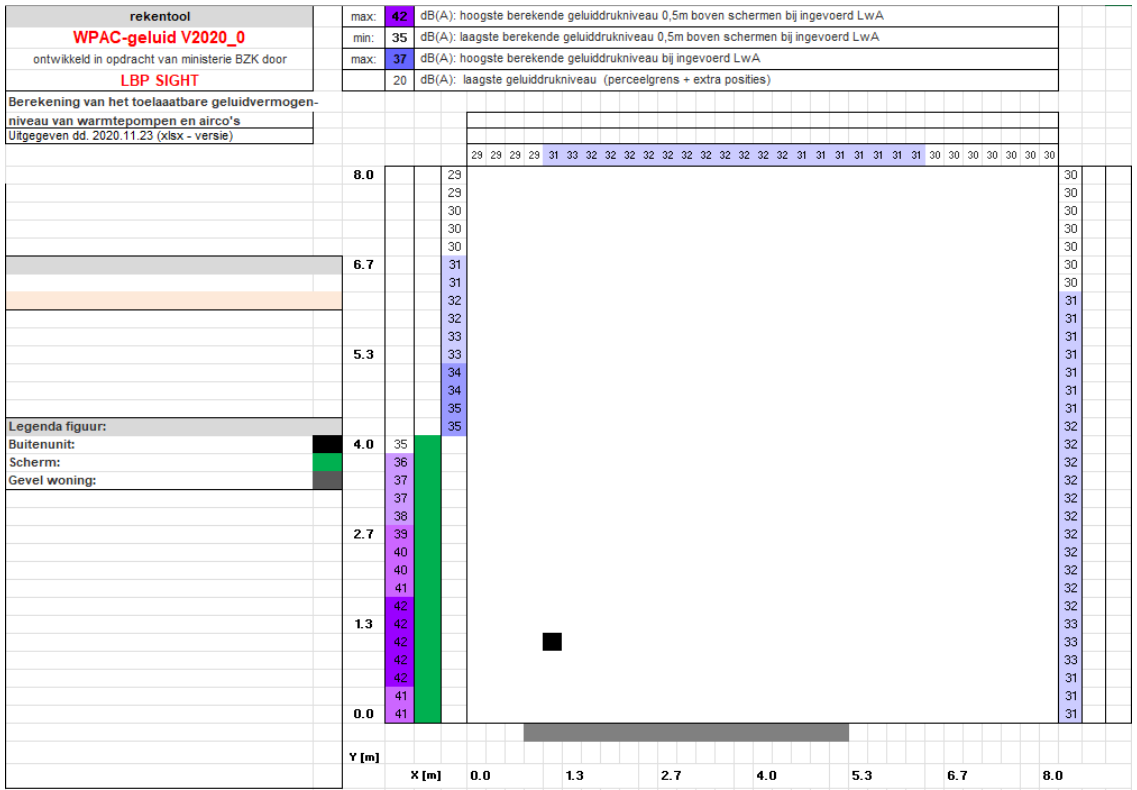


Figure 26: A calculation tool commisioned by the government to predict noise disturbance

If those measurements indicate that the limits are surpassed, the heat pump owner will have to find a solution. The most common solutions are moving the heat pump to a different location or ordering a sound reducing cover.

In order to prevent surpassing the legal limits, installers and users can consult a calculation tool, displayed in Figure 26, that has been developed by LBP sight, an engineering firm with expertise on acoustics. Here the garden wherein the heat pump is placed can be mapped out. A solid noise barrier gives an extra 5dB of allowed noise.

Tonality in the sound of the heat pump gives a penalty of 1-5dB to the heat pump sound. Tonality is the presence of a distinct tone or hum and is specified on the heat pump datasheet.

This calculation tool can give an indication of the adherence to the law, but is only advisory in the case of a legal dispute. However, Groot Zwaaftink mentioned that in practice, there are almost no installers that use it before an installation.

Compared to other countries in Europe, displayed in Figure 27, the noise legislation in the Netherlands is on the lower side, with the exception of France, which is even lower. Note that this graph is highly simplified and the legislations are in reality much more complex.
For details refer to the full report by Fumagalli et al. (2020).

This means that if a sound reducing cover is good enough for Dutch people to stay below the sound limits, the product could also be sold to most of Europe for the same purpose.

Conclusion

There is a limit of 45dB during the day and 40dB during the night measured from the property border. This is mostly problematic for apartments and terraced housing. A calculation tool can be used to give an indication of the sound levels, but is not used a lot in practice. Compared to other countries in Europe, the Netherlands is on the lower side of legislation. This means that the product can also be sold in many other countries in Europe.

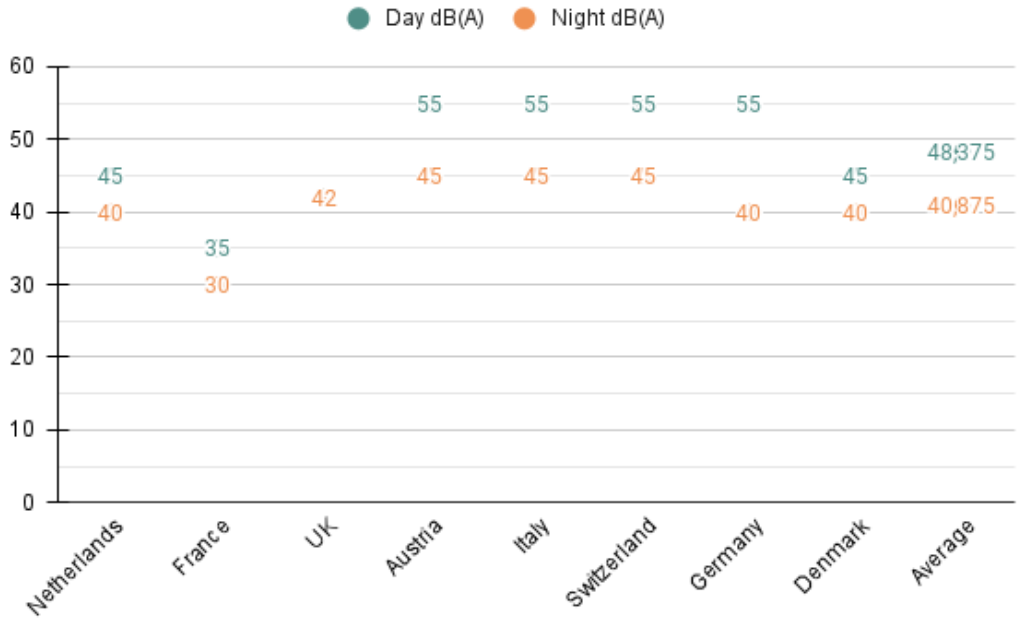
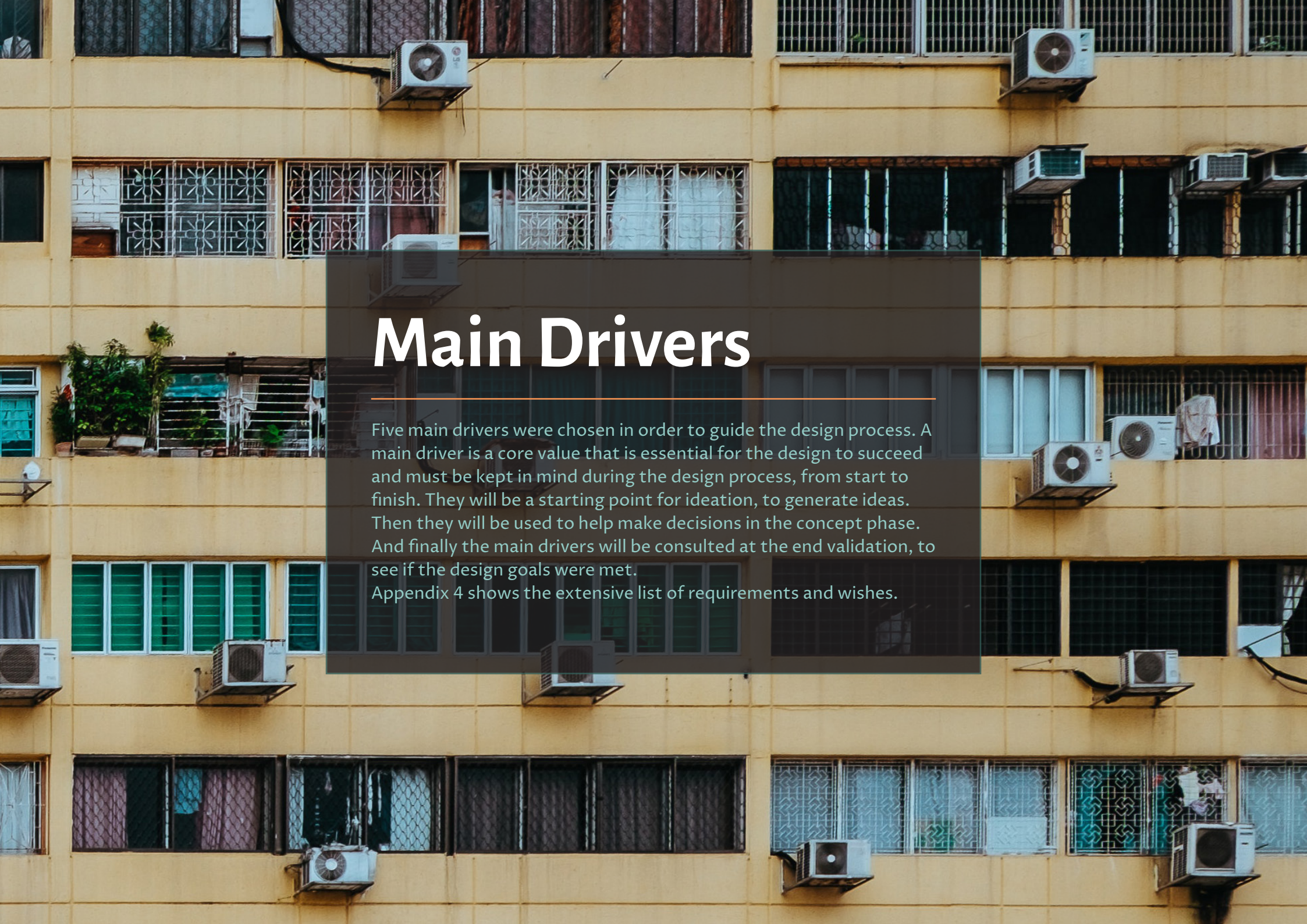


Figure 27: Noise limits of several countries in Europe (Fumagalli et al., 2020)



Main Drivers

Five main drivers were chosen in order to guide the design process. A main driver is a core value that is essential for the design to succeed and must be kept in mind during the design process, from start to finish. They will be a starting point for ideation, to generate ideas. Then they will be used to help make decisions in the concept phase. And finally the main drivers will be consulted at the end validation, to see if the design goals were met.
Appendix 4 shows the extensive list of requirements and wishes.

Peaceful Silence

The cover will reduce the sound of the heat pump by at least 10 dB(A), which is enough to half the loudness of the sound for most frequencies. The goal is to transform the sound of the heat pump from an obnoxious presence to a mere background sound. The sound will only be noticeable when paying very close attention.

Hidden in Plain Sight

Like the owl in the picture, the heat pump will blend in seamlessly with its environment. The heat pump could be unrecognisable and mistaken for something else, or camouflaged so well that it does not stick out. Furthermore, the exterior will have a clean and sleek look that fits in the style of gardens today.

Easy to Assemble

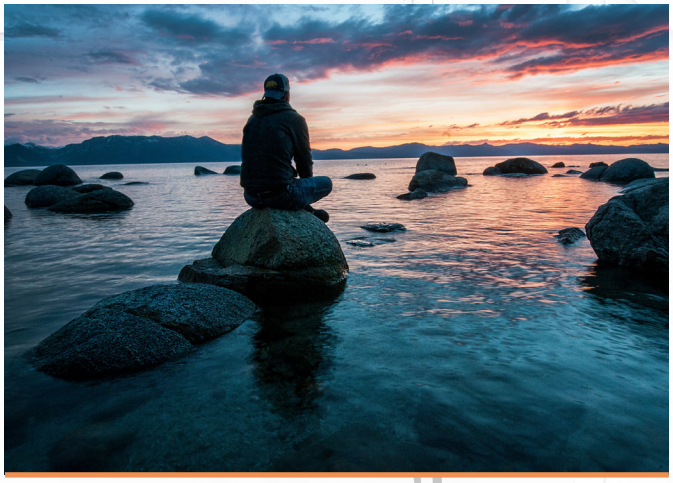
A short installation time is incredibly important for the sound reducing cover. Like this table, it should be intuitive and easy to see which part belongs where and how it is assembled. The assembly process will have as few steps as possible and as few parts as possible. It is also important that no specialised tools are required for the assembly process.

For a Brighter Future

Because heat pumps are part of the energy transition, it is of vital importance that the products surrounding them fit within this theme and are as sustainable as possible. This means using recycled and bio based materials to reduce the carbon footprint as much as possible, as well as making the cover ‘built to last’, to ensure a long life span.

Available Today

The cover will be made with materials and technologies that are available today. For Qventi it is important that the time to market is as short as possible to capitalise on the increasingly large heat pump market. This means it should also be viable to mass produce the product right now.



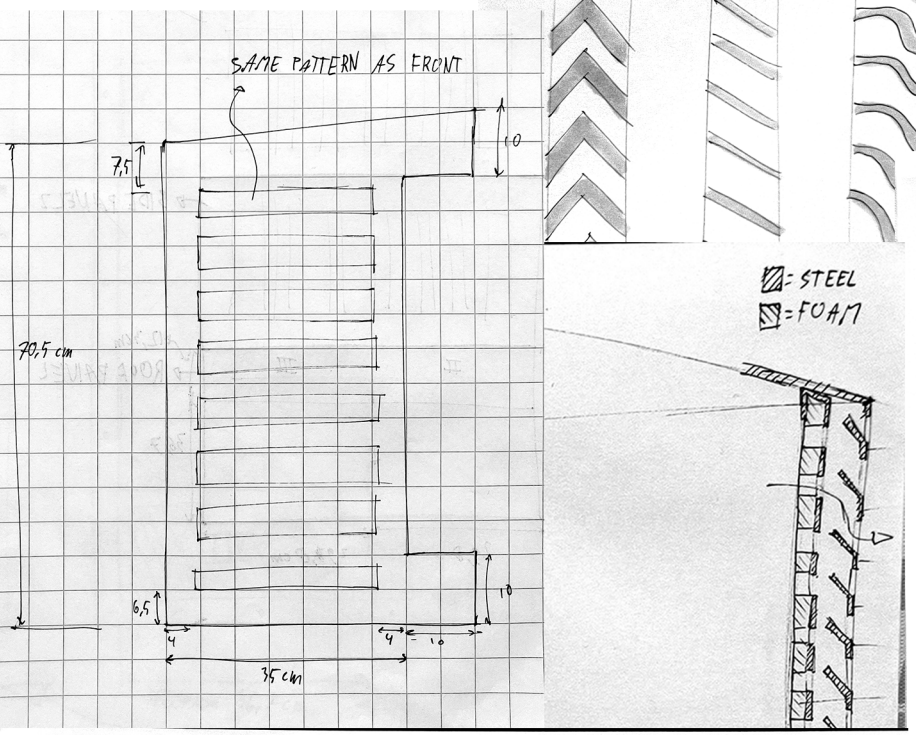
Peaceful Silence

Hidden in Plain Sight

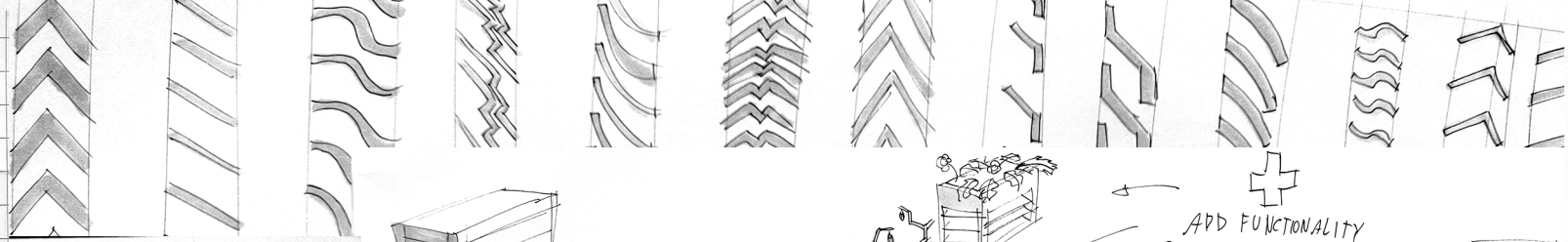
Easy to Assemble

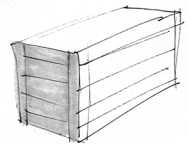
For a Brighter Future

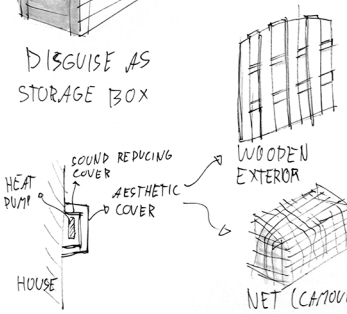
Available Today

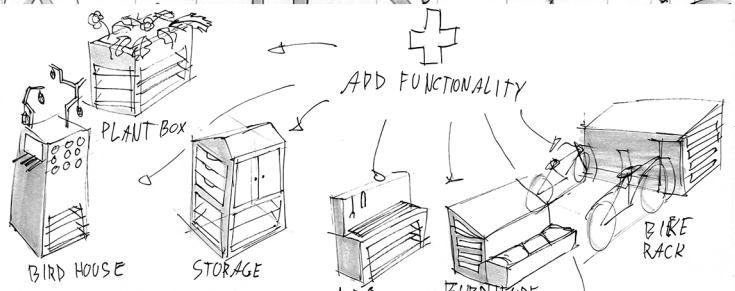

SAME PATTERN AS FRONT
7,5
10
70,5 cm
6,5
4
4
10
35 cm
10

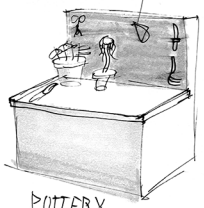
= STEEL
= FOAM

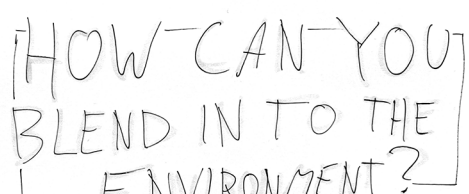


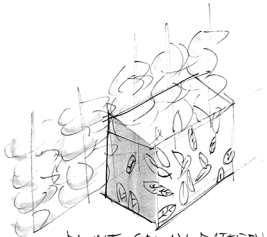

DISGUISE AS
STORAGE BOX

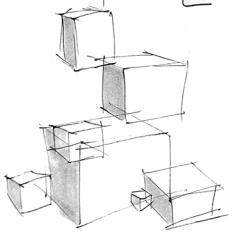

WOODEN
EXTERIOR
SOUND REDUCING
COVER
AESTHETIC
COVER
HEAT
PUMP
HOUSE
NET (CAMOUFLAGE)

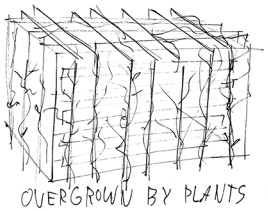

ADD FUNCTIONALITY
PLANT BOX
BIRD HOUSE
STORAGE
BBQ
FURNITURE
BIKE
RACK

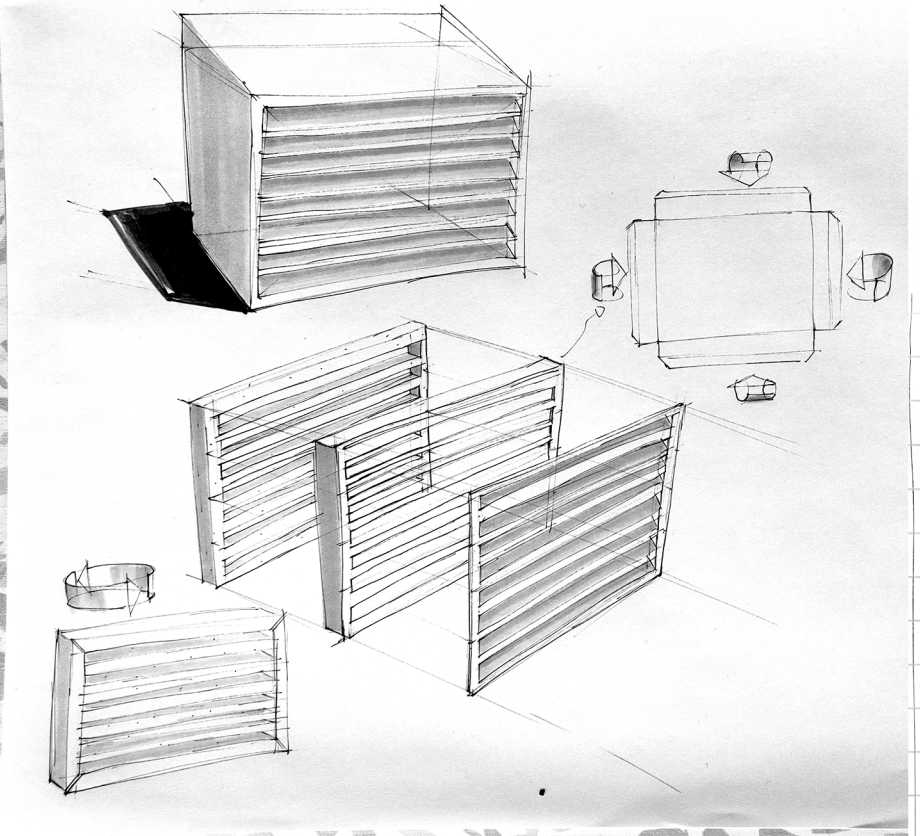

POTTERY
TABLE

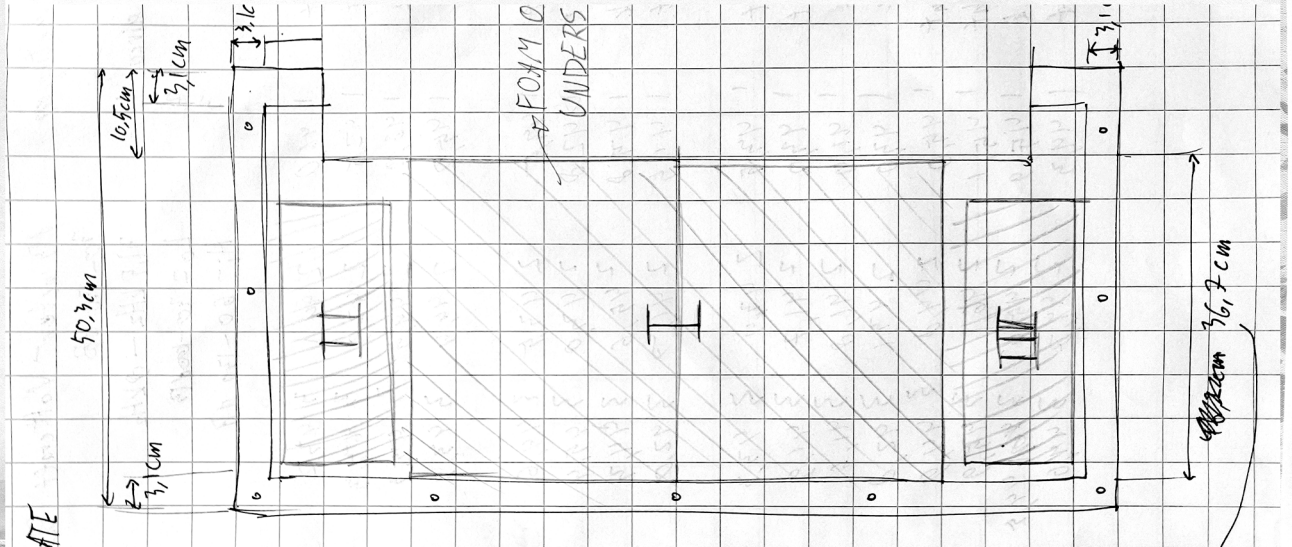

HOW CAN YOU
BLEND IN TO THE
ENVIRONMENT?


PLANT SPRAY PATTERN
/DECALS


MAKE IT AN
ART PIECE


OVERGROWN BY PLANTS




FOAM
UNDERS
10,5cm
2,1cm
50,3cm
2,1cm
3,1
3,1
36,7cm

Ideation

In order to create a design that fits the main drivers as well as possible, it is important to consider many different options.

This chapter describes how ideas were generated and eventually narrowed down to three different concepts.

Then, the chapter closes off by describing how a concept was chosen for the final design.

Brainstorming

To start the design process, the problem was first split into smaller subproblems. For this the main drivers were used. For several main drivers a 'How can you...' was set up, which can be viewed in Appendix 5.

An example of this is displayed in Figure 28, where the question 'How can you easily assemble?' was answered. From the analysis it was found that the most important way to make assembly easier is to avoid lamellas that need to be attached individually, as this requires a lot of screws and a lot of time. The brand 'Reducd' solves this problem by pre-assembling the front and back panel. However, this results in increased costs, as well as requiring the same amount of material.

Thus, two main directions were found that are highlighted in orange. Firstly the single part front (1), where a single plate of sheet metal makes up the front of the cover. Secondly there is the two layer front (2). In this direction two sheet metal layers are combined, which allows an easy 'around the corner' effect which is required for sound dampening. These two directions were then explored further to develop a total of three concepts.

Next to the technical functionality and subproblems, aesthetic explorations were done, which are displayed in Appendix 5. An examplary page is shown in Figure 29.

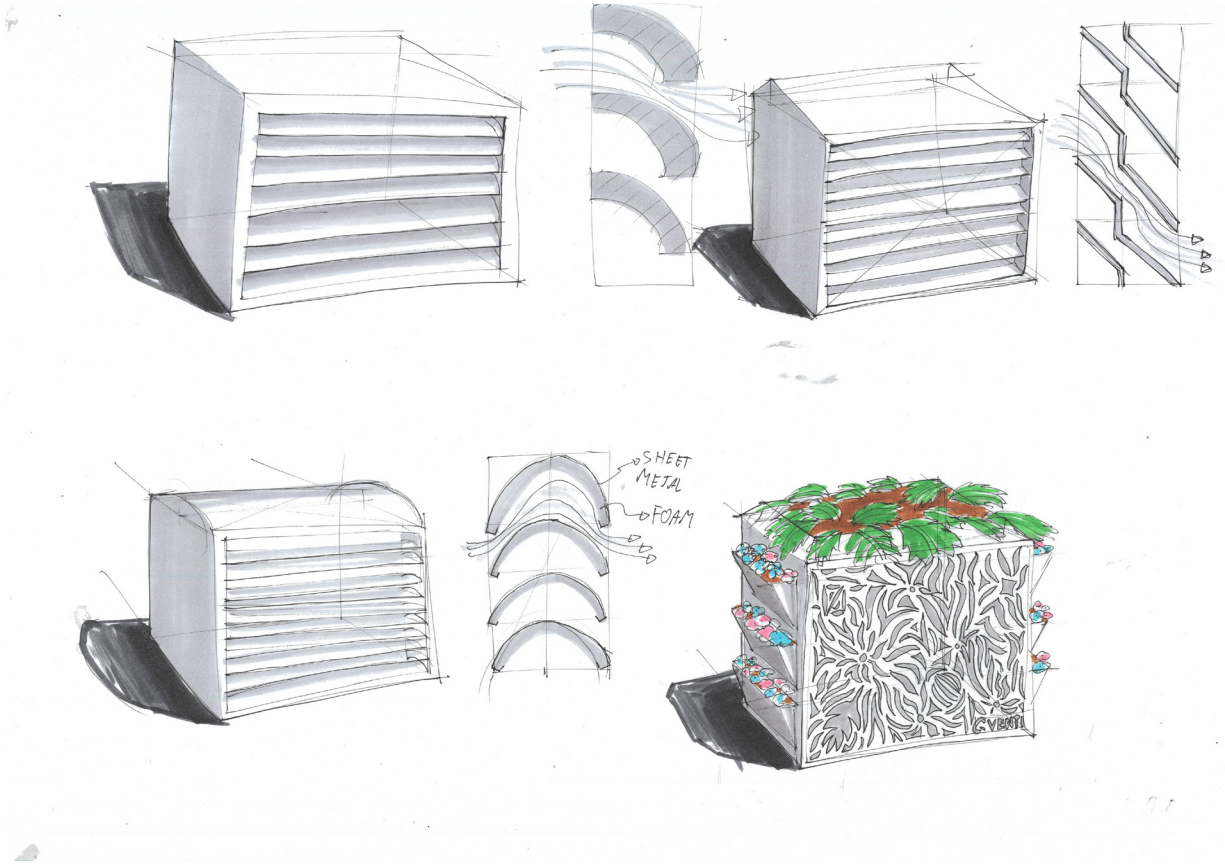
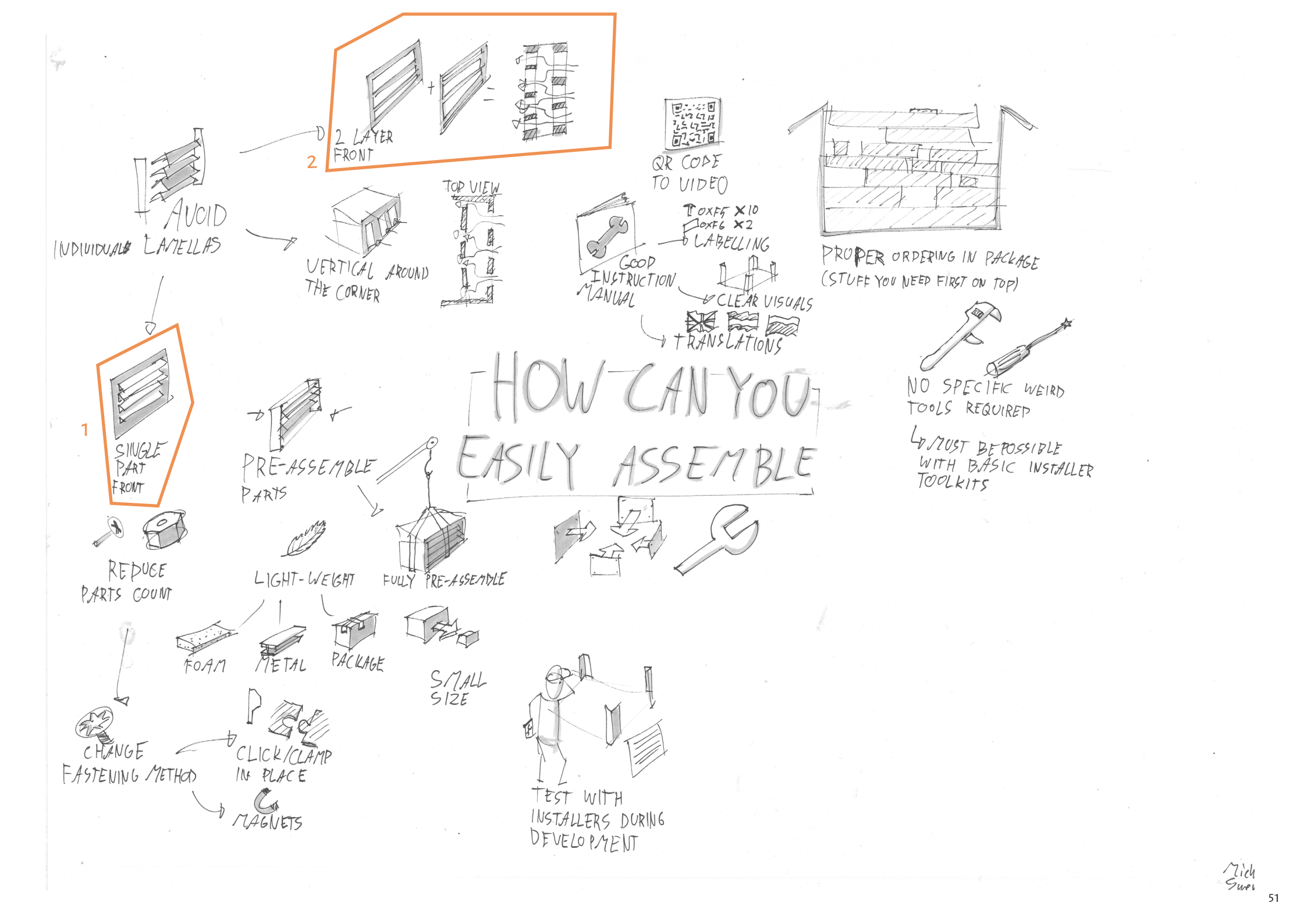


Figure 28: A 'How can you...' exploration to make the assembly process easier

Figure 29: An aesthetic exploration of different lamella types


HOW CAN YOU EASILY ASSEMBLE
2
2 LAYER FRONT
AVOID INDIVIDUAL LAMELLAS
VERTICAL AROUND THE CORNER
TOP VIEW
QR CODE TO VIDEO
GOOD INSTRUCTION MANUAL
BOXES X10
BOXES X2
LABELLING
CLEAR VISUALS
TRANSLATIONS
PROPER ORDERING IN PACKAGE
(STUFF YOU NEED FIRST ON TOP)
NO SPECIFIC WEIRD TOOLS REQUIRED
MUST BE POSSIBLE WITH BASIC INSTALLER TOOLKITS
1
SINGLE PART FRONT
PRE-ASSEMBLE PARTS
REDUCE PARTS COUNT
LIGHT-WEIGHT
FULLY PRE-ASSEMBLE
FOAM
METAL
PACKAGE
SMALL SIZE
CHANGE FASTENING METHOD
CLICK/CLAMP IN PLACE
MAGNETS
TEST WITH INSTALLERS DURING DEVELOPMENT

Concept 1 - The Two-Quiet

Figure 30: By using two layers, aesthetics and sound absoprtion are split up.

This concept makes use of a two layer front which can be seen in Figure 30. The back layer is a simple steel enclosure with horizontal slits. A foam plate is clamped into the steel enclosure.

The front layer is a purely aesthetic layer. In Figure 31 a section view is displayed, which shows how the layers achieve the ‘around the corner’ effect which helps with sound absoprtion.

The advantage of using a two layer front is that the front layer can be shaped in any way, as long as there is enough airflow. This means the sound absorption is delegated to the hidden layer behind it, which enables a large amount of aesthetic freedom for the front. It could potentially look very similar to Qventi’s current aesthetic covers, or something completely different.

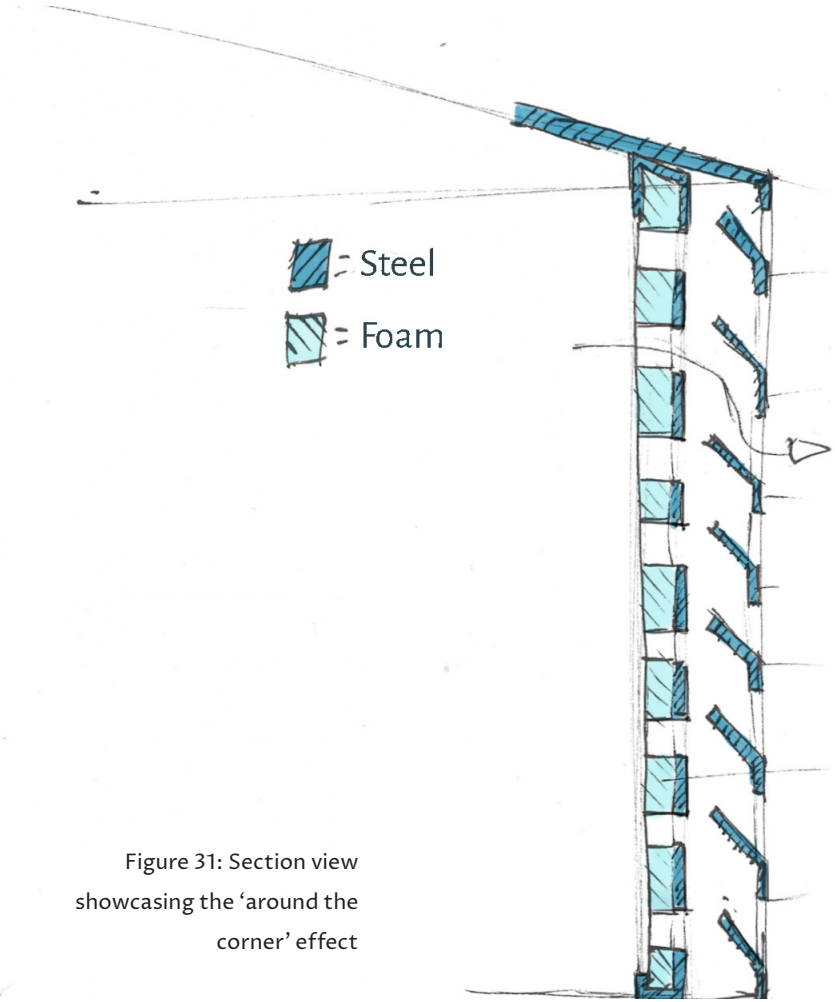
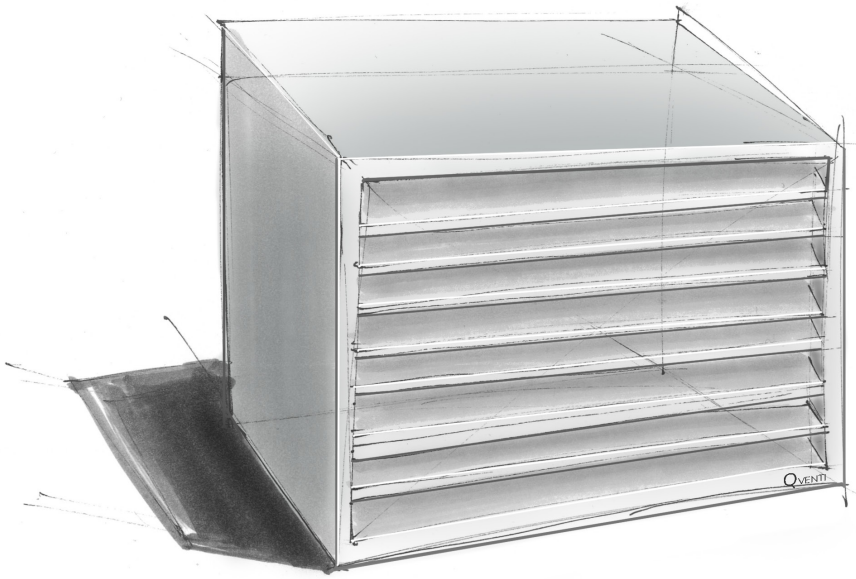
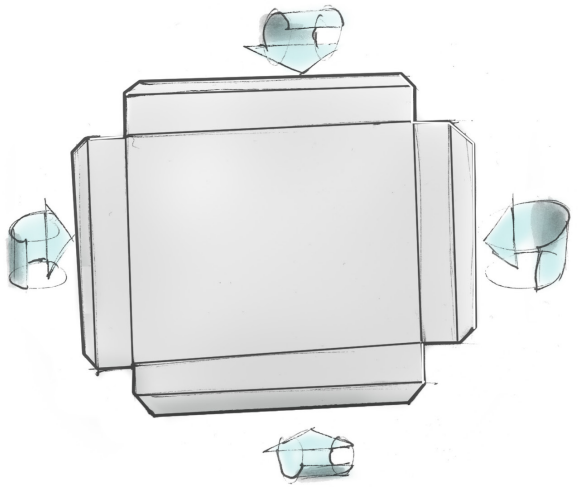
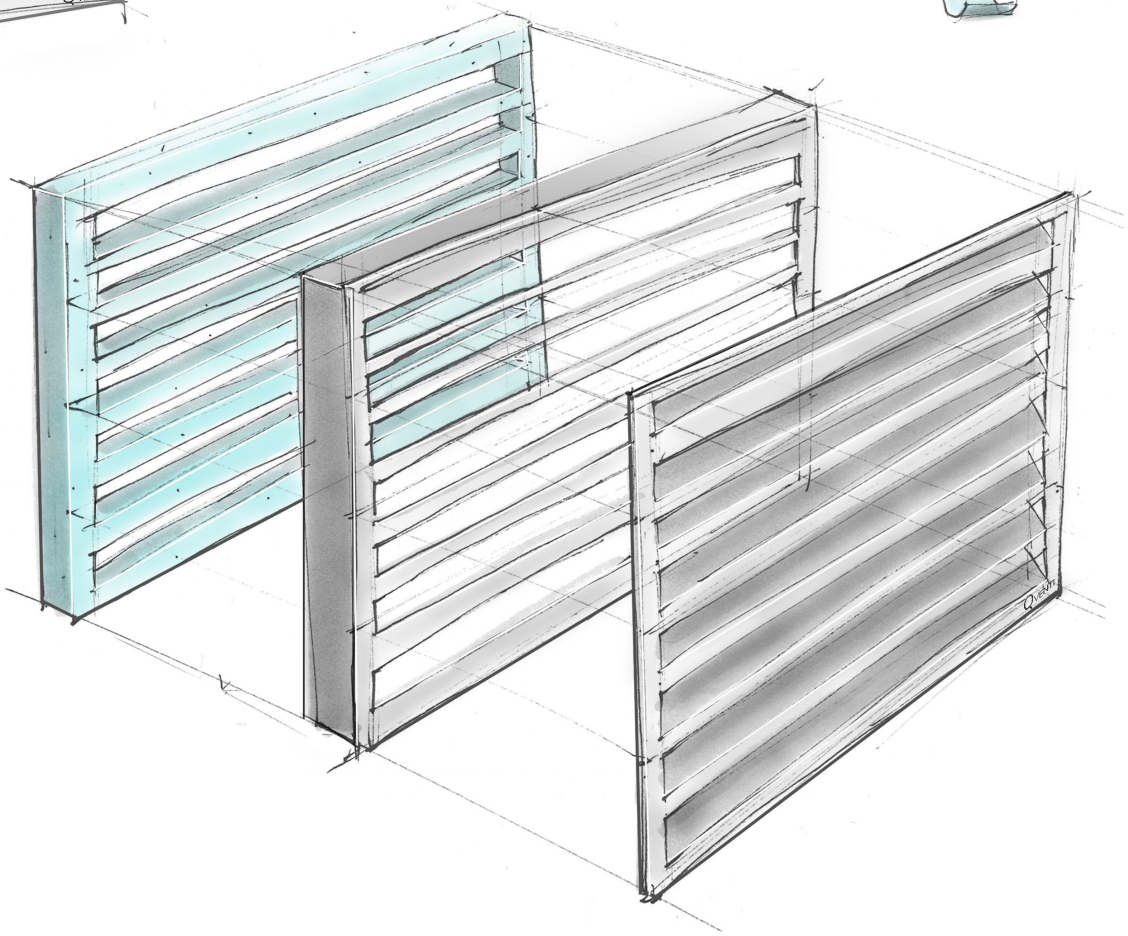
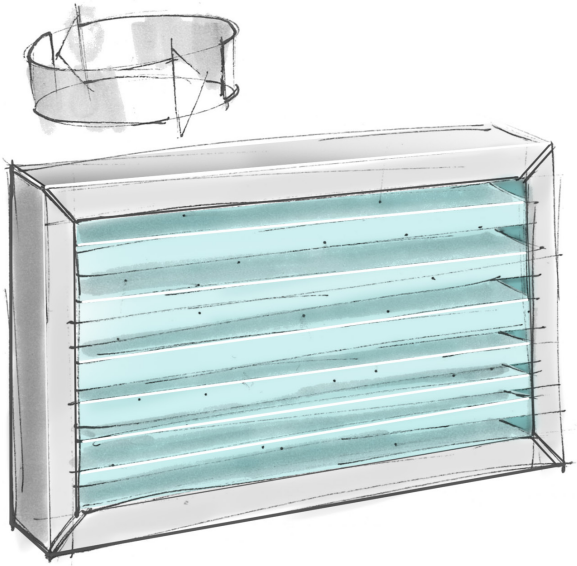


Figure 31: Section view showcasing the ‘around the corner’ effect


QVENTI







Concept 2 - Simple Silence

The second concept, shown in Figure 32 uses a single layer front. The idea is a variation on concept one. However, instead of having one purely aesthetic layer and one sound absorption layer, the two are combined.

The challenge however, is that the foam needs to be tightly secured to oppose small amounts of rain coming in which could potentially damage any glue or adhesives, as well as oppose gravity pulling the foam strips down, shown in Figure 33.

It also adds difficulty in the way of aesthetics, because small amounts of foam could be seen through the grates, depending on the exact size of the slits. This is shown in Figure 34.

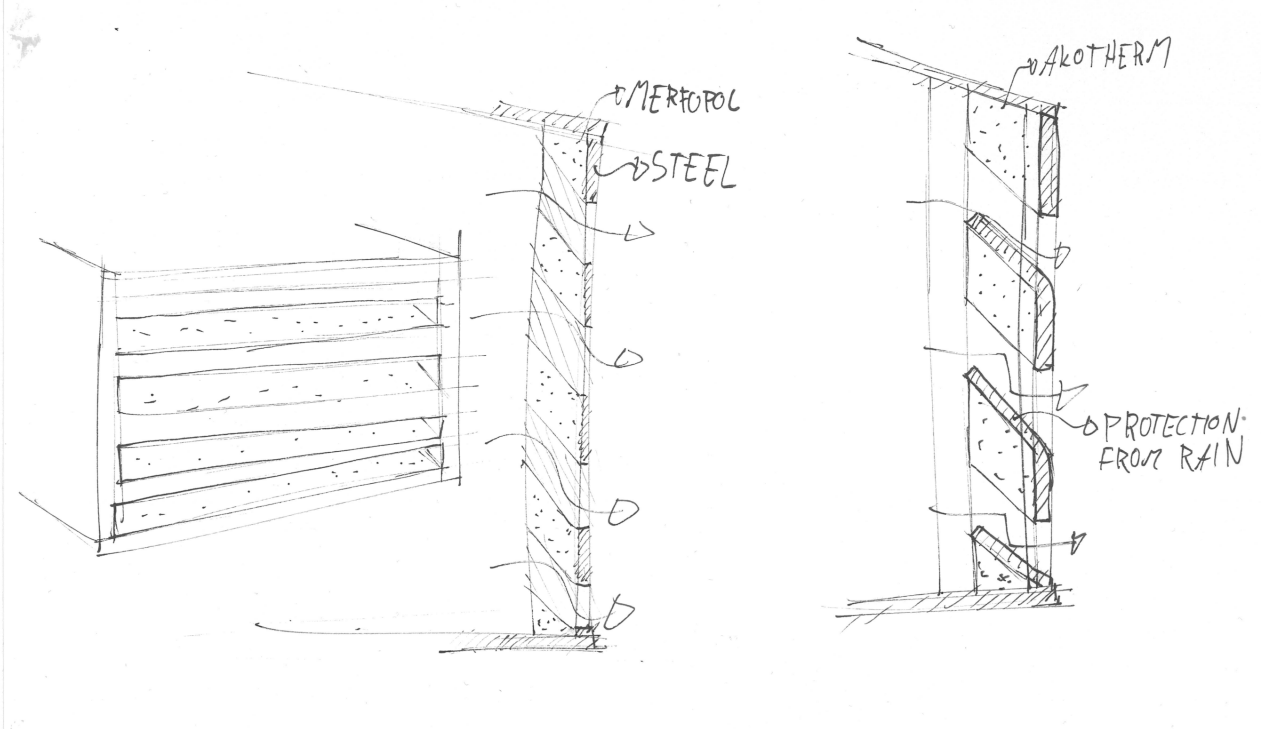


Figure 32: The single layer concept combines both aesthetics and sound absorption into one layer

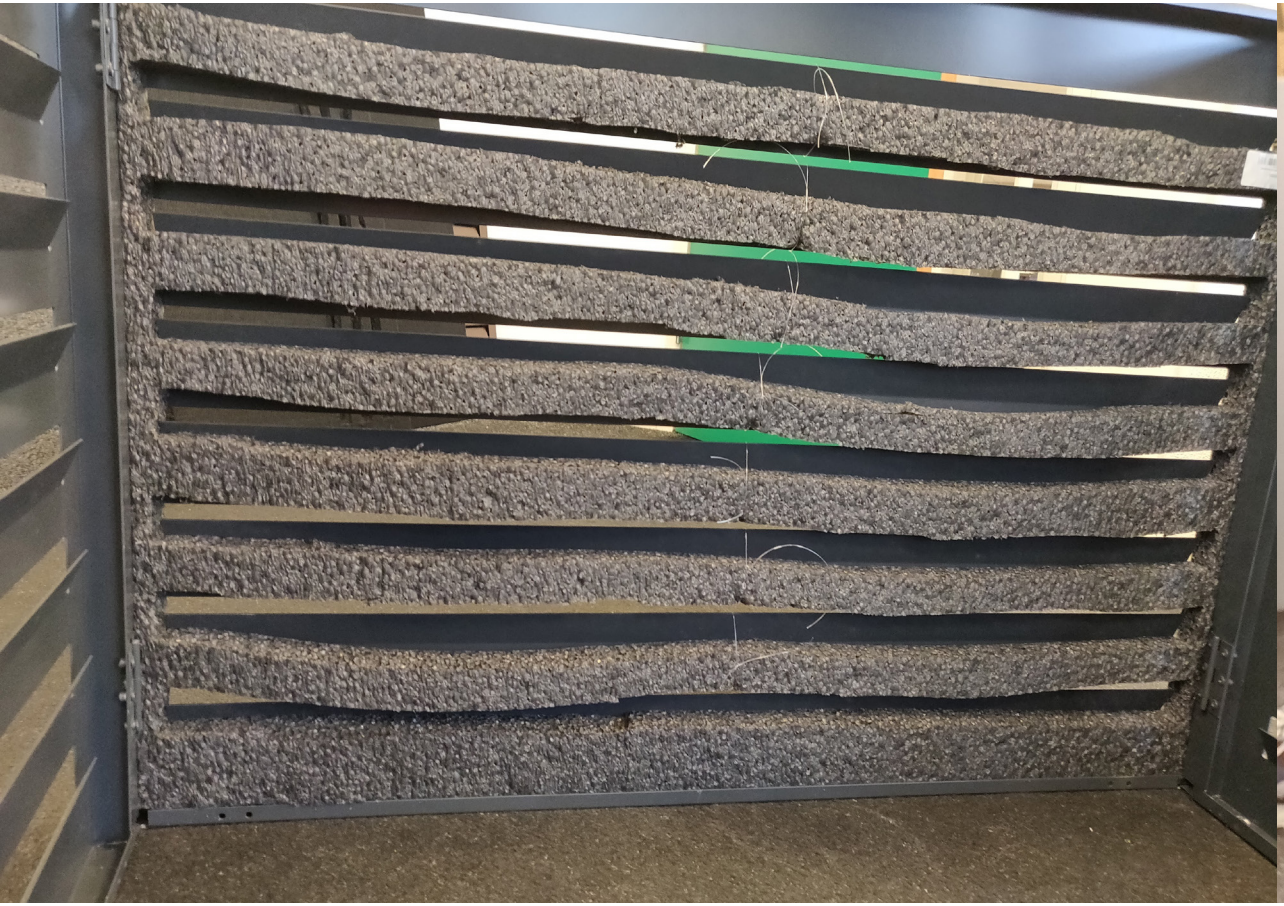


Figure 33: The foam strips have the tendency to ‘sink in’. In this prototype they are held up by fish wire

Figure 34: Foam being visible through the side of the lamellas

Concept 3 - The Hush

This final concept, displayed in Figure 35, also uses a single layer front. In this design a perforated foam layer is used, where many small holes are drilled into the foam to ensure airflow. Compared to the other concepts, the foam here is much more stable. This is because it does not need to be 'held up' and instead supports itself. This design has the advantage that it only uses one layer, and could still use any custom design as a front plate as long as there is enough airflow. Aesthetically, there is a small complication however. If the custom design has holes that are too big, the foam can be seen behind the design, which would be undesirable.

In Qventi's current designs, the lamellas are always bent inwards as this gives a flush design to the exterior look. Due to the foam perforation layer this is not possible in the design displayed in Figure 35. Figure 36, however, shows a variation where an outside bent lamella can still be flush with the cover by insetting the front panel slightly.

Figure 35: The Hush uses a single panel design while still having aesthetic freedom

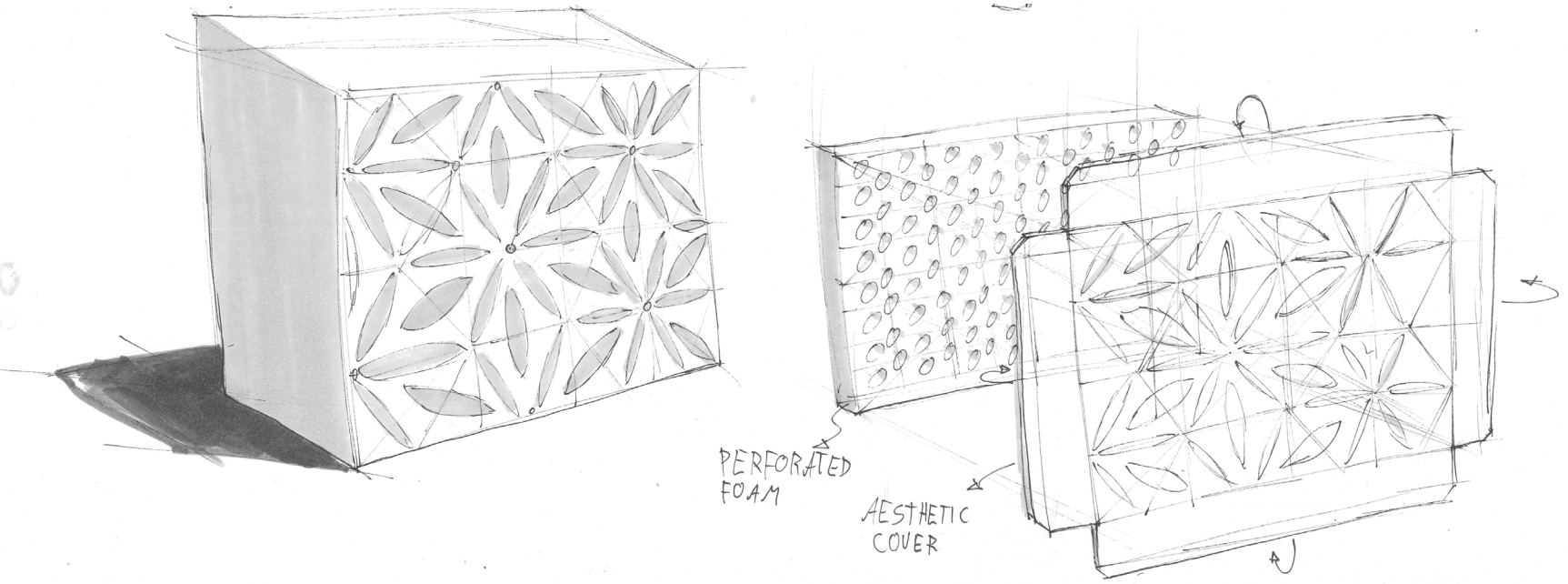
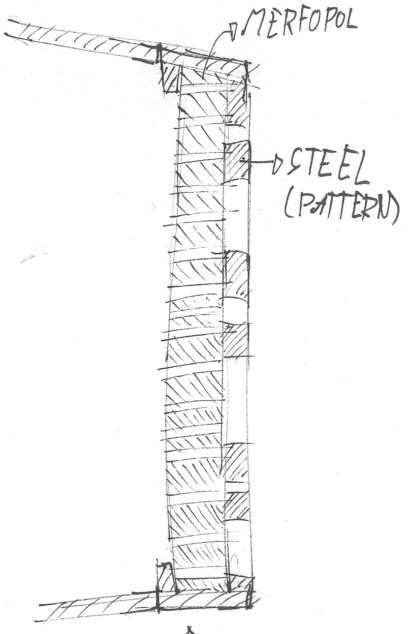
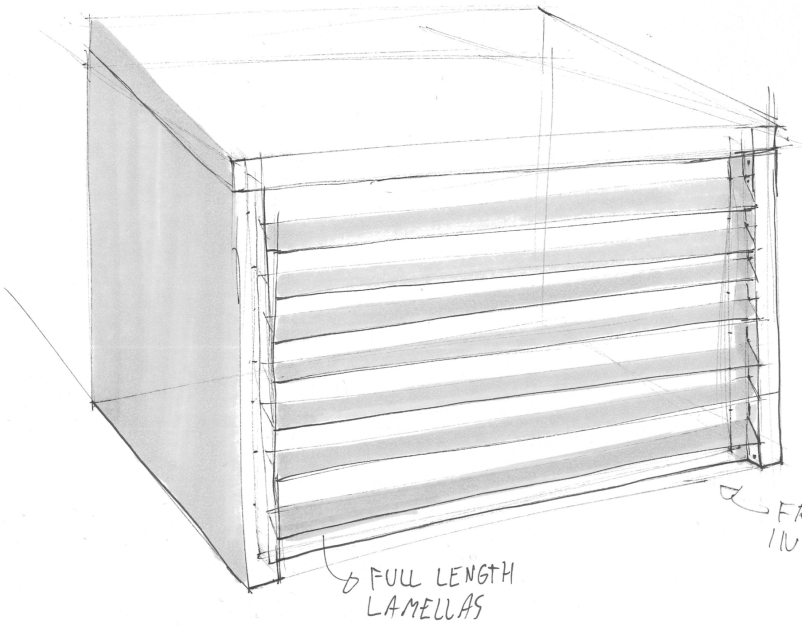
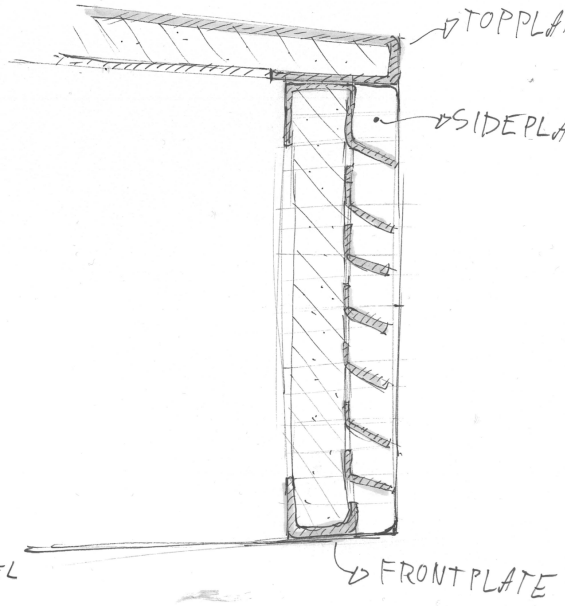


Figure 36: This variation achieves a flush design and aesthetic coverage of the foam layer by sacrificing customisability

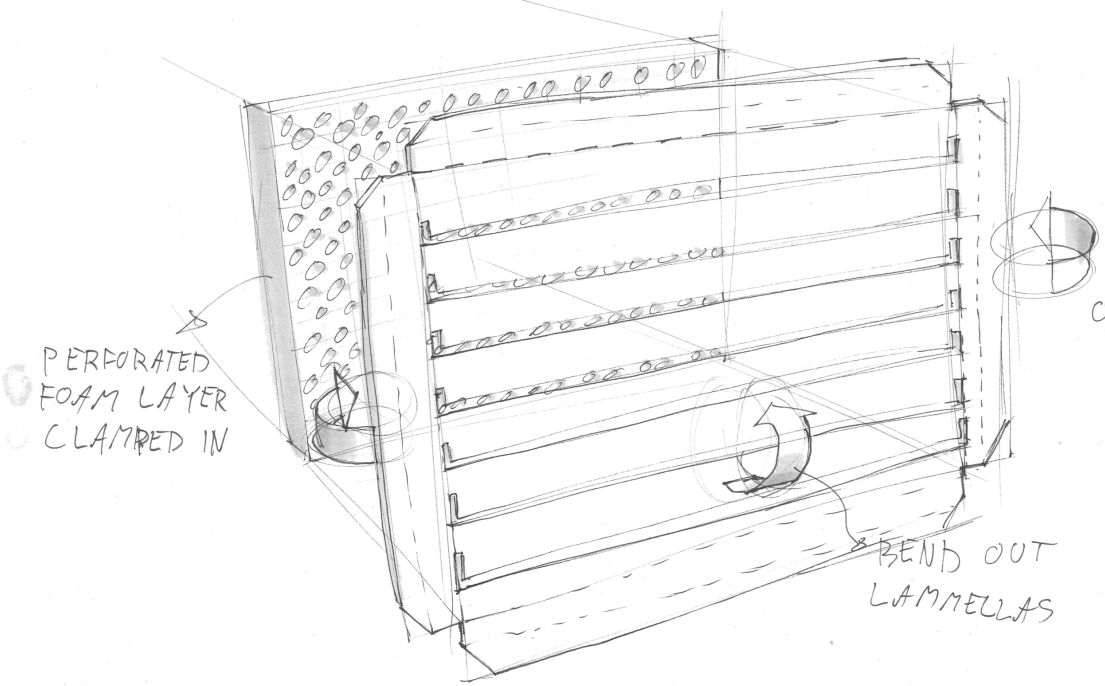


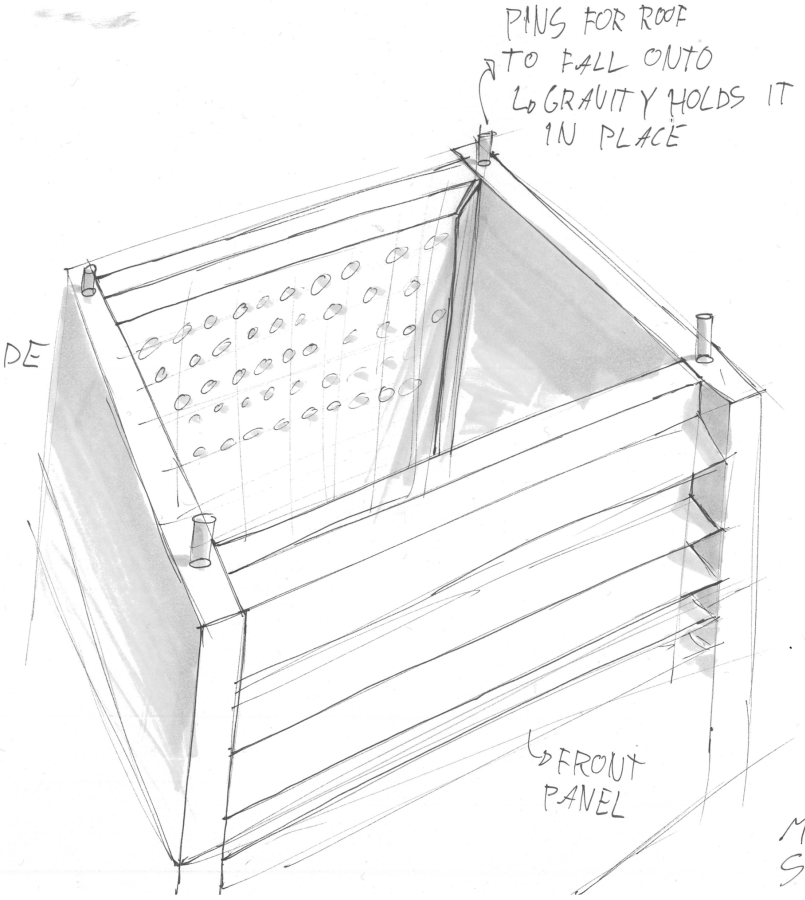




STEEL

FOAM





Micha
Swen

Concept choice

To facilitate the choice between these concepts, the weighted objectives method was used (Boeijen & Daalhuizen, 2010). The criteria consist of the main drivers, as well as several of the most important wishes from Appendix 4, the program of requirements and wishes.

Each criterion has their own weight from one through five based on how important they are for the final concept. Then each concept is rated from one through ten on each of these criteria. Finally, each concept ends up to a total score, which can be seen in Figure 38.

Of the three, the two-quiet is clearly rated the lowest. This is because the two-part design uses more material, which increases the cost, size and CO2 footprint, which heavily outweighs the benefits.

The scores of simple silence and hush are quite close together. So after eliminating the two-quiet, these were compared against each other. The principle working and material usage of the designs are quite similar. The main difference lies in the shape of foam that is used. To compare the feasibility of both of these options some preliminary prototyping was performed. Figure 37 shows the difference between these two foams. It can be seen that the lamella-shaped foam has a tendency to 'sink in', while the perforated foam layer of the hush supports itself.

Because concept two and three both accomplish the same goal, while three has the added benefit of self-supporting foam, the hush was chosen as the concept to continue further with.

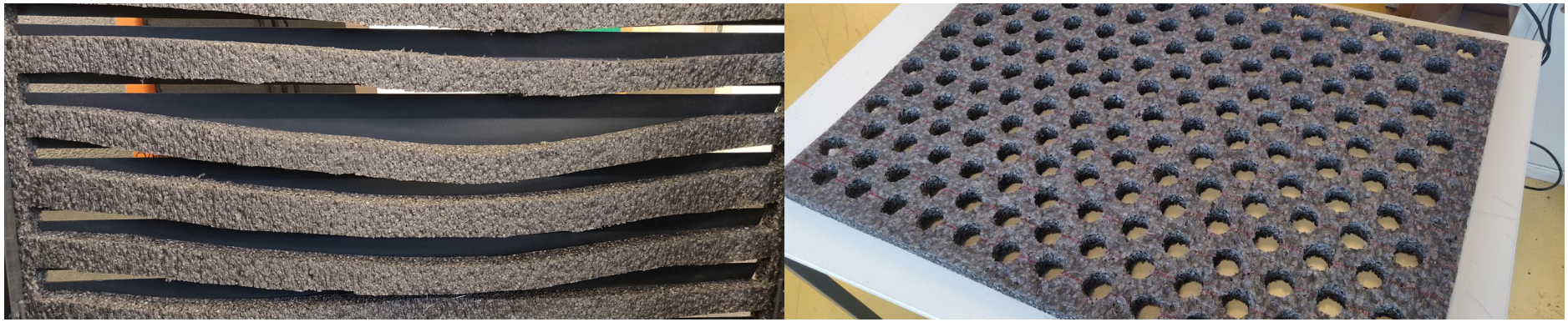
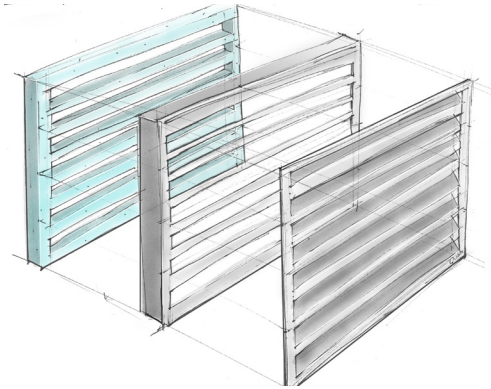


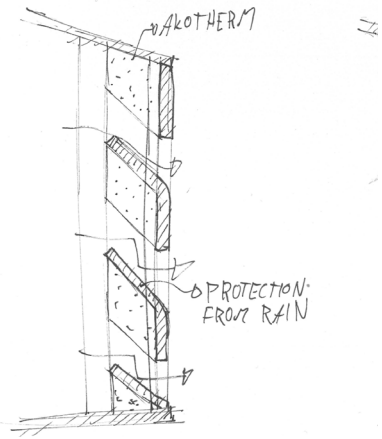
Figure 37: The lamellafoam (left) sinks in while the perforated foam (right) is self supporting



The Two-Quiet

+ Aesthetic freedom of front
+ Foam protected from rain and sun
+ Hidden sound absorption

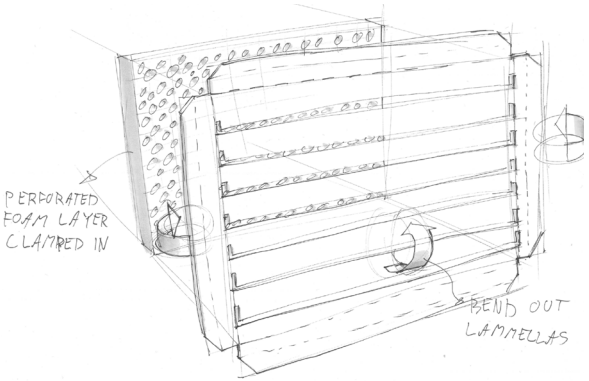
- More material



Simple Silence

+ Small amount of material
+ Thin

- Hard to secure foam
- Hard to fully hide foam

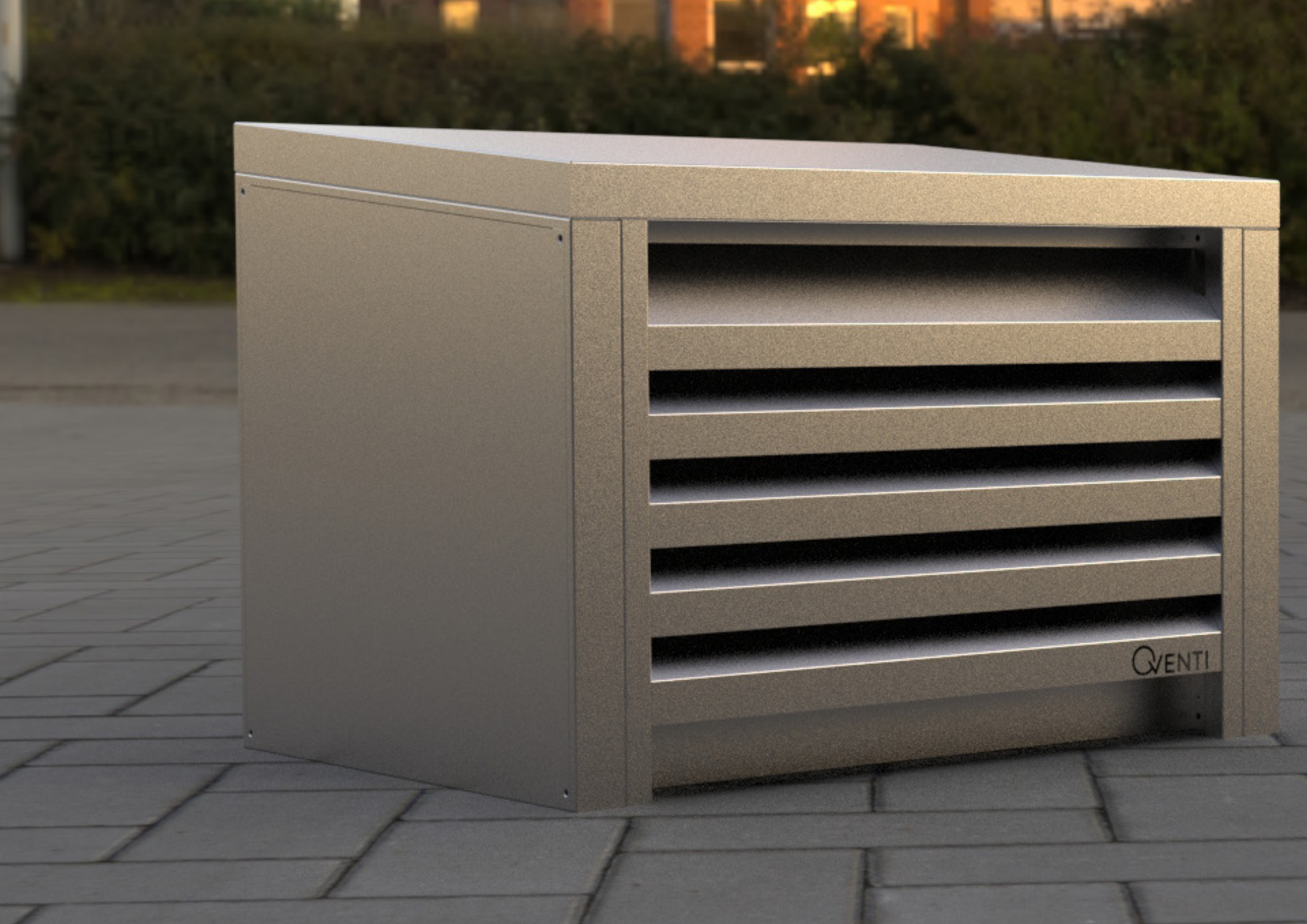


The Hush

+ Foam is self supporting
+ Aesthetic freedom
+ Small amount of material

Figure 38: Results of the weighted objectives method. **Main drivers** are bold.

Criterium	Weight	1: The Two-Quiet	2: Simple Silence	3:The Hush
Peaceful silence (Sound reduction)	5	8	7	7
Easy to assemble	5	6	9	9
Hidden in plain sight (Blend in environment)	4	9	6	7
Low cost	3	6	8	8
Available today (Easy to mass produce)	3	8	8	8
For a brighter future (Co2 footprint)	2	6	8	8
Minimal outside dimensions	2	6	8	8
Aesthetic design freedom	1	9	6	8
Lightweight	1	6	8	8
Total		187	198	204


QVENTI

Embodiment

For a design to make the transition from a concept to a succesful product, every facet must be worked out to a tee. Testing the core principle of the product, choosing the right materials, evaluating the cost price and working out the details of manufacturing.

The purpose of this chapter is to go in depth into all these aspects. By the end, you will understand how all of the details are integrated into a cohesive, multi-faceted design.

Exploded view

The embodiment process consists of many small iterations, where each one contains slight improvements over the previous to become just a tiny bit better: Easier to manufacture, more material efficient, more aesthetically pleasing and so on. In this process, a total of eight design iterations can be differentiated. Appendix 6 explains all of these iterations in more detail, including the improvements and shortcomings of each step along the way.

Displayed in Figure 39 is the final design of the sound reducing cover. It consists of five main panels. Four to make up the sides, and one that serves as a roof. The front panel is made up of four main frame parts and lamellas, which are all riveted together. A perforated foam layer is then clamped in behind the lamellas, to ensure a perfect balance between airflow and sound reduction.

Roughly every six months the heat pump needs to be accessed for maintenance. To facilitate this, doors were added to the side panels of the cover. This can be seen in Figure 40.

It can easily be removed by unscrewing four screws and pulling the foam out of its enclosure. This way the stability of the frame is ensured while maximising the ease of maintenance.

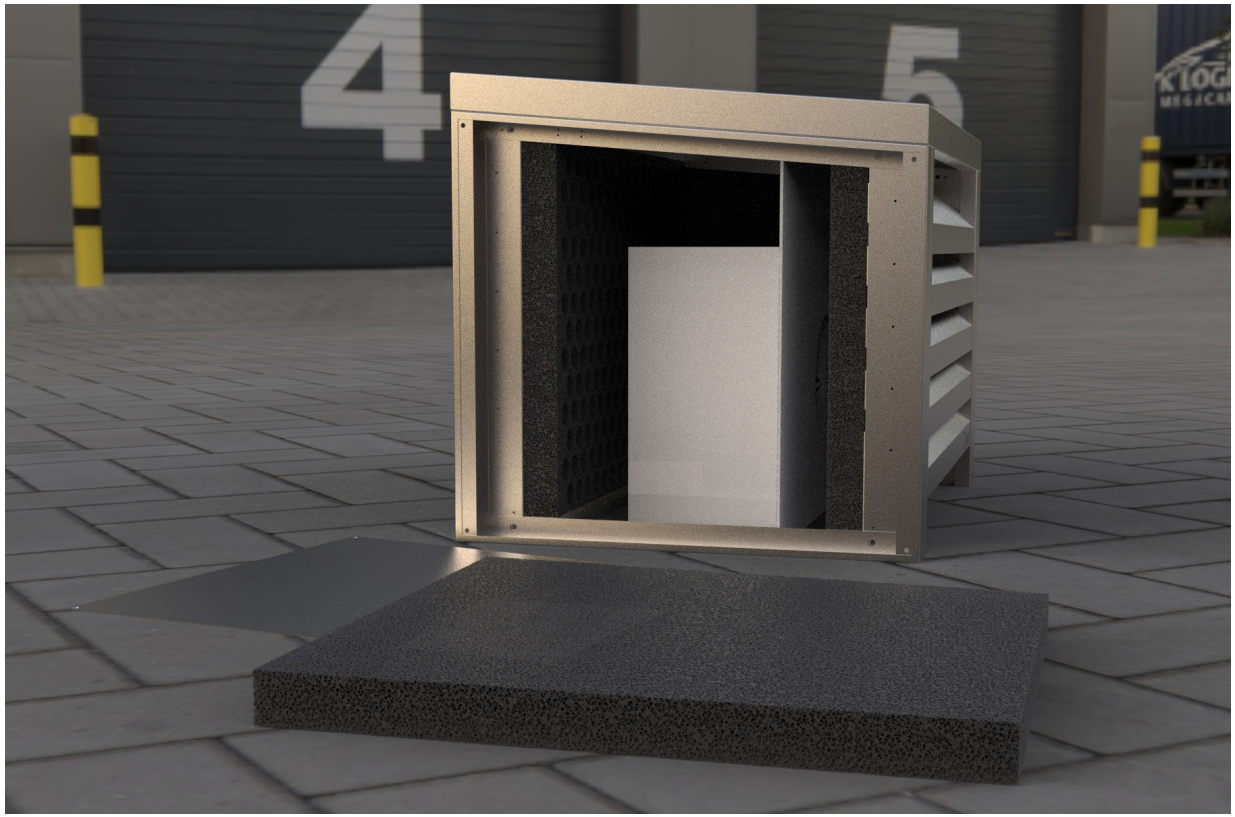
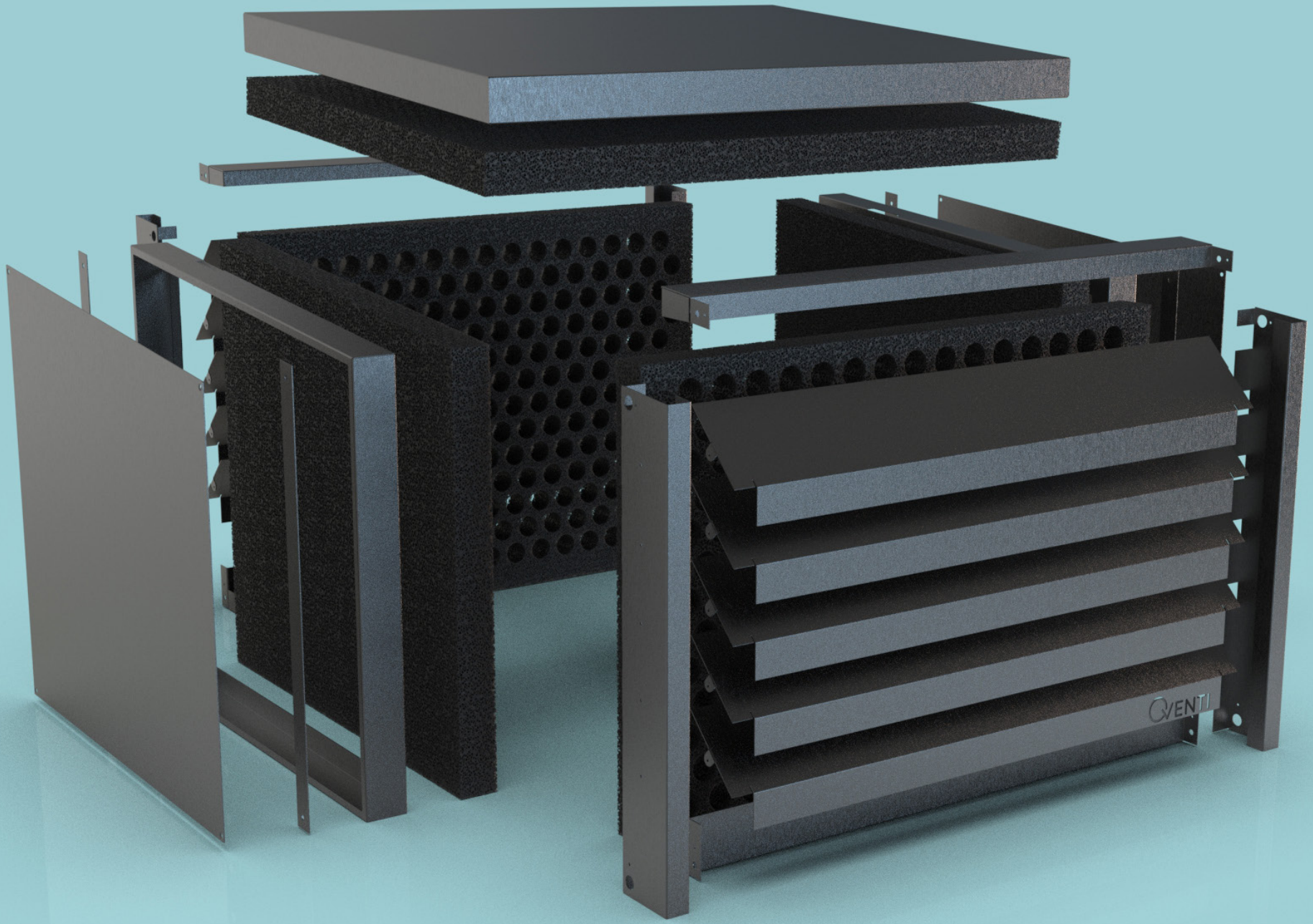


Figure 40: Removable side doors allow for easy maintenance

Figure 39: Exploded view


QVENTI

Design for manufacturing and assembly

Qventi greatly values efficient assembly for their products. For both their aesthetic covers as well as the air conditioning systems, great efforts were made to optimise the installation process. For example, the aesthetic covers have hinges to ease the installation and the air conditioning indoor units have a simple click-on system for their wall mount. This means it is imperative that the hush, too, is as easy to install as possible.

Figure 43 shows the steps of the assembly process.

1. Four high density foam squares are placed underneath the heat pump. This prevents contact sound from travelling through the ground. Then, a hole is cut in the foam layer in the back frame, shaped like the cables that have to go through. This part of the foam is displayed in Figure 41. Now the back panel can be placed over the cables.

2. The side panels are placed. Four screws are inserted at the four corners of the front panel to attach the panels. Figure 42 shows these locations.

3. The recirculation plate is cut to size. This is a polystyrene board which prevents the heat pump from recirculating its own air within the cover. A round hole with the size of the fan is cut out from the middle, after which it can be attached to the heat pump using adhesive velcro strips.

4. The front panel is placed in between the side panels and once again, four screws are used to connect them.

5. Finally, the roof is placed on top. The hidden locking mechanism helps to align it and makes it slot into place. The roof is now kept in place by gravity and can be lifted off in case it is needed.

Figure 42: Screwholes on the inside of the front panel

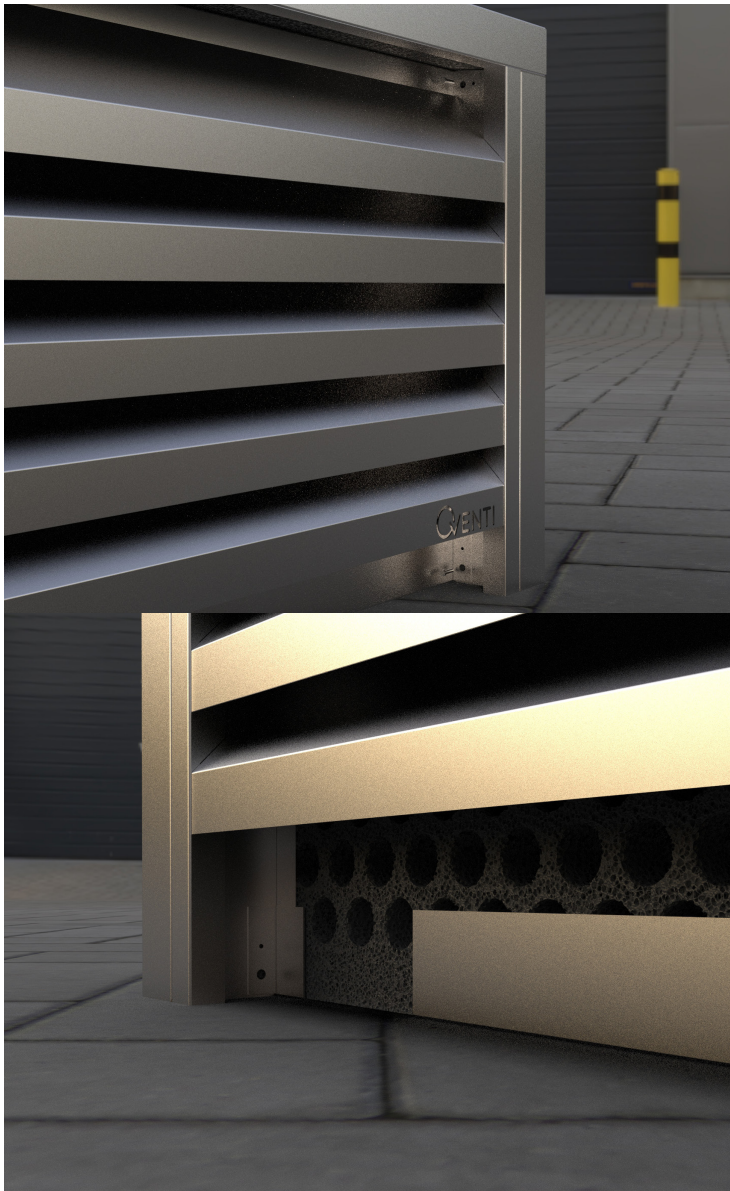


Figure 41: Using a boxcutter, a hole can be cut for the cables

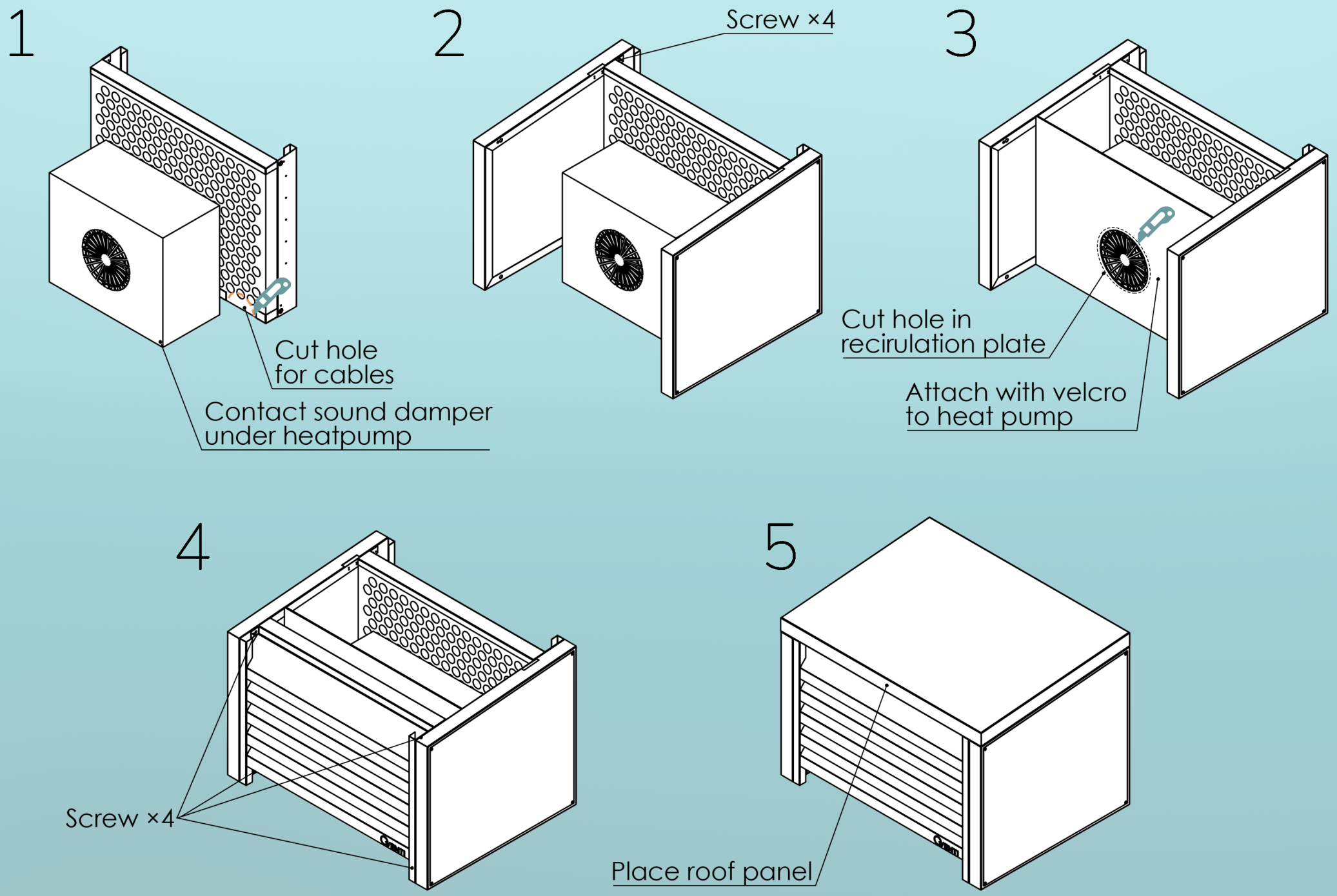


Figure 43: Hush installation guide

The Front Panel

In order to make the installation process for the end-user as easy as possible, each of the five panels are pre-assembled. This process too must be optimised to ensure a fast and efficient production.

The front panel, displayed in Figure 44, is pre-assembled as follows. Firstly, the sides are slid onto the bottom from above, which is displayed in Figure 45. The slot in the bottom perfectly fits the side pieces and locks the rotation. This aligns the rivet holes for attachment of the sides. Then, the lamellas are slid in from the back. By sliding the notch of the lamella into the notch of the sides, the holes are automatically aligned for the rivets. These notches can be seen in Figure 46. The notches also lock the rotation, which means only two rivets are needed per lamella. Then, the top part is slid onto the sides similarly to the connection at the bottom, after which they are riveted together. Lastly, the foam plate gets placed into the frame where it is clamped into place.

Figure 44: Exploded view of front panel

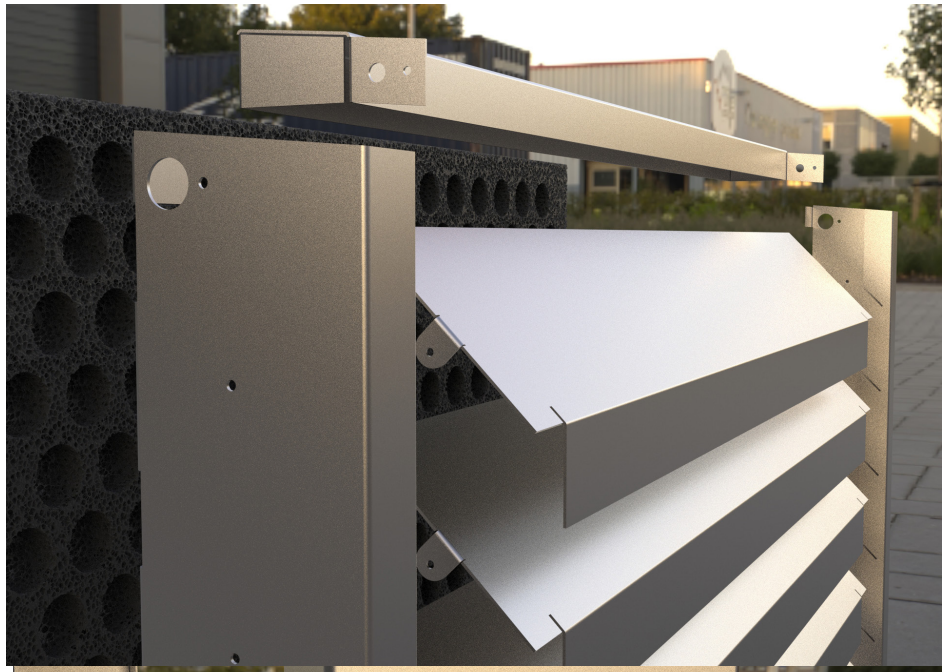


Figure 46: Notches in the lamellas make for an easy pre-assembly

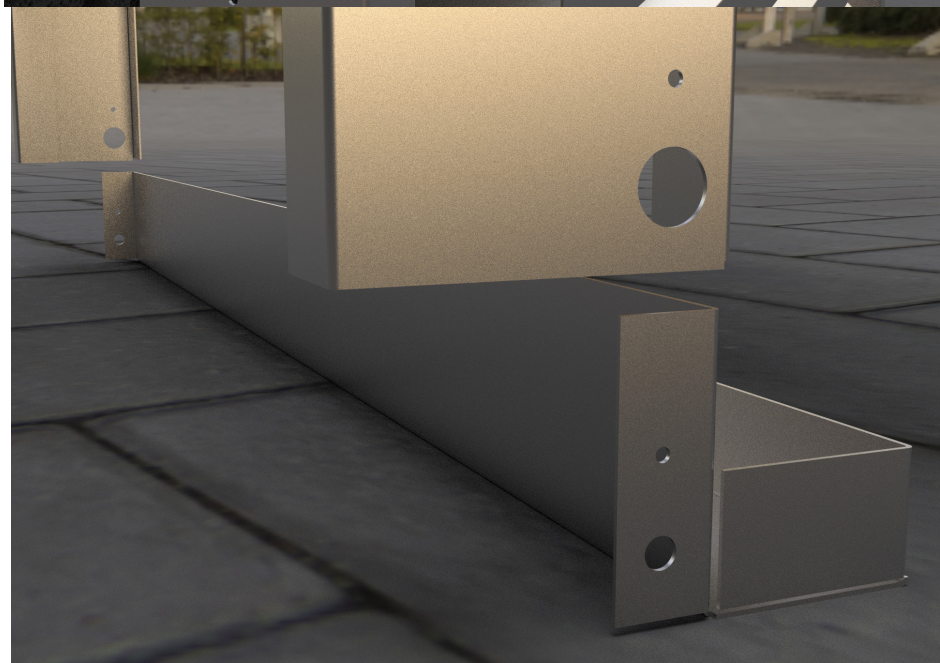
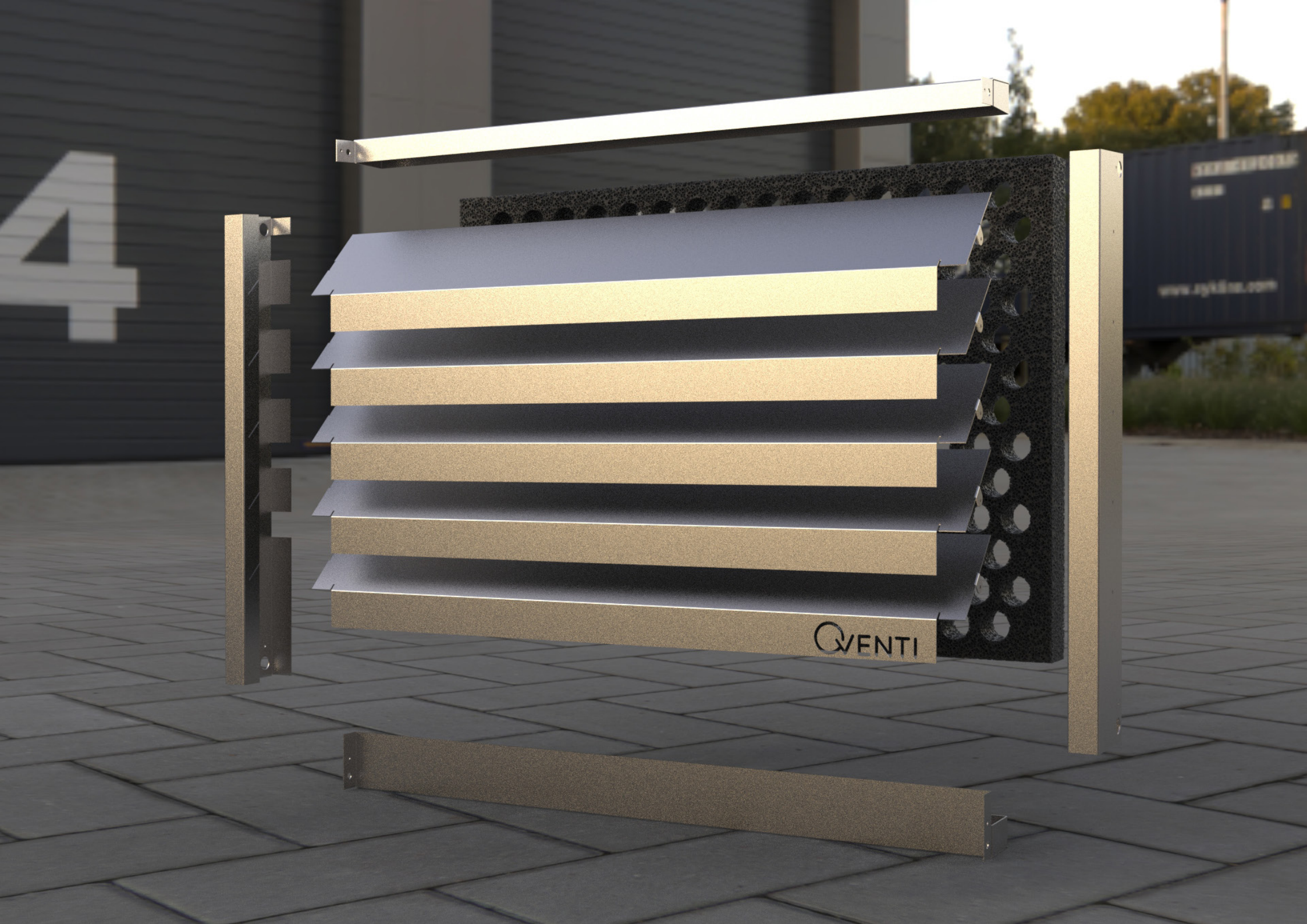


Figure 45: Alignment of bottom and sides of frame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The Side Panel

To reduce the environmental impact of the product, as well as save costs, it is important to reduce the amount of waste material as much as possible. The side panel employs a clever solution in order to achieve this. During the process of laser cutting the frame, the middle sheet, which would normally be waste material, can be reused as the door. This can be seen in Figure 50.

For the pre-assembly, two support strips, displayed in Figure 51, are placed inside the frame and welded into place, which can be seen in Figure 47. The support strips fit exactly into the frame. This means that no manual alignment is needed. This is shown in Figure 52. Then, blind rivet nuts are installed into the support strips. The door is placed in front, and screws are installed into the countersunk holes, displayed in Figure 48. Blind rivet nuts are also installed on the inside of the frame, for the connection to the front and back frames.

The blind rivet nuts utilise an innovative solution, where pentagonal shaped holes are used with round high torque blind rivet nuts. This increases the strength of the connection and saves time on alignment of the blind rivet nuts compared to traditional hexagonal holes (Scheijbeler, 2023).

For the connection to the roof, a hidden locking mechanism is utilised, displayed in Figure 49. The left part is installed underneath the hole displayed in Figure 53, using nuts and bolts. The right part of the mechanism is installed on the roof. It allows for an easy alignment between the roof and mainframe and is kept in place through gravity. If needed the roof can easily be lifted out.

Figure 48: Countersunk holes

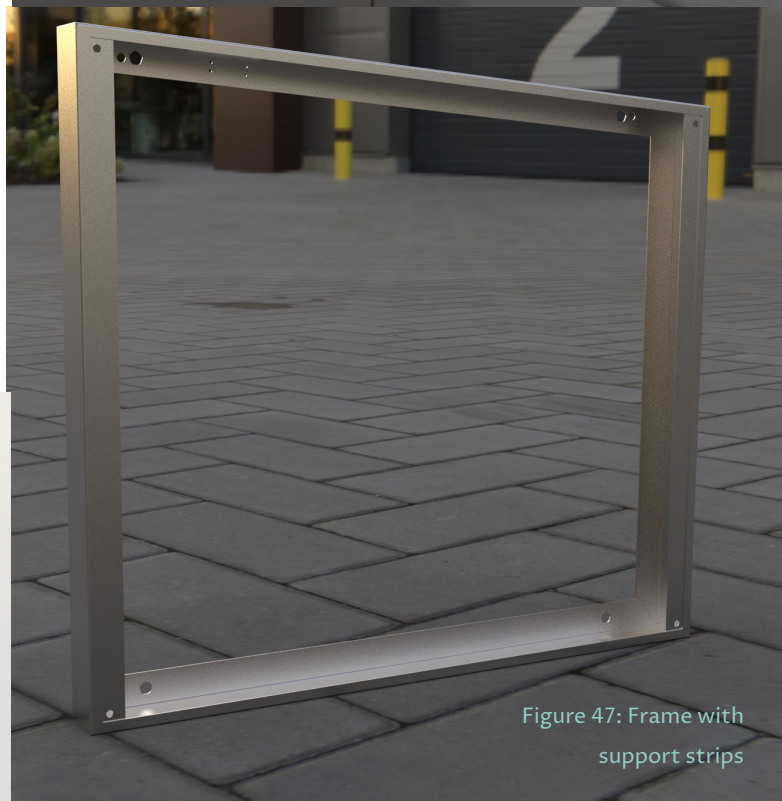


Figure 47: Frame with support strips

Figure 49: Hidden locking mechanism

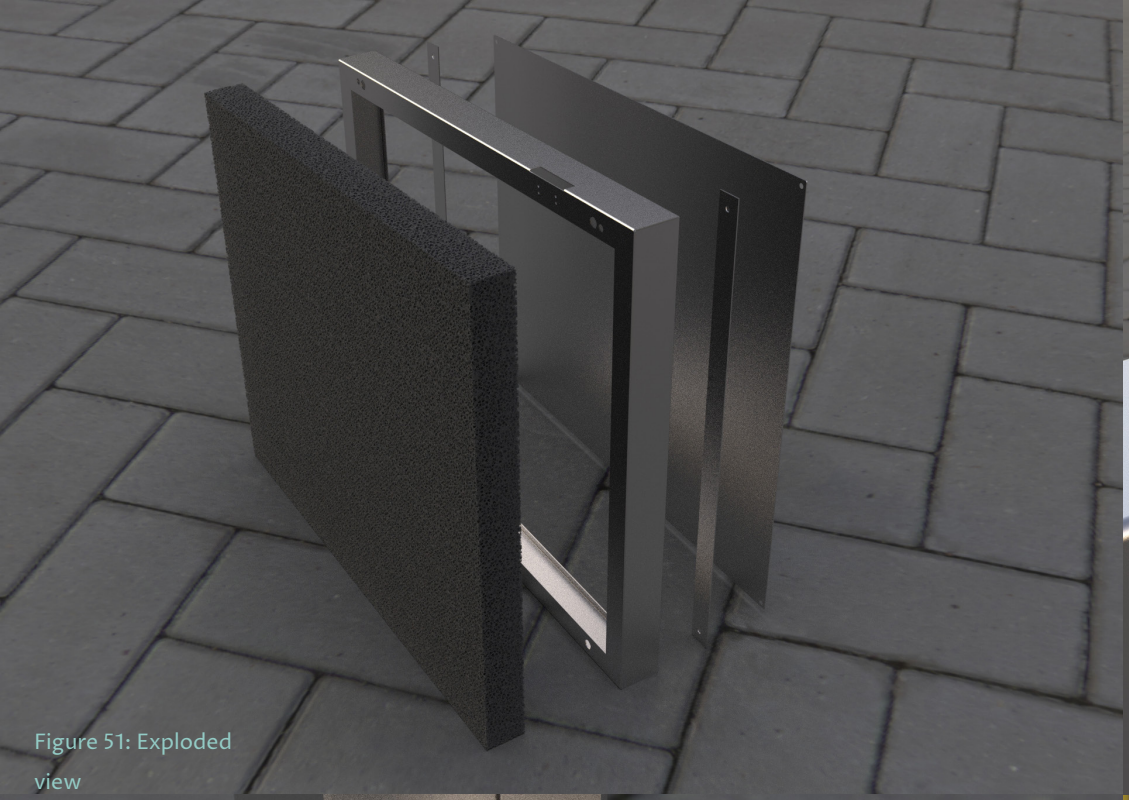


Figure 51: Exploded view

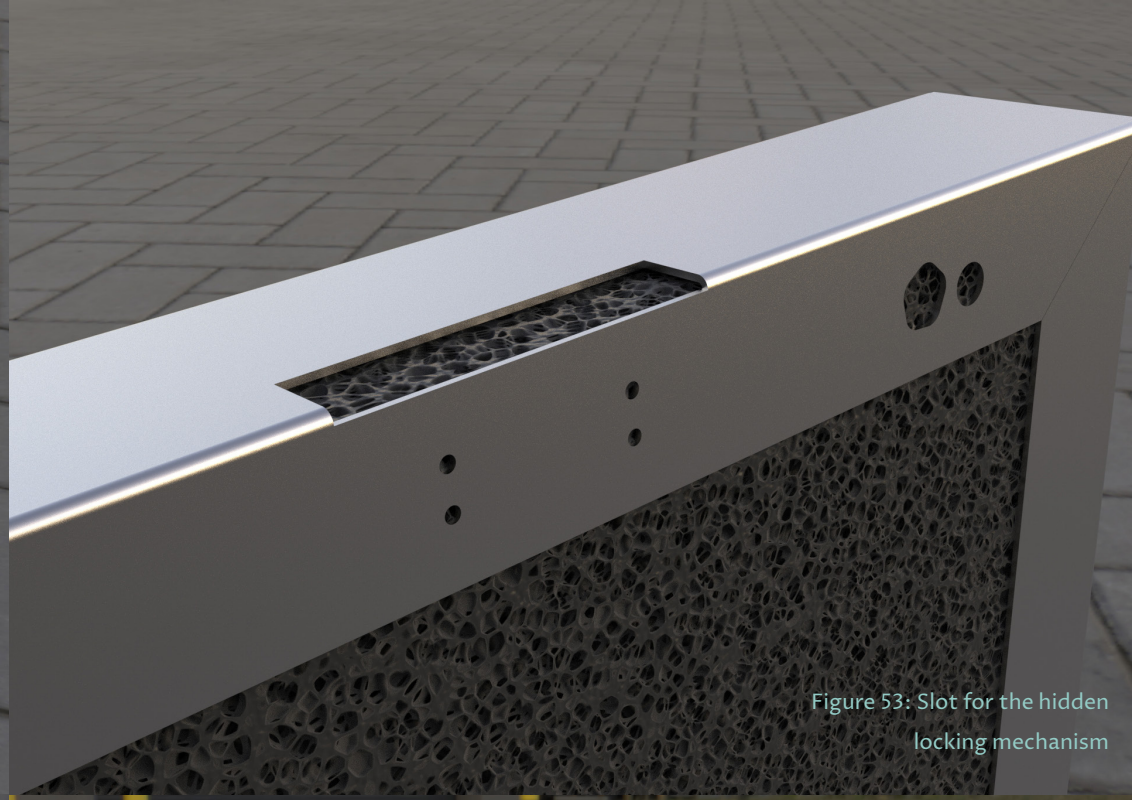


Figure 53: Slot for the hidden locking mechanism

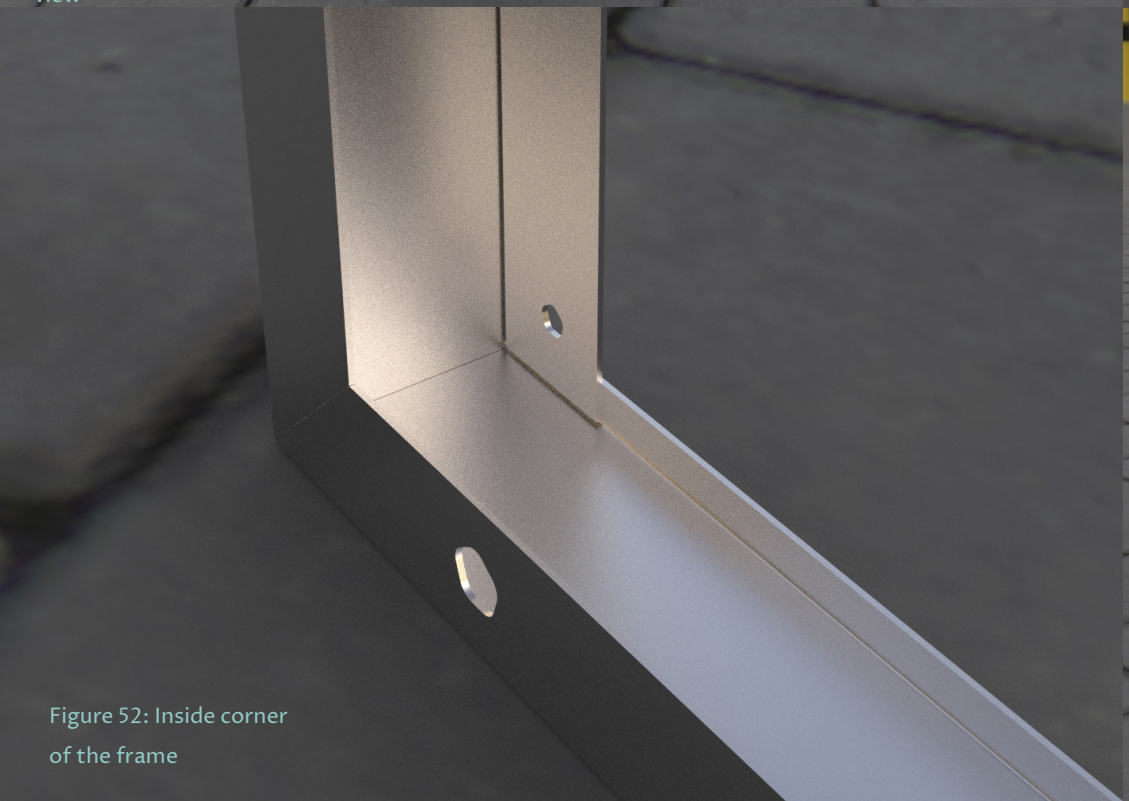


Figure 52: Inside corner of the frame

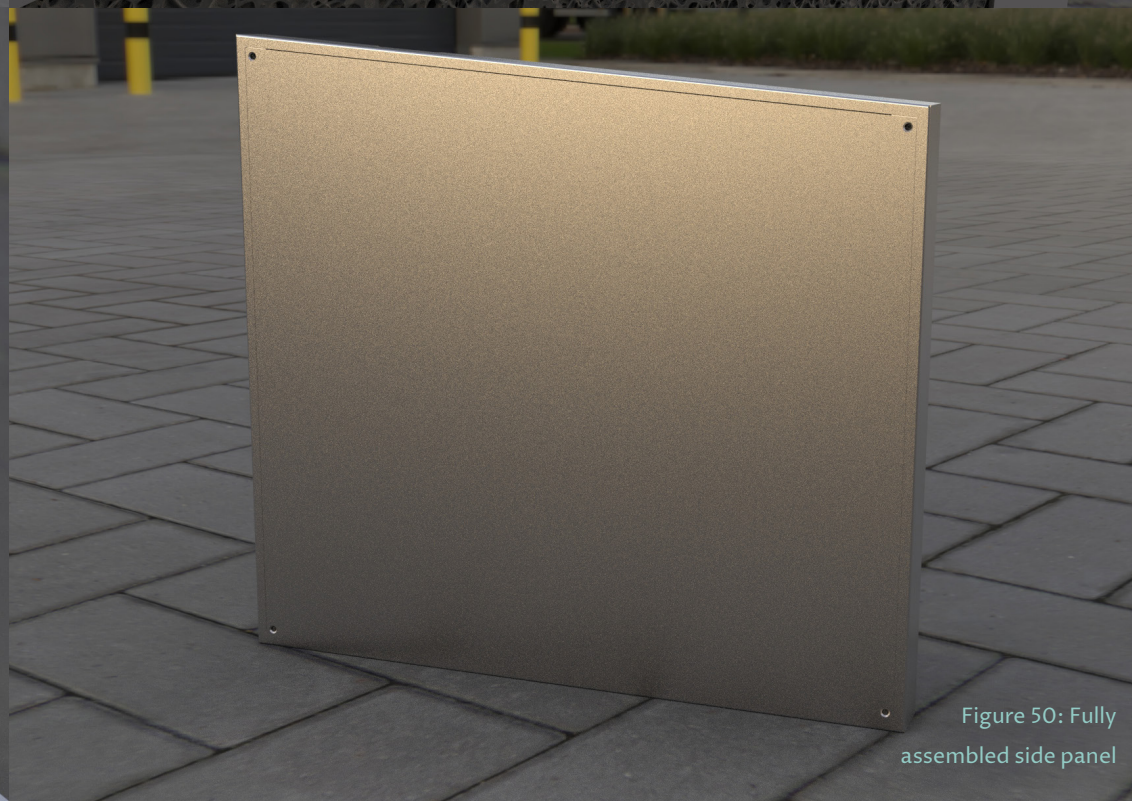


Figure 50: Fully assembled side panel

Figure 54: Magnelis product example

Materials

Figure 55: Co2 footprint of magnelis (ArcelorMittal, n.d.)

For the cover, magnelis was chosen, displayed in Figure 54. It is slightly more expensive, but has many advantages above traditional galvanised steel. It has a better corrosion resistance, performing three times better. Also, the best magnelis coating variant has a design life of more than fifty years.

A special feature is that it has a self healing effect, which protects uncoated edges, holes and scratches. Magnelis also has a lower CO2 footprint, shown in Figure 55, because a thinner layer of coating is needed. It is also well suited for recycling. (ArcelorMittal, n.d.)

For magnelis, a thickness of 1.5mm was chosen. This thickness gives enough weight, totaling up to 111 kg for the entire cover, which is comparable to currently existing covers, seen in Appendix 3.

This thickness was also discussed with Cowsill (2023) in a consultation, where he agreed that increasing the thickness to 2mm would not yield significantly better sound reduction.

The sound reducing foam is black stratocell whisper FR, seen in Figure 56. This consists of expanded polyethylene. It is very lightweight, water resistant and fire retardant. It has also been tested in a simulated 'one in 50-year storm', after which it kept 100% of its sound reducing capabilities. Besides this, it has been tested to exceed 50 years of outdoor life testing. (Sealedair, 2022)

Whisper is also a bad thermal insulator, especially compared to traditional sound reducing foams. This means the heat pump can get rid of its excess heat easily to ensure a high efficiency. (Cowsill, 2023)

A thickness of 60mm was chosen. Because the 60mm variant is doubly laminated, while the 50mm is not, it performs much better at reducing lower frequencies, which are present in the sound of heat pumps. Meanwhile, a thicker variant does not make much difference compared to the 60mm one. (Sealedair, 2022)

To avoid vibration insulations, regufoam D300, shown in Figure 57, is placed below the heat pump. This dense polyurethane foam dampens the contact sound of the heat pump, preventing sound from escaping.

Finally, the recirculation plate is made from polystyrene, shown in Figure 58, and attached to the heat pump using velcro. Polystyrene is easy to cut using a box cutter and still stops airflow, making it easy to work with for the end user.

Figure 56: Stratocell whisper foam

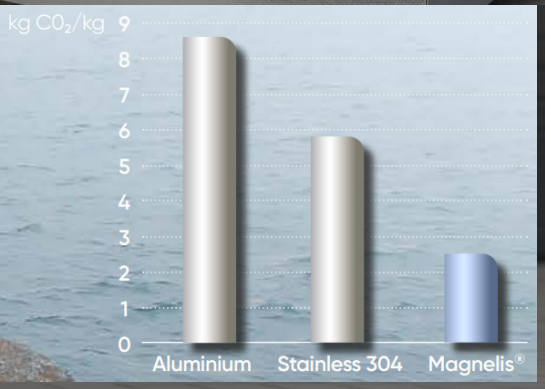


Figure 58: Polystyrene sheets

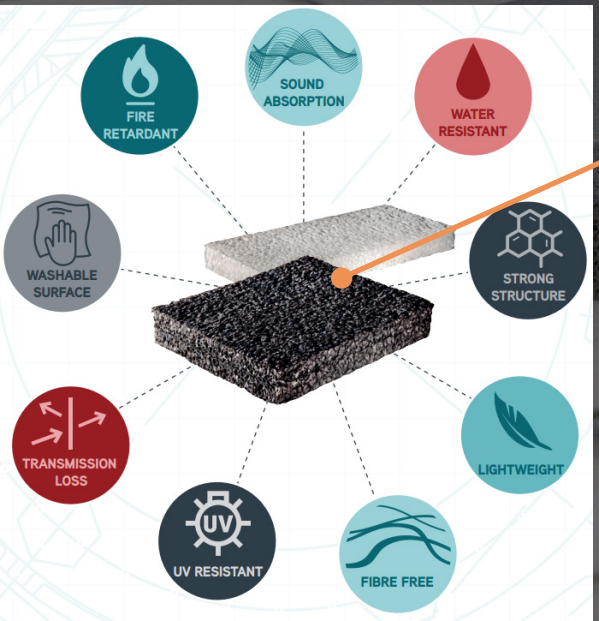


Figure 57: Regufoam

Configure to order

The traditional way of making products with custom sizing is to have an engineer manually change a 3d model and create the drawings for each case individually. This is called Engineering to Order or EtO.

Configure to order or CtO is a new way to automate this process. By way of an online configurator the customer can change the sizing of the product and personalise it by way of optional features, design details and colours. After that a personalised model is automatically generated, along with the quote, bill of materials and technical drawings. This can then be sent to the manufacturer automatically to start the production process. (Cadac, 2017)

Qventi will sell a range of standard sized models in standard colours, which will be mass produced. If the case of a customer does not fit a standard size, configure to order can be used. By inputting the size of their heat pump and checking that they have enough space available, a model will automatically be generated along with the quote and bill of materials, which will allow them to receive a fully personalised heat pump cover.

Currently, a SolidWorks add-in called DriveWorks is utilised to automate the model. As of now, the height, width and depth can be used as an input to create a fully custom sized model. Figure 59 displays several examples of different sizes and colours for unique cases. Note that in reality, these heat pumps would all have to be positioned a small distance away from the wall in order to leave room for the air intake.

The next steps in automating the model will be to build an online configurator and to add additional features. For example, the possibility to have a cable hole in the side panel instead of the back. Another feature that would be useful would be the option to choose for an against the wall cover, or a cover that is hung up. CtO could also be used to select different amounts of sound reduction by altering the foam thickness and sheet metal thickness.

Figure 59: Examples of models generated using CtO


Vaillant

Cost price

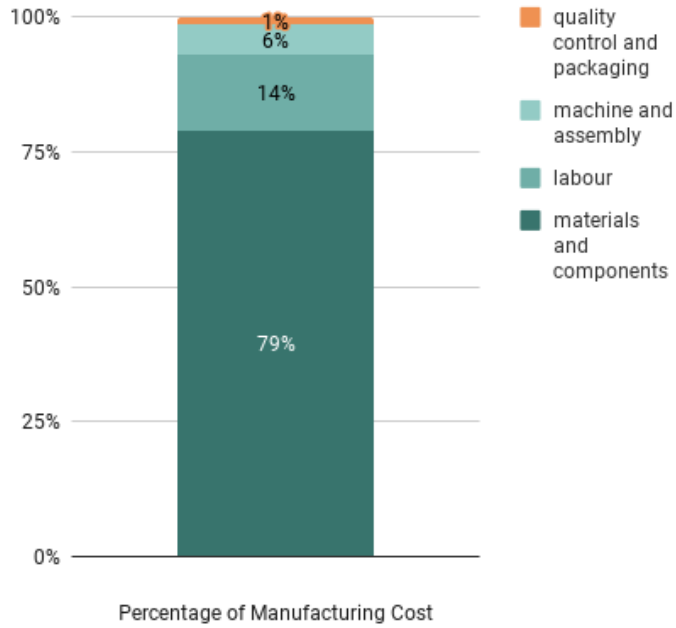
As Qventi wants to realise a CtO workflow, it is important that production is closeby for a quick delivery time. To be exact, the production will take place at a steel manufacturer in the Netherlands. Besides a quick delivery time, this makes the production less dependent on shipping containers with high minimum order quantities. A close production also reduces the CO2 footprint, ensures better labour conditions and is good for marketing. The steel manufacturer will have the option to powder coat in house, negating extra logistical costs and wait times.

It is important to realise this added customer value of a close production location. Especially because of a phenomenon called the ‘smile curve’, which describes how in recent years, the pre- and post fabrication stages are becoming more important for adding customer value than the actual manufacturing of the product (Baldwin & Ito, 2022).

To achieve a realistic cost price for the hush, a quote was made by the steel manufacturer for different order amounts and surface finishes, upon which the cost price calculation was then based. A theoretical framework of Tempelman (2021) was utilised to build up the individual parts of the price.

The numeric breakdown is sensitive information, as competing brands could gain an advantage knowing Qventi’s cost buildup. The exact numbers can be viewed on request by contacting Qventi.

Figure 61: Breakdown of the manufacturing cost



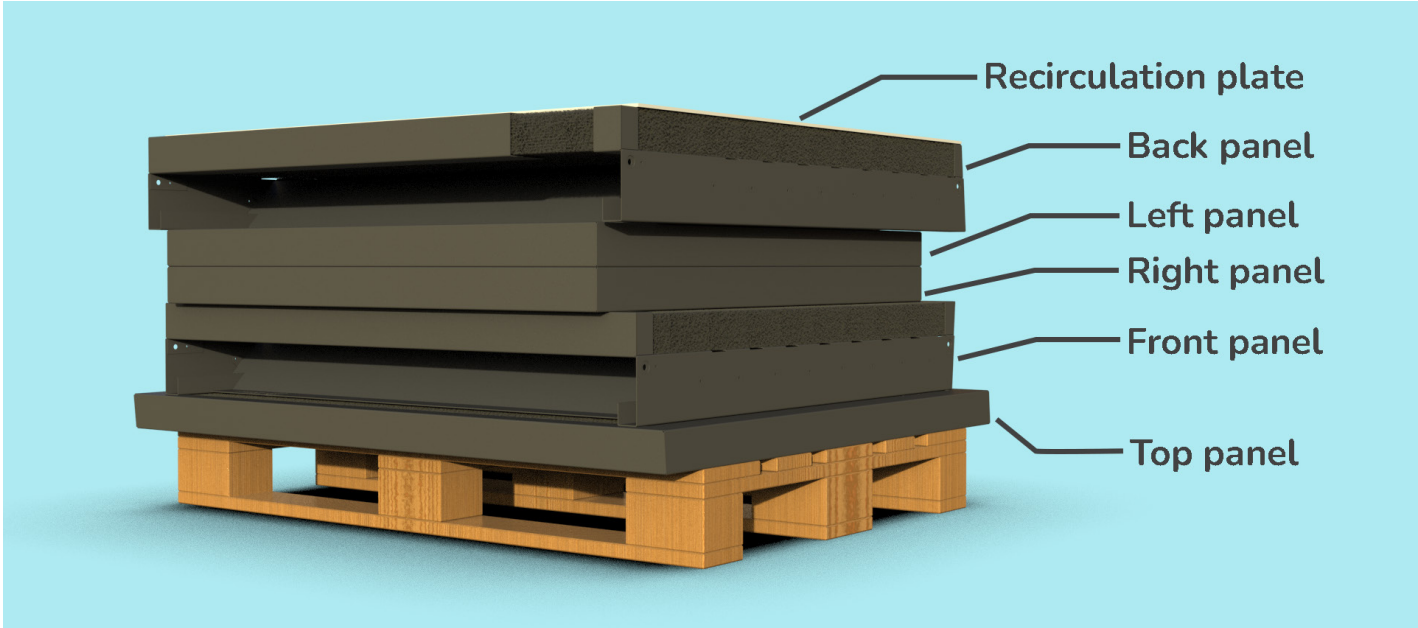


Figure 60: Components of hush stacked on a europallet (1200x800mm)

Figure 61 displays a relative build up of the price. As can be seen, the manufacturing cost or MC is 80% from materials and components. In this category, the magnelis and foam material costs are the main contributors.

To optimise the material usage of magnelis, a nesting algorithm was utilised (Deepnest.io, 2018). This was used to determine the amount of necessary sheets. In total, 2.4 sheets of magnelis are needed per product. The shape of the components, along with cutting the door from the middle of the frame, foregoes a lot of waste material. Of the 2.4 sheets, only 18% is waste material, which can then be recycled.

The next highest cost is labour at 14%. This consists of the wages of the operators for activities such as laser cutting, welding and bending. Then, 6% is for the cost to run machines and assembly. This is mainly the electricity that is used by the machines. Finally, 1% is quality control and packaging. Figure 60 displays how the components fit on a standard euro pallet. The panels are stacked in a specific order, where the first panel that is needed is stored on top, and the last panel on the bottom. This increases the efficiency of the assembly process, as the panels do not need to be moved around as much.

In width, the package of stacked panels is exactly the same size as the pallet, increasing the efficiency of storage. In depth, the materials are slightly longer than the pallet, sticking out 9cm on the back and the front. This means that in a warehouse, the pallets should be stored side to side for optimal storage efficiency.

From the MC, there are three sales channels, displayed in Figure 62. The most common one will be to a wholesaler. Here customers can buy the hush in standard size directly for €2065,- including VAT. Customers can also buy the hush for this amount through the Qventi website, where they will pay the same amount, with a larger profit margin for Qventi.

The last sales channel is to installers. The installers will then sell the cover to customers and install them for them. If a customer buys a cover through an installer they will be paying €2200,- which includes the cost of installation. This number can of course vary heavily per installer.

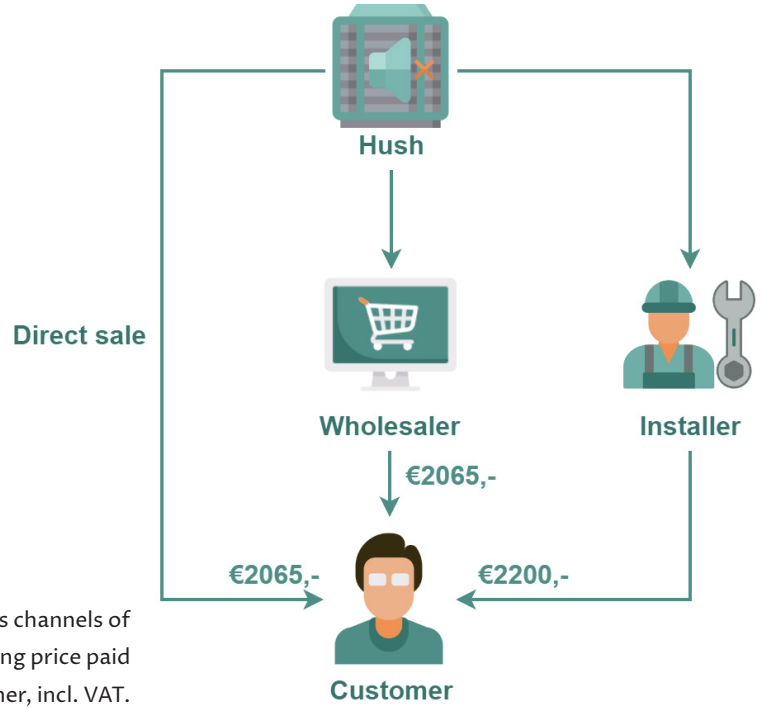


Figure 62: Sales channels of the hush including price paid by customer, incl. VAT.

Testing in Anechoic Room

Introduction

The purpose of functional prototypes is to test the core function of the product. In this case, to test the amount of sound reduction of the hush. Different foam configurations were tested to see how they performed. The goal of the research is to evaluate how much sound is reduced and to find improvements for the design to better reduce sound.

Method

For this test, an existing aesthetic cover of Qventi was embedded with foam to simulate the effect of the end product. In an anechoic room shown in Figure 63, six configurations were tested, shown in Figure 64. For each configuration the sound was measured one meter from the noise source on the front, left, right and backside. A high quality microphone was used while the speakers played a sound recording of a heat pump. Before starting the test however, the microphone was calibrated using white noise and a hand-held decibel meter.

During the test, the sound was played and recorded for six seconds in each of the four positions.

The data analysis consists of two parts. Firstly, the intensity analysis. This part looks at the overall intensity of the sound samples and calculates the overall sound reduction in dB(A)/ Secondly, the frequency analysis. This analysis looks at how different frequencies are affected using one-third octave bands.

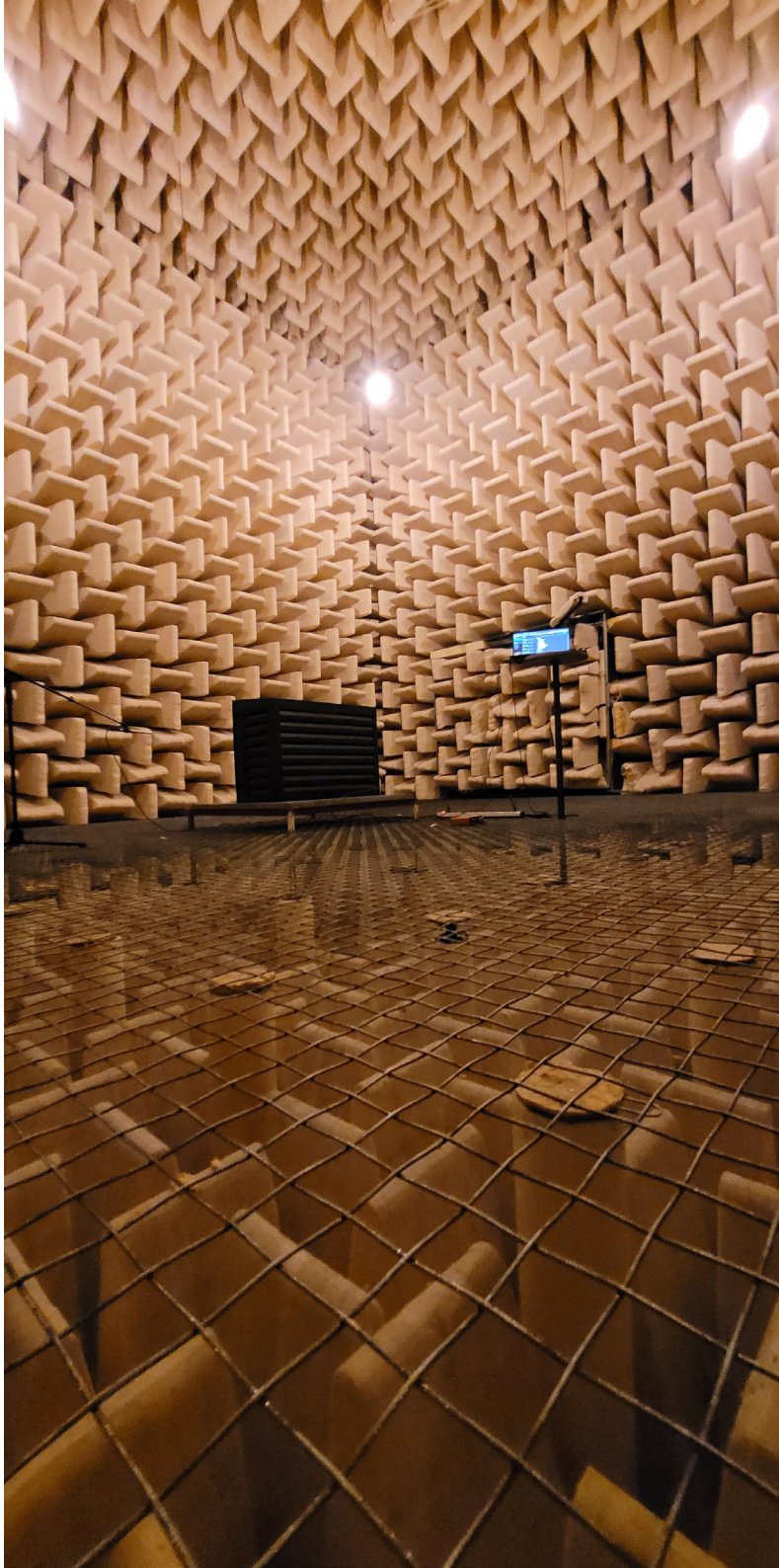
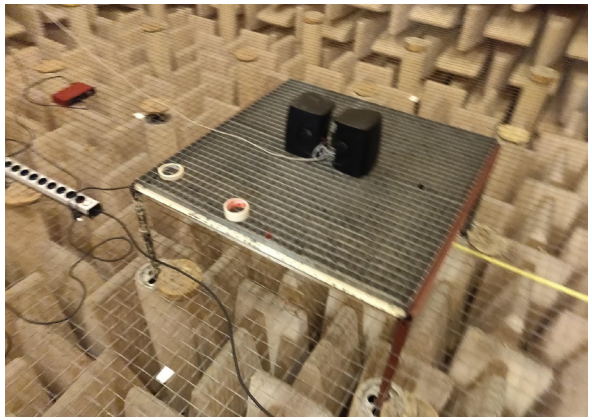


Figure 63: Test setup in the anechoic room of Delft

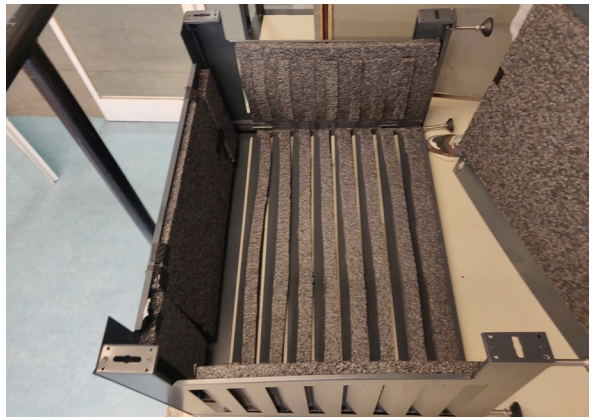


Heat pump no cover

A measurement of the heat pump sound without any cover.

Cover no foam

The aesthetic cover is placed over the speakers, without any foam inside.



Lamella foam

Side-, top- and backpanels are covered in closed foam of 25mm. This means there are no holes cut out in these pieces. Front panel has lamella shaped cutouts.

Perforated foam

The front panel has a pattern of holes.

Closed foam

All sides, including the front are fully covered with closed foam.

Double foam

All sides are covered in two layers of 25mm, totaling up to 50mm. This is the only configuration where the sides are fully closed off, including the hole for ventilation.

Figure 64: The six configurations of the test

Testing in Anechoic Room - Intensity Analysis

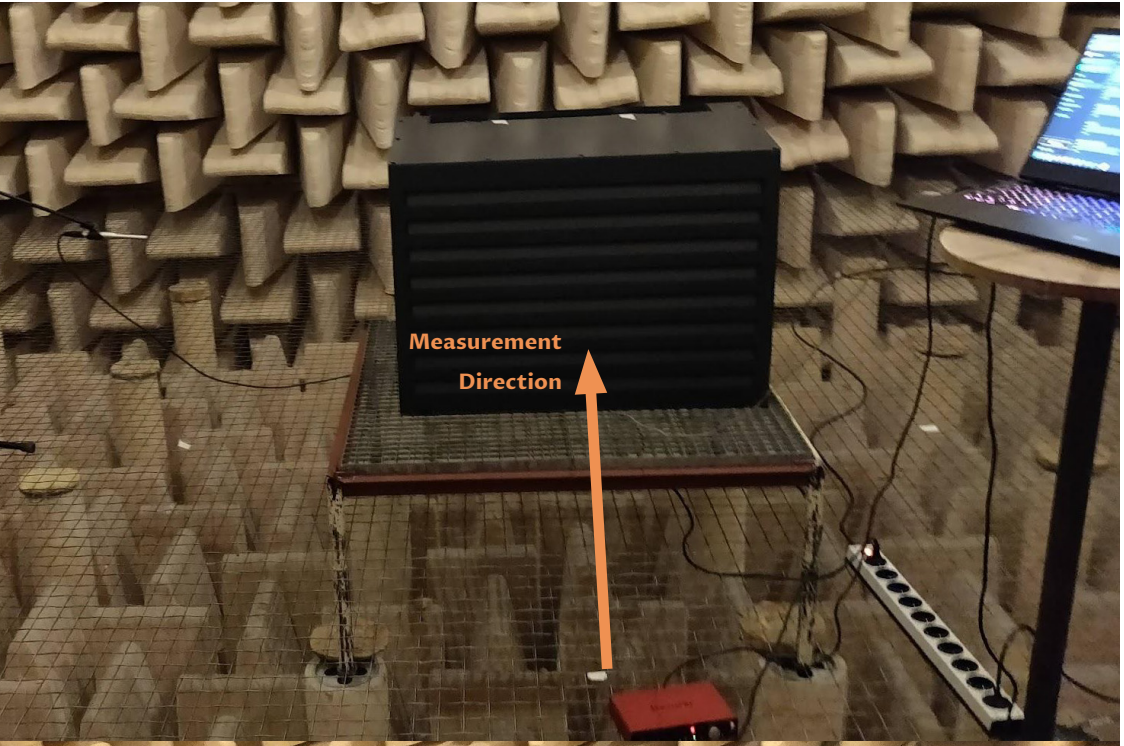
Figure 65 shows the intensity levels of the front position. Because of the setting of the anechoic room, the added reverberations introduced by the cover result in a small increase in volume. In previous tests that were performed outside, it was found that adding the cover without any foam did not affect the volume of the heat pump.

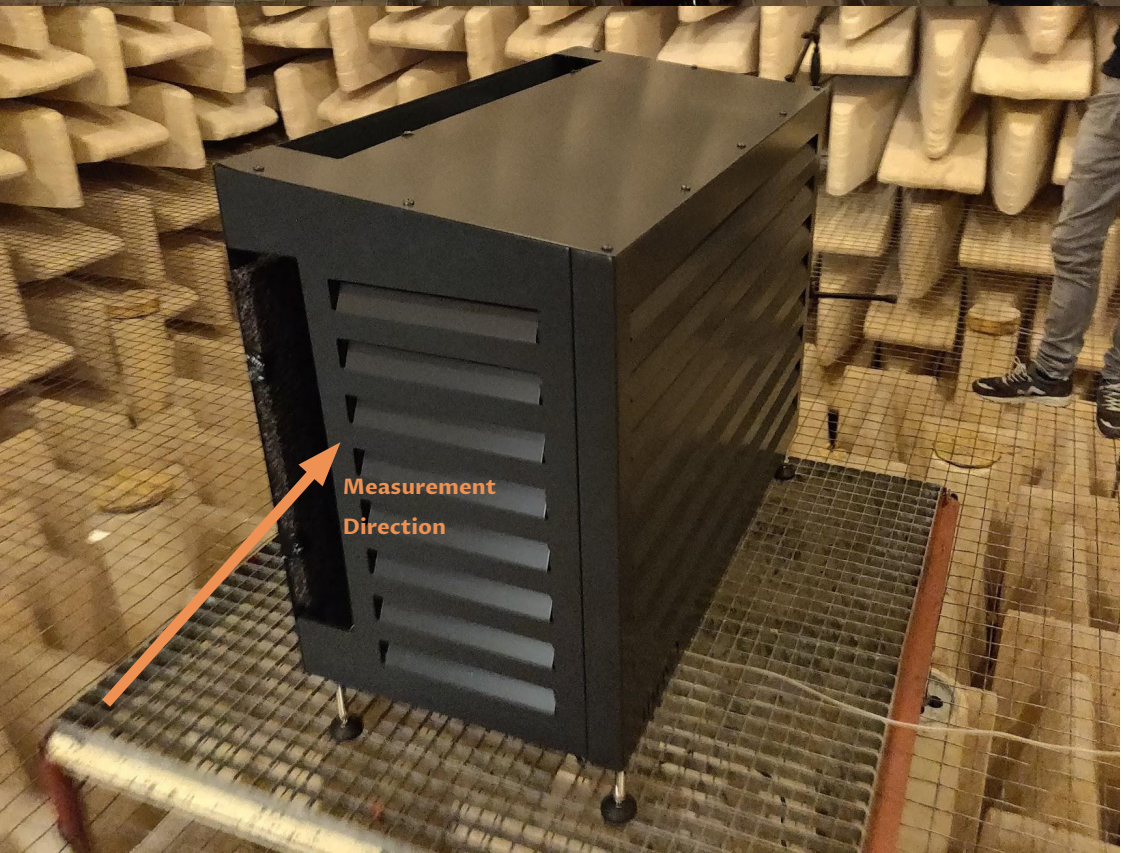
Adding one layer of 25mm foam to the cover seems to do very little, as the intensity changes close to nothing. A double layer, meaning 50mm of foam, does seem to make a small noticeable difference. It is however still very little.

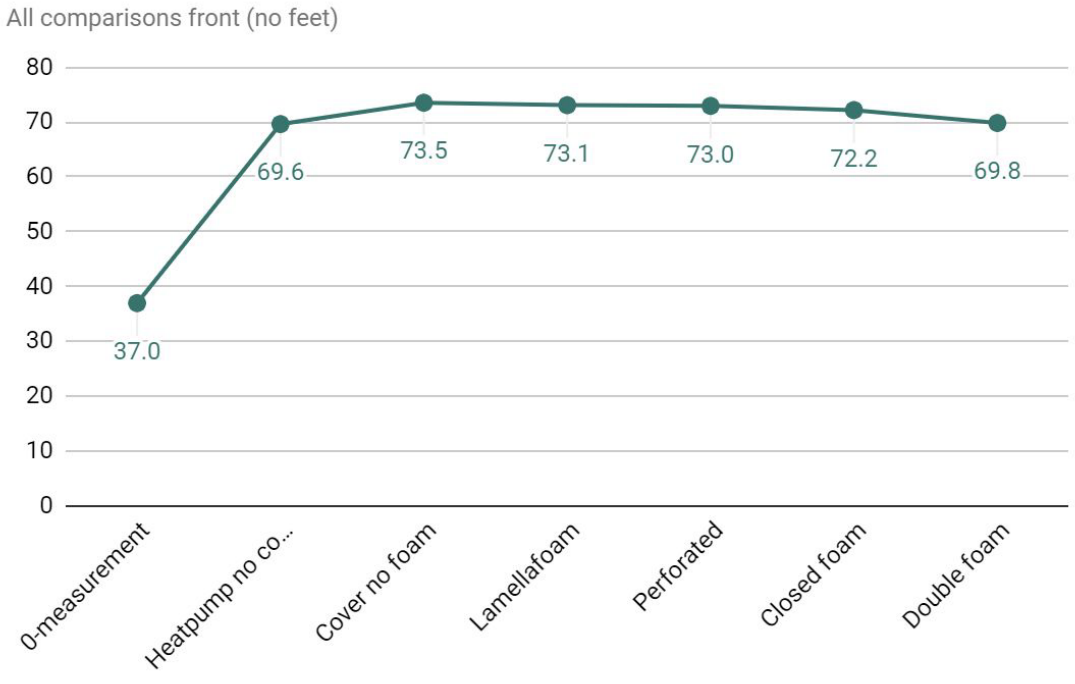
Intensity of the left measurements, displayed in Figure 66, also show little effect. Namely due to the fact that Qventi's aesthetic covers have a hole in the side for increased airflow. There was however a small difference perceived when this hole was plugged up, which is the case in the double foam setup.

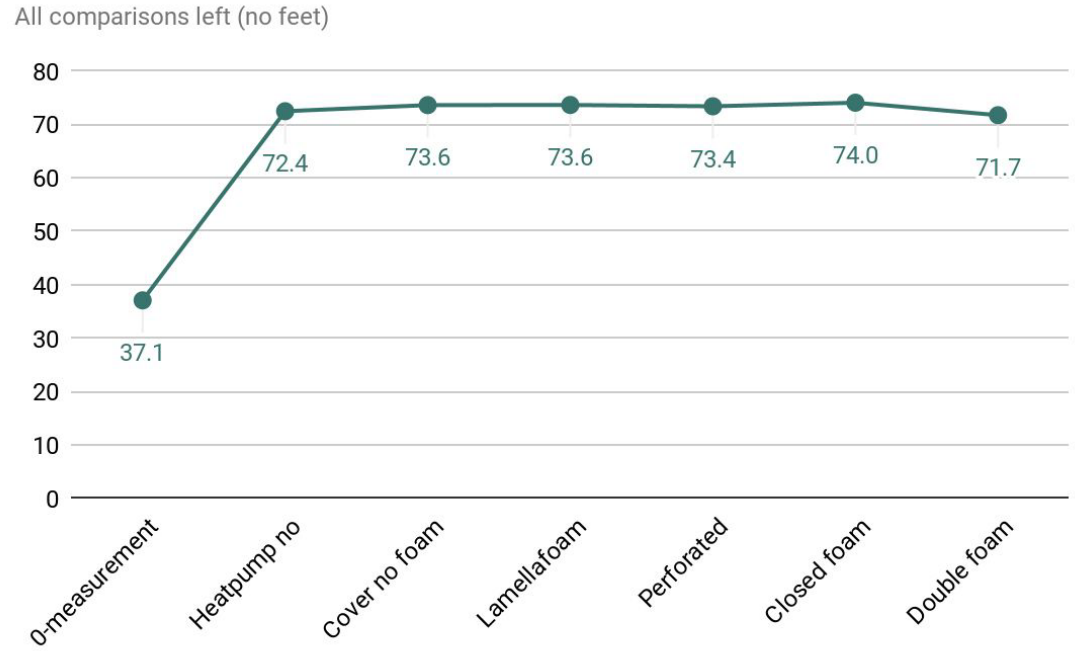
Figure 65: Intensity of front measurements

Figure 66: Intensity of side measurements


Measurement
Direction


Measurement
Direction


All comparisons front (no feet)
80
70
60
50
40
30
20
10
0
37.0
69.6
73.5
73.1
73.0
72.2
69.8
0-measurement
Heatpump no co...
Cover no foam
Lamellafoam
Perforated
Closed foam
Double foam


All comparisons left (no feet)
80
70
60
50
40
30
20
10
0
37.1
72.4
73.6
73.6
73.4
74.0
71.7
0-measurement
Heatpump no
Cover no foam
Lamellafoam
Perforated
Closed foam
Double foam

Testing in Anechoic Room - Frequency Analysis

Figure 67 displays the frequency curve of the heat pump sound. It can be seen that the most intense frequencies lie at 125-200Hz with another peak at 630Hz. It can also be seen that the curve is similar in shape to that of the original heat pump recording. This means the speaker is emulating the sound of a heatpump properly. The original recording appears to be louder, in reality this is because it is not calibrated using white noise. Figure 68 shows the intensity curves of all other configurations, with Figure 69 showing the difference in intensity compared to the original heat pump sound.

Firstly, it is clear that the lower frequencies are not dampened at all. Only the double foam layer has a noticeable effect at 250Hz. Secondly, it is clear that the tested configurations do decrease the higher frequencies significantly. However, since the heat pump sound is mainly lower frequencies, this does little to reduce the overall intensity.

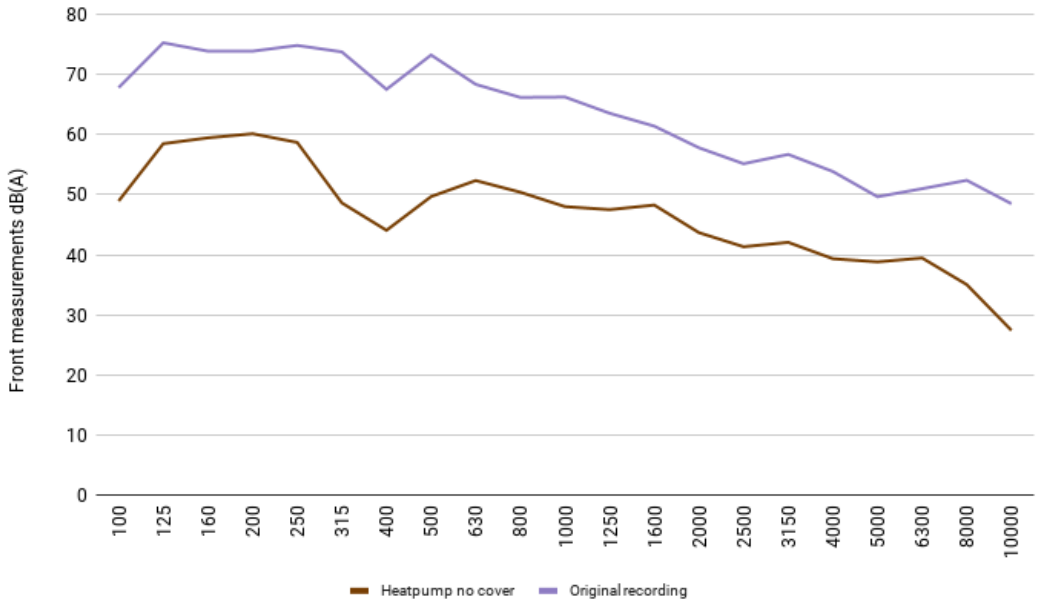


Figure 67: Frequency curve of heat pump sound without any cover, compared to the original recording

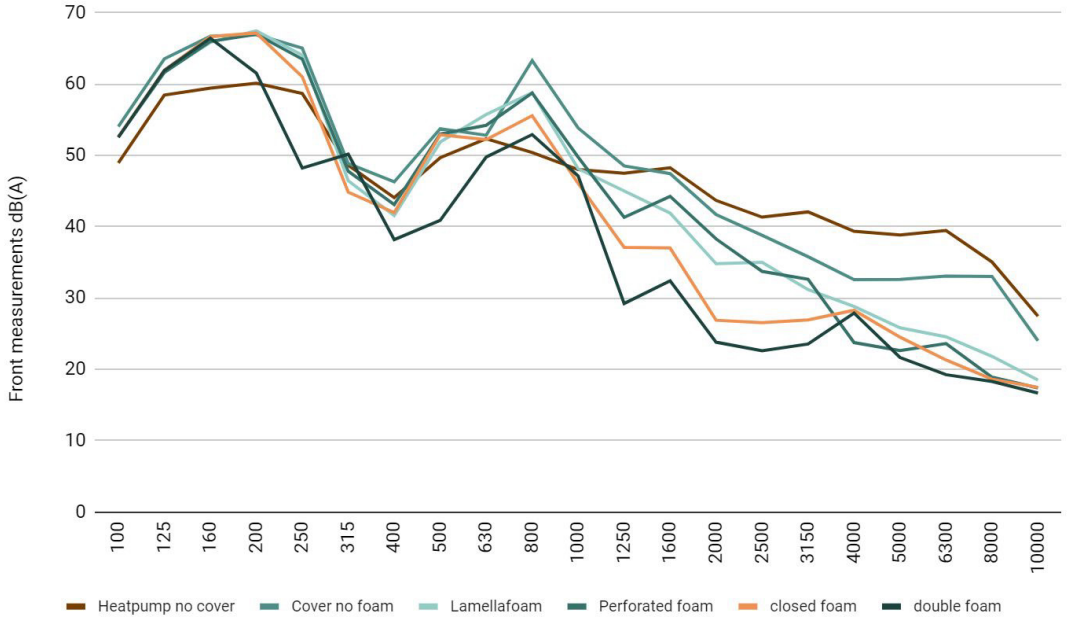


Figure 68: Frequency curve of all six configurations

Limitations

There was no solid underground under the speaker, which meant sound could escape underneath. The speakers were also positioned lower than the sound source of a real heat pump.

Conclusion

From the intensity analysis, it can be concluded that more weight is needed to properly reduce the sound. The cover of Qventi only weighs 25Kg, while competition of sound reducing covers are upwards of 100Kg. Furthermore, the 25mm thickness of foam is definitely not enough to make a substantial difference in overall intensity.

From the frequency analysis, we see that the sound of a heat pump mainly lies in the 125-250Hz range, with another peak at 630Hz. In order to reduce the sound in these ranges, a thicker version of whisper is needed.

Next Steps

The results of the test were discussed with Andrew Cowsill, a representative for the manufacturers of whisper foam with the nickname 'Whisper Guru'.

From this discussion, it was decided that the 60mm variant is best suited for this design, as it is especially designed for these relevant frequencies, as it has an Aw value of 0.79 at 200Hz, compared to 0.4 of 50mm, and 0.13 of 25mm (Sealed Air, 2022).

It was also decided that a sheet metal thickness of 2mm would not yield signicantly beter performance than 1.5mm. So 1.5mm was chosen as a new thickness.

Finally, the hole shape was changed from circular to a 'slot' shape as it is more efficient in reducing sound while keeping the same rate of air flow.

Figure 69: Difference in intensity compared to heat pump sound for all frequencies

Evaluation

In order to evaluate the design, evaluation sessions were held with the target user groups of installers and end customers. In these sessions the design was shown in order to evaluate the assembly process, price and aesthetics. Besides the evaluation sessions, the hush was compared to the two most important brands, Merford and Reducd.

Users

Alexandra, who was also interviewed in the analysis phase, was shown the design of the hush and asked to give her honest opinions about the design, shown in Figure 70. She thought the look of the design was sleek, clean and robust. The aspects that made it sleek were the hidden screw holes and the straight angles of the design.

Alexandra also liked the angled roof, as she would not have to clean it and water would not build up on top. She also mentioned that the removable doors are really nice. Alexandra also really liked the name ‘Hush’, because of the “Shh” at the end. Because Alexandra is an outsourcing user, she would never install the cover herself. Nonetheless, she thought the assembly process was streamlined and looked easy.

Figure 70: Explanation of the design

Figure 71: Aesthetic comparison to competition

Figure 72: Alexandra’s garden

Finally, if she could personalise the design in any way she wanted, she would choose for a white powder coat, as it fits the furniture of her garden, shown in Figure 72.

The second part of the evaluation consisted of a comparison similar to the one performed in the analysis phase, this time with the Qventi hush among the covers, shown in Figure 71. Of all models, she thought the hush was the most aesthetically pleasing. She thought this because it was sleeker than the rest and had a more pretty appearance. About the appearance of the hush, she said the following: “I would be curious what it is, I don’t immediately see that it’s a heat pump housing.”

Finally, regarding the price point of the hush, she mentioned that if it was the same price as Reducd and Merford, she would definitely choose for the hush.

Installers

Lambert was also asked about the new design. He is one of the owners of installation company Denissen and was also interviewed during the analysis phase. Lambert thought the design looked really sleek, and thought it looked easy to assemble. However, to truly evaluate the ease of assembly, he mentioned that he would have to actually install a 1:1 prototype himself. Lambert was also slightly unsure about the cable management. Specifically he was not sure how much space was needed to bend the cables of a heat pump to the back.

Lambert was worried about the proper functioning of the heat pump, and mentioned that he would want to see the results of a test that guaranteed the efficiency of the heat pump with the cover on top. If this was proven however, he said that he would include the hush in every quote that was made by his company.

Competition

Figure 73 displays the characteristics of the Hush compared to Reducd and Merford. These three models all have the exact same inside volume. As can be seen, the Hush is more low cost, lighter and more compact. The amount of parts is also comparable to Reducd, while not requiring any special tools. The only aspects that are yet to be tested are the amount of sound reduction and the actual installation time. If the sound reduction is proven to be on par with Reducd and the installation time is faster, the Qventi hush will exceed the competing brands in all aspects.

	Merford Dice-05	Reducd S	Qventi Hush
dB reduction	15dB	14dB	TBD
Price	€ 2,200	€ 2,275	**€ 2,065**
Weight	123kg	160kg	**113kg**
Extra Volume	0.90m³	0.58m³	**0.54m³**
Metal part count	27	5	5
Screws	(up to) 100	12	**8**
Nuts	(up to) 100	0	0
Other parts	(up to) 55	6	6
Special tools required	×	Rivet gun, angle grinder	×
Installation steps	22	9	9
Advertised install time	2 people 2 hours	1 person 1 hour	**45 minutes**
Actual install time (based on reviews)	"8 hours" (Van Tilborg, 2021)	"a few hours" (Van Osch, 2022)	TBD

Figure 73: Comparison between the hush and competing brands.

Conclusion

The heat pump market is growing rapidly and new noise legislation creates issues for many people living in terraced housing and apartments. The assignment was to develop a sound reducing heat pump cover for Qventi. It should reduce the sound sufficiently, while being aesthetically pleasing and easy to assemble. It should also be smaller, lighter and sold for a lower price than the main competitors.

Through market analysis, it was found that 10-15dB reduction was needed to stay within legal limits and data was gathered about the types of heat pumps and sound reducing covers. Through interviews, installers were found to value ease of delivery, ease of installation and ease of quoting. There are researching users, who research and install by themselves, and there are outsourcing users, who leave everything to the installer.

From the analysis, five main drivers were determined: Peaceful silence, hidden in plain sight, easy to assemble and available today. Through ideation, three concepts were made which were evaluated using the main drivers. From here, one concept was chosen.

An anechoic chamber was used to test an aesthetic cover of Qventi with varying configurations of foam. Through this, The key heat pump frequencies were found, along with the optimal foam thickness and sheet metal thickness for the final design.

Through nine iterations, the final design was reached. It consists of five sheet metal panels, with clamped-in foam. A recirculation plate splits the inner area into two compartments, preventing the recirculation of air. Anti-vibration foam is placed underneath the heat pump to prevent contact sound.

The model was optimised for assembly by reducing the part count and pre-assembling the panels. Two doors were created on the side panels for easy maintenance access. The roof panel slots into place using a hidden locking mechanism.

Magnelis was chosen as a metal for its high corrosion resistance, long lifespan, recyclability and low CO2 footprint. For the foam, stratocell whisper was chosen for its sound reduction capabilities, low weight, moisture resistance and long lifespan.

Qventi will sell a range of sizes, with the option of custom sizing using a configure to order workflow, where models, technical drawings and quotes are automatically generated based on the specific case of the user. The first model Qventi will bring to the market will be priced at €2065,- for consumers.

This model has the same inside volume as its two biggest competitors, but is lighter, lower cost, more compact and easier to install.

Through an evaluation with users and installers, the hush was found to be more aesthetically pleasing than the rest of the market. Mainly because of the hidden screw holes and the sleek, clean and robust design.

The most important next steps consist of testing the sound reduction, testing the effect on heat pump efficiency and testing the installation process.

Recommendations

Peaceful silence

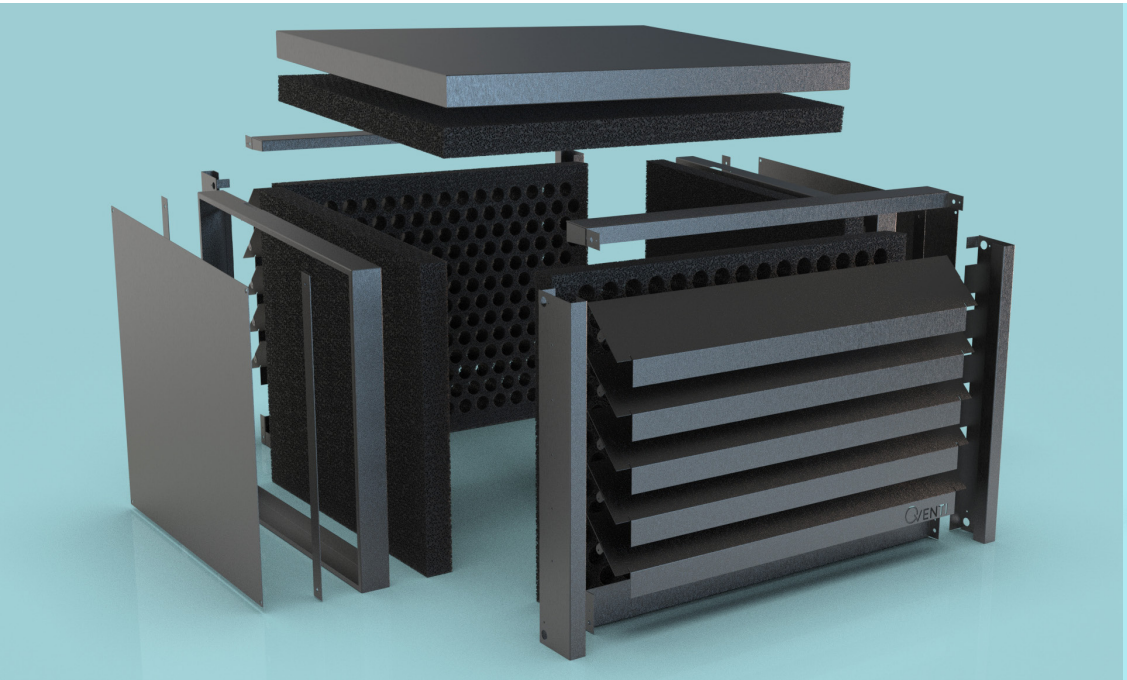
The most important step of this project is proving the functionality. Qventi is currently in the process of making a 1:1 prototype, which will then be used to test the sound reduction of the cover. Firstly this will be tested by Qventi themselves. Then, if the results are promising, by an independent acoustic engineering firm. The impact on heat pump efficiency should also be tested using this prototype.

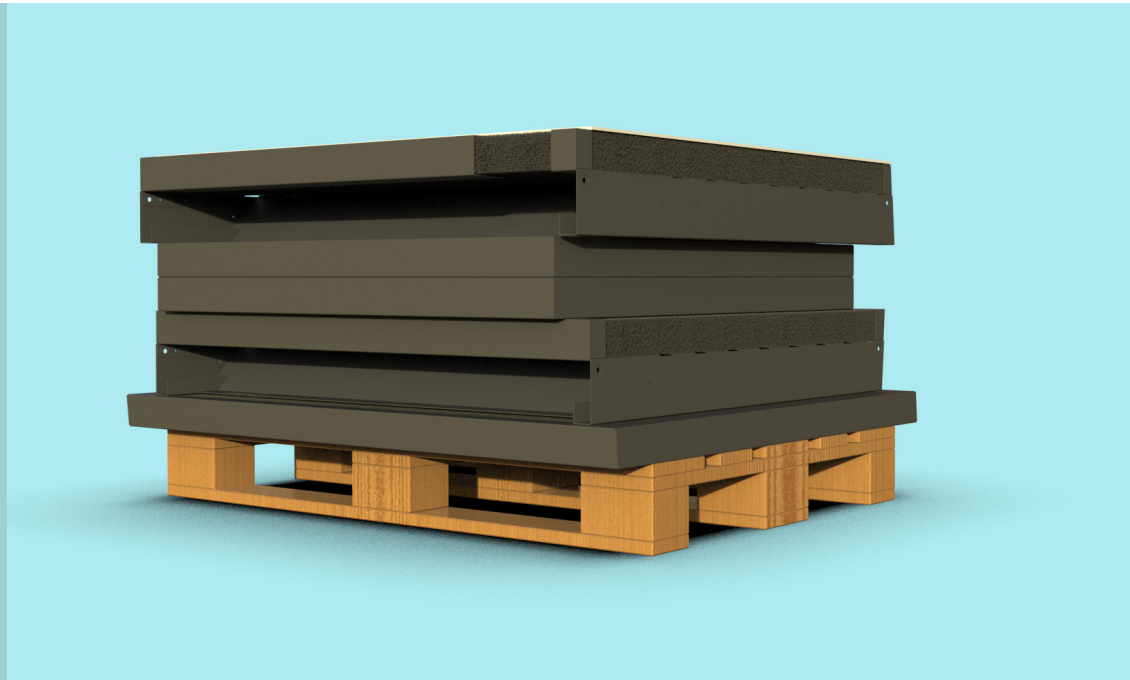
Hidden in plain sight

Even though the two people that were talked to during the evaluation were very enthusiastic about the exterior look of the hush, more evaluation of the aesthetics is necessary. This can be done by having more qualitative interviews along with surveys.

Easy to assemble

To evaluate the ease of assembly properly, real testing must be performed with the prototype. Although it was found that the assembly process is more than likely already better than that of the competition, a real evaluation with multiple installers is vital to prove it.





For a brighter future

The hush is made from extremely durable materials that will last a long time outdoors. However, the strength of the cover should be evaluated further. One way is physical testing of the prototype, trying scenarios like sitting on the cover, kicking a football against the lamellas or bumping into it with a heavy object. Then, FEA simulations, calibrated with the physical tests, can be performed to optimise the strength. Another way that can be employed is a FMEA or failure mode and effect analysis, to map out all the different ways failure can occur and to assess the impact of those failures (ASQ, n.d.).

The possibilities of bio based foams should also be explored further. Namely expanded cork and biofoam are promising, as they are already available for mass production and can be perforated similarly to stratocell whisper.

Available today

Qventi is already in the process of setting up a production network for the hush. It is vital that they will be able to launch a first version of the product as soon as the functionality is proven. After this, the following product developments can be explored. Firstly, a variation of the hush with a cable hole in the sides, specifically for already installed split units with a cable connection to the side. Secondly, a model with air-intake on the sides which can be placed against the wall. Thirdly, a model that can be hung up, for heat pumps mounted on walls.

Finally, Qventi should develop the automated model further to fully integrate it using CtO. To start off, automate the drawings, bill of materials list and quote generation. Then, implement it using DriveWorks Solo, working semi-automatically. If this proves successful, upgrade to DriveWorks Pro for a fully automatic online configurator.

Reflection

During my six years of education as an industrial designer, I slowly became aware of who I want to be as a designer. During Manufacturing and Design I first came into contact with production methods and how to design for them. Through courses like Advanced Embodiment Design I realised that I am extremely passionate about making my designs come to life.

Not stopping at a concept, but working out all the important details in SolidWorks, thinking about connection methods and optimising it for manufacturability.

What I wanted for my graduation project was to go ‘all the way’. To create something that would actually be manufactured and learn how this process works in the real world, instead of in the context of a university project. With this project, I feel that I have fully succeeded in reaching my goal.

I learned a lot about the manufacturing of sheet metal. A production method that I knew very little about at the start of this project. But through many meetings with a fastening consultant and sheet metal manufacturers I managed to optimise my design more and more for this manufacturing method, which was a nice experience.

I also learned that being proactive with followup- emails and calls really pays off and helps you get what you want.

During this project, I performed three sound tests that all did not have a positive outcome. In fact, the first two were almost completely useless. While it felt bad at the time of the experiment to have wasted some time, I learned to appreciate that a failed experiment can still provide plenty of useful learnings. Even if it is only a couple of small things, take them to heart and see what value it can bring to the project.

Overall, I am really happy with the way my graduation project went. It was exactly what I hoped it would be and I hope that the Qventi hush becomes a staple in the world of sound reducing heat pump covers.

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Appendix 1 - Original project brief

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT
Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Swen
initials: M. S. given name: Micha
student number:
street & no.:
zipcode & city:
country:
phone:
email:

Your master programme (only select the options that apply to you):
IDE master(s): ★ IPD ○ DfI ○ SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: ○ Honours Programme Master
specialisation / annotation: ○ Medisign ○ Tech. in Sustainable Design ○ Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Erik Tempelman dept. / section: SDE - MM
** mentor: Martijn Haans dept. / section: HCD - HICD
2nd mentor: Tim Hoogendoorn
organisation: QVENTI
city: Breda country: The Netherlands
comments (optional):

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

TU Delft

Procedural Checks - IDE Master Graduation

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Erik Tempelman date - - signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: ____ EC
Of which, taking the conditional requirements into account, can be part of the exam programme ____ EC
List of electives obtained before the third semester without approval of the BoE

○ YES all 1st year master courses passed
○ NO missing 1st year master courses are:

name date - - signature

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ○ APPROVED ○ NOT APPROVED
Procedure: ○ APPROVED ○ NOT APPROVED
comments

name date - - signature

Initials & Name M. S. Swen Student number 4654471
Title of Project Develop a new sound reducing heat pump cover

Develop a new sound reducing heat pump cover

project title

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

start date 01 - 11 - 2022

15 - 05 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

Qventi is a company formed in 2020 and is currently owned by the parent company Findyourgroup. Qventi specialises in selling air conditioning and casings to both businesses and consumers. The casings are aluminium exteriors that are mounted around the air conditioning unit or heat pump exterior. Their primary goal is to make the look of the air conditioning unit more appealing. This aesthetic change is shown in Figure 1. Next to aesthetics however, there is also the problem of sound. Many air conditioning units and heat pumps run at 70-75 dB, but some of the quietest modern models run at 40-50 dB (Rodriguez, 2020). However, since April 2021, the maximum sound pressure allowed at the edge of the property was set at 40 dB at night and 45 dB during the day (Geluidsmetingwarmtepomp, 2021). Next to the requirements of legislation, this sound can also create a disturbance for the users themselves, because air conditioning units and heat pump exteriors are often placed in gardens, a place where the sound can quickly become annoying. Unfortunately, the current casings have a negligible effect on reducing sound. So, this poses a new challenge for Qventi: create a new heat pump cover that reduces the sound to within acceptable levels. For this new product, there are two other important stakeholders:

Consumers
Firstly, it is important that the casing is aesthetically pleasing and it fits with the exterior look of their house. This is for instance achieved by providing the option of multiple colours, displayed in Figure 2. Secondly, the casing needs to reduce the sound of the heat pump exterior or air conditioning. This is important for both comfort of the consumer and for meeting standards set by legislation. Thirdly, the casing should be as small as possible as to not take up too much space of their garden. Lastly, it is important that the sound reducing casing is still affordable.

Installers
Air conditioning units, heat pumps and casings must always be installed by qualified installers. This is because a special certificate is required to handle and install cooling systems (Mijnzzp, 2022). Thus, consumers must always purchase an air conditioning system in combination with an installer. This means it is very important for Qventi to take the needs of installers into consideration. For installers, it is important that the casing is easy and quick to assemble. It is also important that the casing is as light as possible for easy handling and that the casing takes up the least amount of space, so it can easily be transported.

Geluidsmetingwarmtepomp. (2021). Wetgeving geluidsoverlast warmtepompen. Retrieved 27 October 2022, from https://www.geluidsmetingwarmtepomp.nl/blog/668092_wetgeving-geluidsoverlast-warmtepompen

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Rodriguez, J. (2020). Air Conditioner and Heat Pump Noises: A Complete Guide. Retrieved 27 October 2022, from https://indoortemp.com/resources/air-conditioner-heat-pump-noises

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: An airconditioning unit without casing (top) and with casing (bottom)

image / figure 2: CAL100-series casings in four different colours

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

The goal of this graduation project is to develop a new sound reducing casing for air conditioning units and heat pump exteriors for Qventi. This new product could make use of existing or new technologies to reduce sound. The casing needs to be usable for exterior units that are stood against a wall on the ground as shown in Figure 1, but also for units mounted on the wall and for units that are stood by themselves, for example on top of a roof. The new casing has no limitations in the way of materials used. Finally, the new casing should be producible within 1 year.

There are several issues with currently existing sound reducing casings. For one, they are very large in size and heavy compared to normal casings. Furthermore, sound reducing casings are a lot more expensive. To illustrate this difference, when comparing the regular CAL100BA casing from Qventi (n.d.) to the 15dB sound reducing DICE-05 from Groenehoedduurzaam (n.d.), it can be seen that the price increases from €350,- (regular) to €2200,- (sound reducing), the outside dimensions from 100×50×70cm to 120×125×106cm, and the weight from 8.5kg to 123kg.

Qventi. (n.d.). CAL100BA. Retrieved 29 October 2022, from https://qventi.com/cal100ba-basisunit/

Groenehoedduurzaam. (n.d.). Merford DICE Geluidreducerende buitenunit cover. Retrieved 29 October 2022, from https://www.groenehoedduurzaam.nl/dice-warmtepomp-airco-omkasting.html

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

This project will consist of an analysis of the needs and wishes of end-users and installers, an analysis of competing sound reducing products and existing sound reducing technologies. This will be followed by an ideation phase leading to the development of a concept. Then the embodiment of the design will be completed using a functional prototypes, a 3D model, validation with users and installers, manufacturing details, technical drawings and cost price estimations.

This project will start off with an analysis consisting of two parts. Firstly, the needs and wishes of end-users and installers, which will be found through interviews, analysing existing research and experience from Qventi, and assembling an existing product myself to see what issues arise. Secondly, an analysis will be made of existing and new sound reducing technologies through literature research, analysing existing products and by talking to experts. This analysis phase will result in a list of requirements and wishes which will start off the concept development phase.

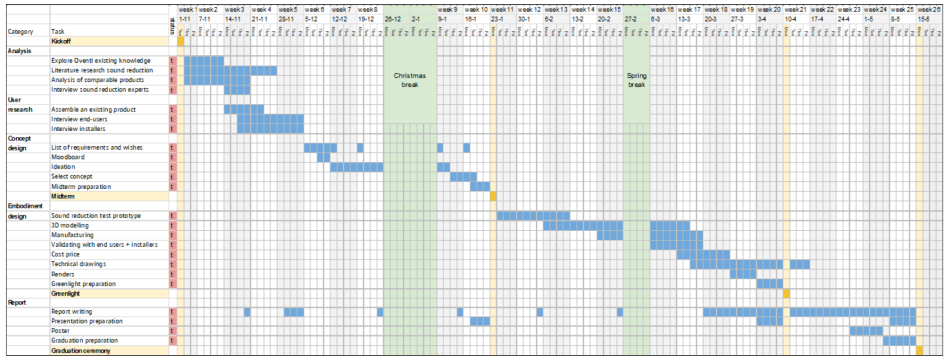
The goal of the concept development phase is to first generate a large variety of solutions. Then, the list of requirements and wishes will be used to select one concept for the embodiment design phase. In this final phase the technical part of the concept will be validated using a functional prototype. Then, a 3D model will be developed and the design will be finalised by working out the manufacturing details, technical drawings and a cost price estimation. The final design will also be validated with end-users and installers.

I expect to design a solution that makes sound reducing casings for air conditioning and heat pump exteriors affordable, smaller in size and lighter than currently existing products, while fitting to the needs and wishes of end-users and installers.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 1 - 11 - 2022 15 - 5 - 2023 end date



For my graduation project, I will work four days (Monday, Tuesday, Thursday and Friday) a week for the entire duration, for a total of 25 weeks. In this time there are two planned vacations: a 2-week christmas break in December and a 1-week spring break in February. This means the total project will last from 01-11-2022 until 15-05-2023. The four main dates are marked in yellow and consist of the kickoff on day 1, the midterm on day 40, greenlight meeting on day 80 and the graduation ceremony on day 100.

The project is divided into three phases. Firstly, in the analysis and user research phase (week 1-5) the focus will lie on building a foundation for the design: researching needs of end-users and installers, analysing existing products and researching helpful technology. Secondly, the concept design phase (week 6-10) will make use of this theoretical foundation to ideate many different solutions in order to then converge to one concept before the midterm. Thirdly, the embodiment design phase (week 11-25) consists of creating a functional prototype and working out the embodiment details, such as the 3D model, manufacturing details, cost price evaluation and technical drawings. The last category in the planning is called report, and consists of writing the thesis report and other end-deliverables.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I am passionate about making designs come to life. My strength as a designer lies in making the step from a potent idea to a real feasible design. Working out the details, the materials and how it's manufactured. I also enjoy making different types of prototypes, such as functional prototypes, using 3D printing, laser cutting and other tools. Another part of design I am passionate about is working with new technologies. I enjoy talking with experts about new and existing technologies to solve a problem, and get inspired by them in the process. I prefer working with physical products rather than services or digital products and want to use this project to sharpen my embodiment skills even more.

These are the main competencies I hope to improve further in this project:

- Managing large projects
I hope to get more experience with managing and filling in large projects where I have a lot of freedom. In most courses in the past there were many obligatory deliverables which partially shaped the activities in my projects. In this project I hope to gain more experience in shaping a large scale design project by myself and learning how to use my time effectively.

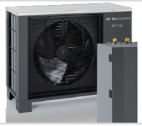
- Design for manufacturing
After finishing my master I plan on working in manufacturing or in a design consultancy focussed on detailing and complex problems. For this I would like to sharpen my manufacturing skills, including how to design for different manufacturing methods, as well as 3D modelling and my technical drawing skills.

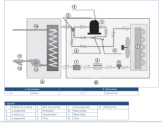
- Tackling complex subjects
In this graduation opportunity, I really like the challenge of diving into a new complex topic that I don't know much about. I want to test myself and see how quickly I can get familiar with the technology of sound reduction and apply it as fast and efficiently as possible.

FINAL COMMENTS

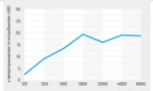
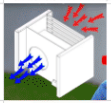
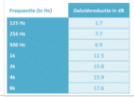
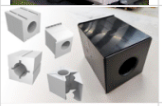
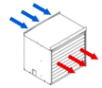
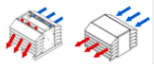
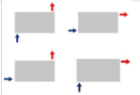
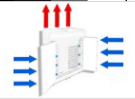
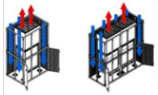
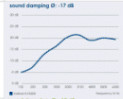
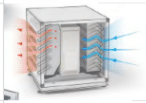
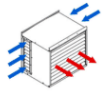
In case your project brief needs final comments, please add any information you think is relevant.

Appendix 2 - Heat pump data sheet

Brand	Name	Image	Type	Price (2021) (incl	Price (2022) (incl	ISDE-subsidy (2	l [mm]	d [mm]	h [mm]	V [m³]	Power	Sound production
Atlantic	**Aurea 5 R32 Hybrid add-on, mono blok 5kW**		monoblc	€ 4.525,00	€ 5.225,00	€ 2.550,00	870mm	340mm	550mm	0,16m³	5kW	61
Ferroli	Omnia Hybrid C split, 4kW		split	€ 7.250,00	No longer sold	€ 2.550,00	900mm	330mm	860mm	0,26m³	4kW	67
Vaillant	aroTherm, VWL 55/5 AS + VWL 57/5 IS, 5 kW split		split	€ 6.500,00	€ 7.450,00	€ 2.700,00	1100mm	450mm	770mm	0,38m³	5kW	55
Itho Daalderop	HP-S 55 6kW split		split	€ 6.200,00	€ 6.550,00	€ 2.700,00	930mm	350mm	790mm	0,26m³	6kW	66
Atag	Energion, M Hybrid-all 4, 4kW monoblock		monoblc	€ 5.960,00	€ 6.375,00	€ 2.700,00	1020mm	370mm	760mm	0,29m³	4kW	59
Daikin	**Intergas Hybride, EHYHBH 05AV32 + EVLQ 05CV3 5 kW split**		split	€ 5.550,00	€ 7.850,00	€ 2.550,00	830mm	300mm	740mm	0,18m³	5kW	60
Bosch	Compress, 7400i 5 B, 5 kW monoblock		monoblc	€ 7.800,00	€ 9.075,00	€ 2.700,00	930mm	600mm	1380mm	0,77m³	5kW	53
Remeha	**Elga Ace, 4 kW split**		split	€ 4.550,00	€ 5.225,00	€ 2.400,00	850mm	340mm	550mm	0,16m³	4kW	57
Nibe	NIBE F2120-16		monoblc		€ 15.900,00	€ 3.600,00	1280mm	612mm	1160mm	0,91m³	8kW	55
Minimum value				€ 4.525,00	€ 5.225,00	€ 2.400,00	830mm	300mm	550mm	0,16m³	4kW	53
Maximum value				€ 7.800,00	€ 15.900,00	€ 3.600,00	1280mm	612mm	1380mm	0,91m³	8kW	67
Average				€ 6.041,88	€ 7.956,25	€ 2.716,67	968mm	410mm	840mm	0,37m³	5kW	59

Brand	Name	Silent mode	Airflow	See through
Atlantic	**Aurea 5 R32 Hybrid add-on, mono blok 5kW**	x	back to front	
Ferroli	Omnia Hybrid C split, 4kW	silent night modus with 2 modes, to be set by user	back to front	
Vaillant	aroTherm, VWL 55/5 AS + VWL 57/5 IS, 5 kW split	silent night modus, to be set by installer	back to front	
Itho Daalderop	HP-S 55 6kW split	silent night modus, to be set by installer	back to front	
Atag	Energion, M Hybrid-all 4, 4kW monoblock	silent night modus, -3dB, to be set by user	back to front	
Daikin	**Intergas Hybride, EHYHBH 05AV32 + EVLQ 05CV3 5 kW split**	silent night modus, 3 modes, to be set by user	back to front	
Bosch	Compress, 7400i 5 B, 5 kW monoblock	silent night modus, automatic control based on outside temp or times, to be set by user	back to front	
Remeha	**Elga Ace, 4 kW split**	silent night modus, -5dB, to be set by installer	back to front	
Nibe	NIBE F2120-16		back to front	
Minimum value				
Maximum value				
Average				

Appendix 3 - Sound reducing covers data sheet

Brand	Name	Image	Price	in l	in d	in h	in V	out l	out d	out h	out V	extra V	Weight	Technology Image	Technology description	Airflow	Sound reduction	Sound isolation graph	Against wall	Stand alone	Hung on wall
Qventi	CAL100BA		€ 350	930	460	670	0.29m³	1000	500	700	0.35m³	0.06m³	9kg		None		0dB		1	1	1
Merford	Dice-05		€ 2,200	1050	660	990	0.69m³	1200	1250	1060	1.59m³	0.90m³	123kg		Lamellas with akotherm		15dB		0	1	0
Reducd	S		€ 2,275	1060	650	990	0.68m³	1220	950	1090	1.26m³	0.58m³	123kg		Lamellas with foam		14dB(A)		0	1	0
Merford	Ace-01		€ 3,250	1090	650	990	0.70m³	1230	1350	1060	1.76m³	1.06m³	167kg		NoiseTrap® Blox made from polypropylene, filled with merfopol, better sound reduction at low frequency		17dB		0	1	0
Solflex	HC100NP		€ 1,599	1100	450	950	0.47m³	1210	910	1080	1.19m³	0.72m³	130kg		Lamellas with foam		10dB(A)		0	1	0
Climaleon	Wave 05 (Solflex HW100NP)		€ 1,899	1060	490	655	0.34m³	1165	1200	758	1.06m³	0.72m³	50kg		Lamellas with foam		7dB(A)		0	1	0
Stavoklima	Alfa S (Solflex QHW100NP)		€ 1,949	800	350	1055	0.30m³	1560	790	1115	1.37m³	1.08m³	128kg		Simple grate		13dB(A)		1	1	0
Alixo	ALX-5400-020 (Solflex HD100NP)		€ 2,199	1000	460	1020	0.47m³	1385	1100	1155	1.76m³	1.29m³	40kg		expanded polypropylene (EPP)		6dB(A)		0	1	0
Kellner	(Solflex V100NA)		€ 7,499	1000	850	1700	1.45m³	1860	1450	2400	6.47m³	5.03m³	650kg		Lamellas with foam		19dB(A)		0	1	0
Solflex	SQV100NP		€ 7,999				0.00m³	1600	1600	3400	8.70m³	8.70m³	520kg		Lamellas with foam		25dB(A)		0	1	0
Kellner	KVS100 (Solflex KVS100)						0.00m³	1871	1461	2350	6.42m³	6.42m³	600kg		Lamellas with foam		17dB(A)		0	1	0
Kellner	KHS100 (Solflex KHS050)						0.00m³	1075	1166	1129	1.42m³	1.42m³	200kg		Lamellas with foam		15dB(A)		0	1	0
Solflex	HC100NPSA		€ 1,599	1000	450	950	0.43m³	1210	910	1080	1.19m³	0.76m³	130kg		Lamellas with foam		10dB(A)		1	0	1

Notes	Notes image
Openable door in sides	
buy back system, easily removable roof	
It's one type of product, but can be configured on-site for different airflow	
openable doors, able to set in sequence	
openable doors, able to set in sequence	

Appendix 4 - Program of Requirements and Wishes

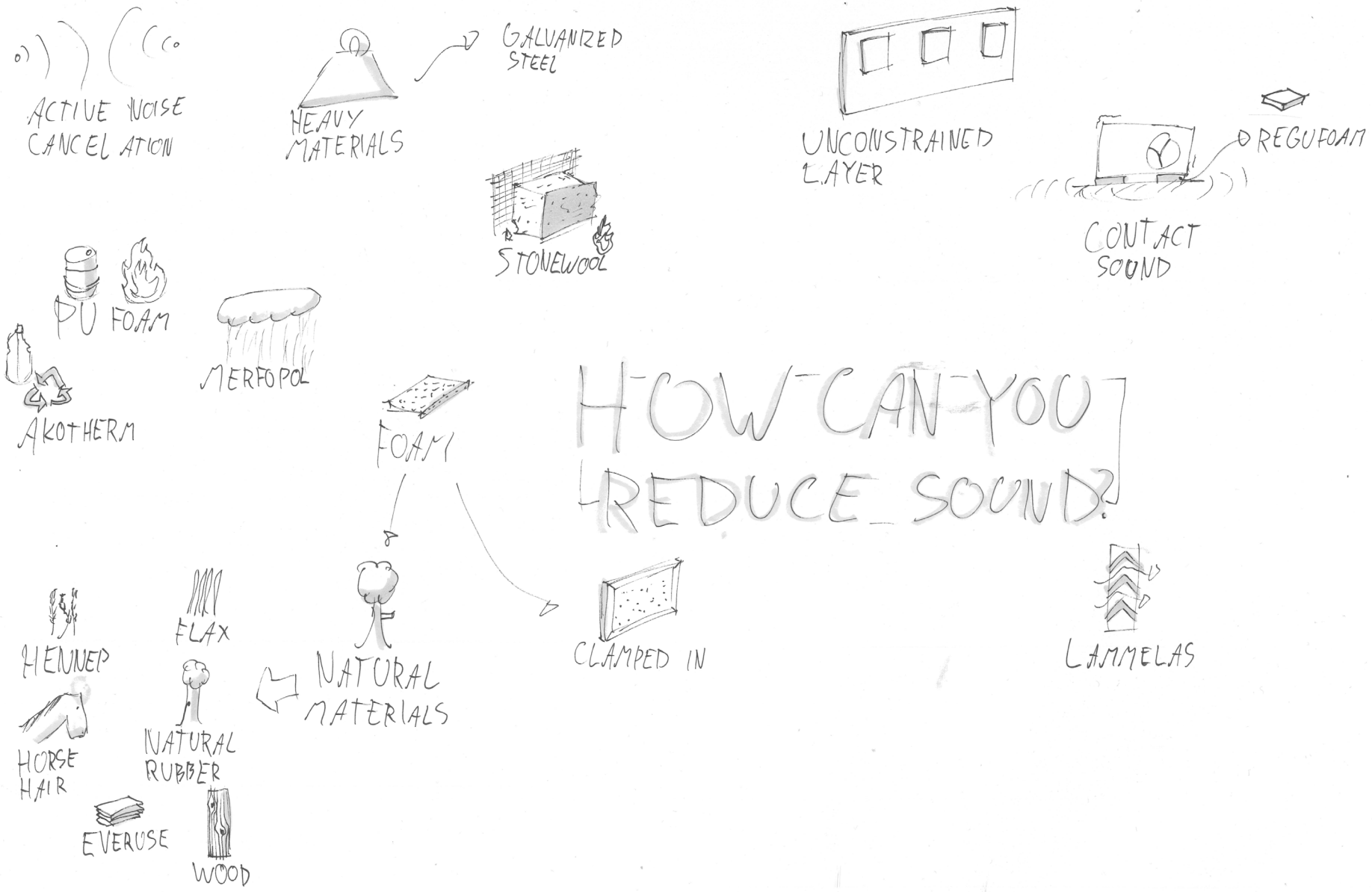
Requirements

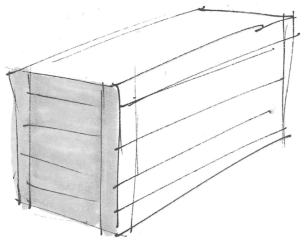
1. Reduce the sound of heat pumps by at least 10 dB(A)
2. Possible to use for stand alone and stood against wall
3. CtO possible for large orders, changing dimensions, design details and amount of sound reduced
4. Use recycled or bio-based foam to dampen sound
5. Use materials that are currently widely available
6. Possible to access the heat pump for maintenance/repair
7. In packed form, fit on a standard euro-size pallet
8. Water can not collect on top of the cover
9. Water can not collect inside of the cover
10. Fits all heat pumps of 'Heat pump product research'
11. Assembly within 2 hours by 1 person
12. €1500 maximum price for consumers (smallest size)
13. Maximum weight of 100kg
14. Allows heat pump to operate at at least 97% efficiency compared to no cover
15. Resistant to wind of up to 145 km/h
16. Resistant to temperatures of -25C to 45C
17. Lifetime of at least 10 years
18. Sun-proof
19. Conform to EU-regulations

Wishes

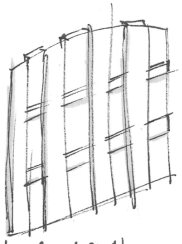
1. As quick to assemble as possible
2. Reduce the sound as much as possible
3. As good of a fit to the moodboard as possible
4. As many bio based materials as possible
5. As long of a lifetime as possible
6. As easy to repair as possible
7. As quick of a time to market as possible
8. As low of a carbon footprint as possible
9. As low cost as possible
10. As many recycled materials as possible
11. As small as possible (outside dimensions)
12. As light as possible

Appendix 5 - Sketches

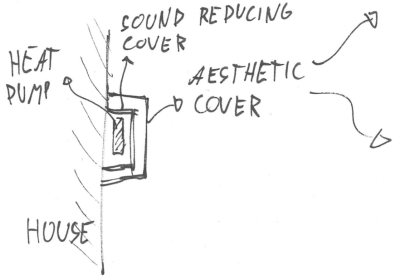


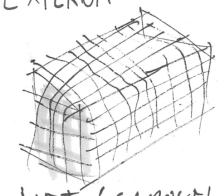


DISGUISE AS STORAGE BOX



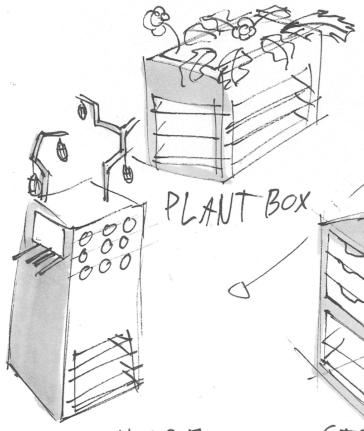
WOODEN EXTERIOR





NET (CAMOUFLAGE)

HOW CAN YOU BLEND IN TO THE ENVIRONMENT?

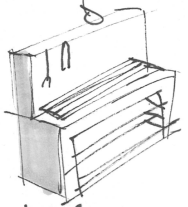


PLANT BOX

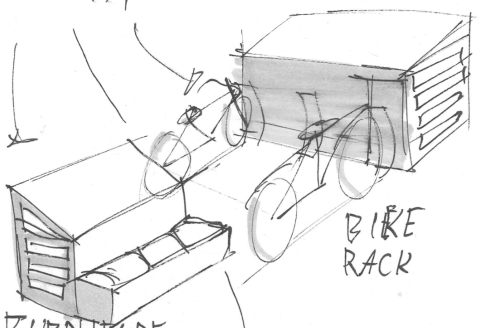
BIRD HOUSE

STORAGE

ADD FUNCTIONALITY

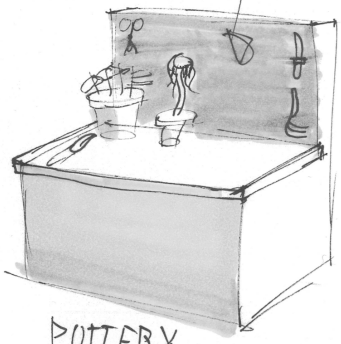


BBQ

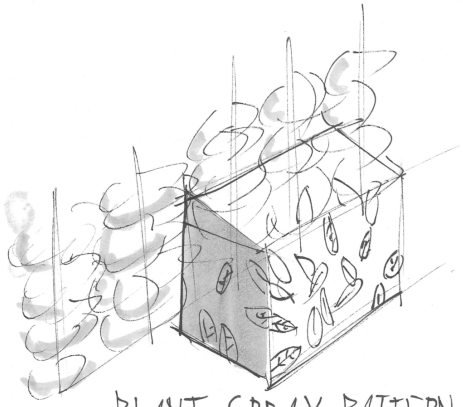


FURNITURE

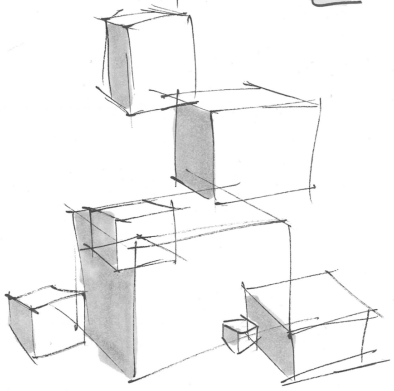
BIKE RACK



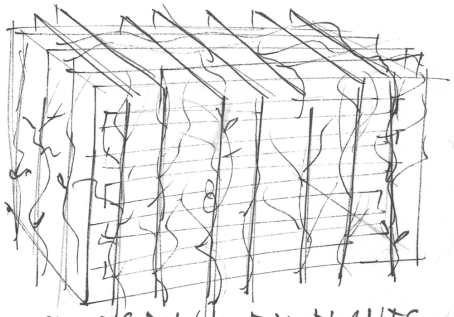
POTTERY TABLE



PLANT SPRAY PATTERN /DECALS



MAKE IT AN ART PIECE



OVERGROWN BY PLANTS

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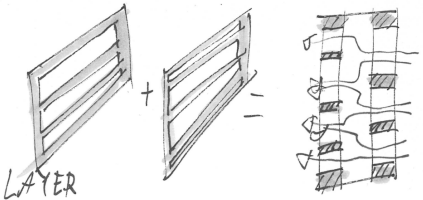
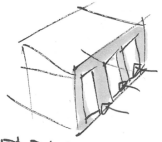
Swon

HOW CAN YOU EASILY ASSEMBLE



2 LAYER FRONT

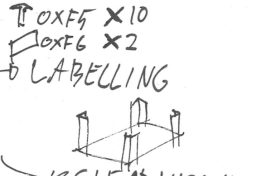
AVOID INDIVIDUAL LAMELLAS



VERTICAL AROUND THE CORNER

QR CODE TO VIDEO

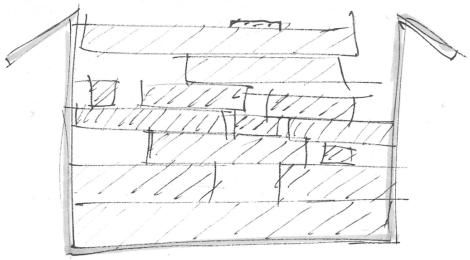
GOOD INSTRUCTION MANUAL



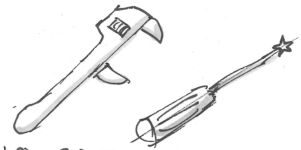
LABELLING

CLEAR VISUALS

TRANSLATIONS

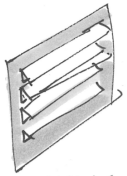


PROPER ORDERING IN PACKAGE (STUFF YOU NEED FIRST ON TOP)

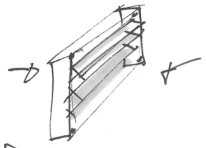


NO SPECIFIC WEIRD TOOLS REQUIRED

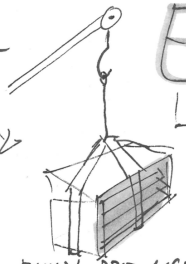
↳ MUST BE POSSIBLE WITH BASIC INSTALLER TOOLKITS



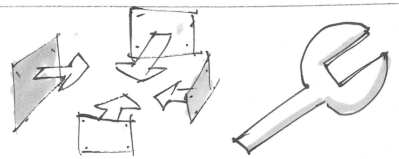
SINGLE PART FRONT



PRE-ASSEMBLE PARTS

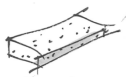


FULLY PRE-ASSEMBLE



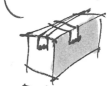
REDUCE PARTS COUNT

LIGHT-WEIGHT

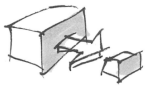


FOAM

METAL



PACKAGE

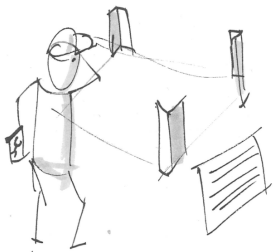


SMALL SIZE

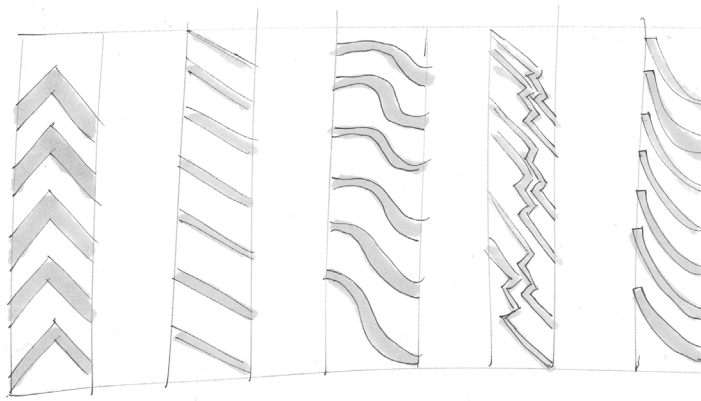
CHANGE FASTENING METHOD

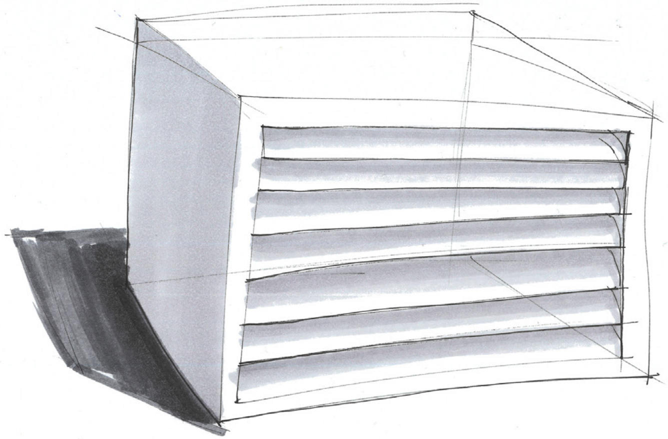
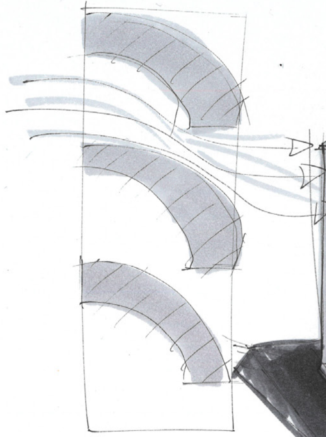
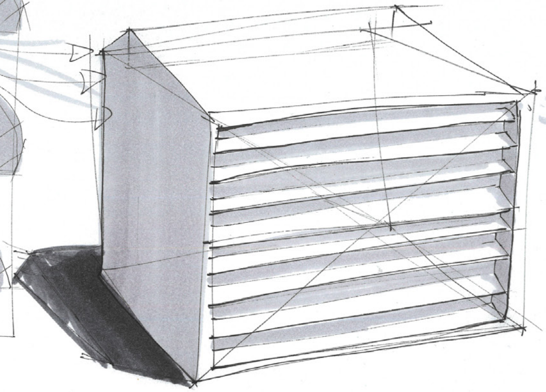
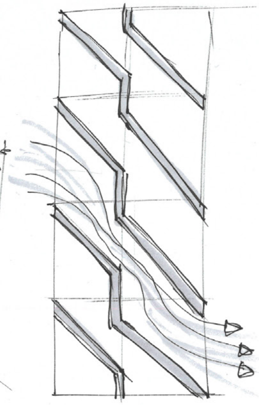
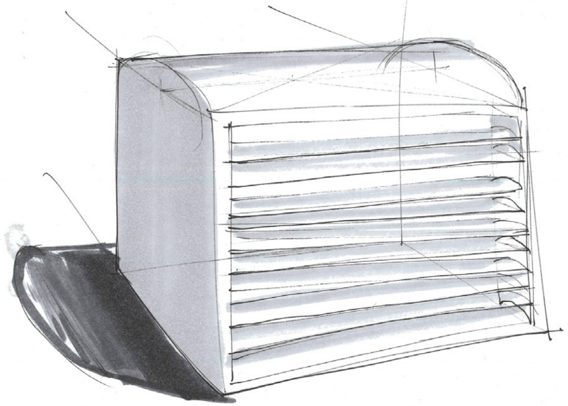
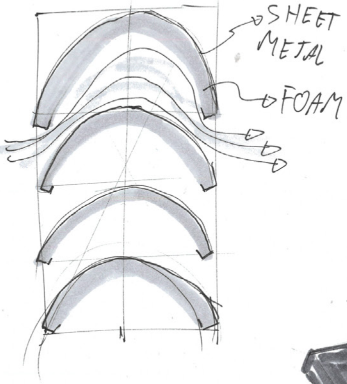
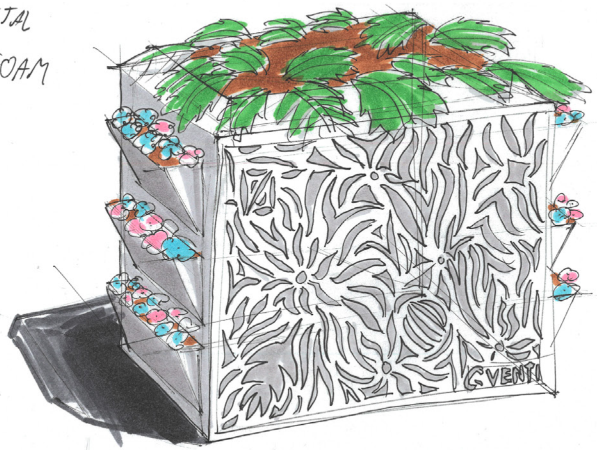
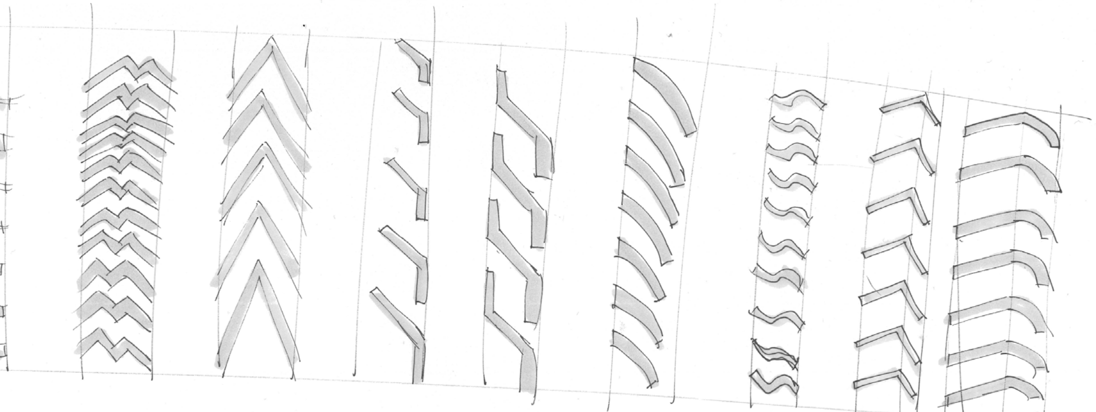
CLICK/CLAMP IN PLACE

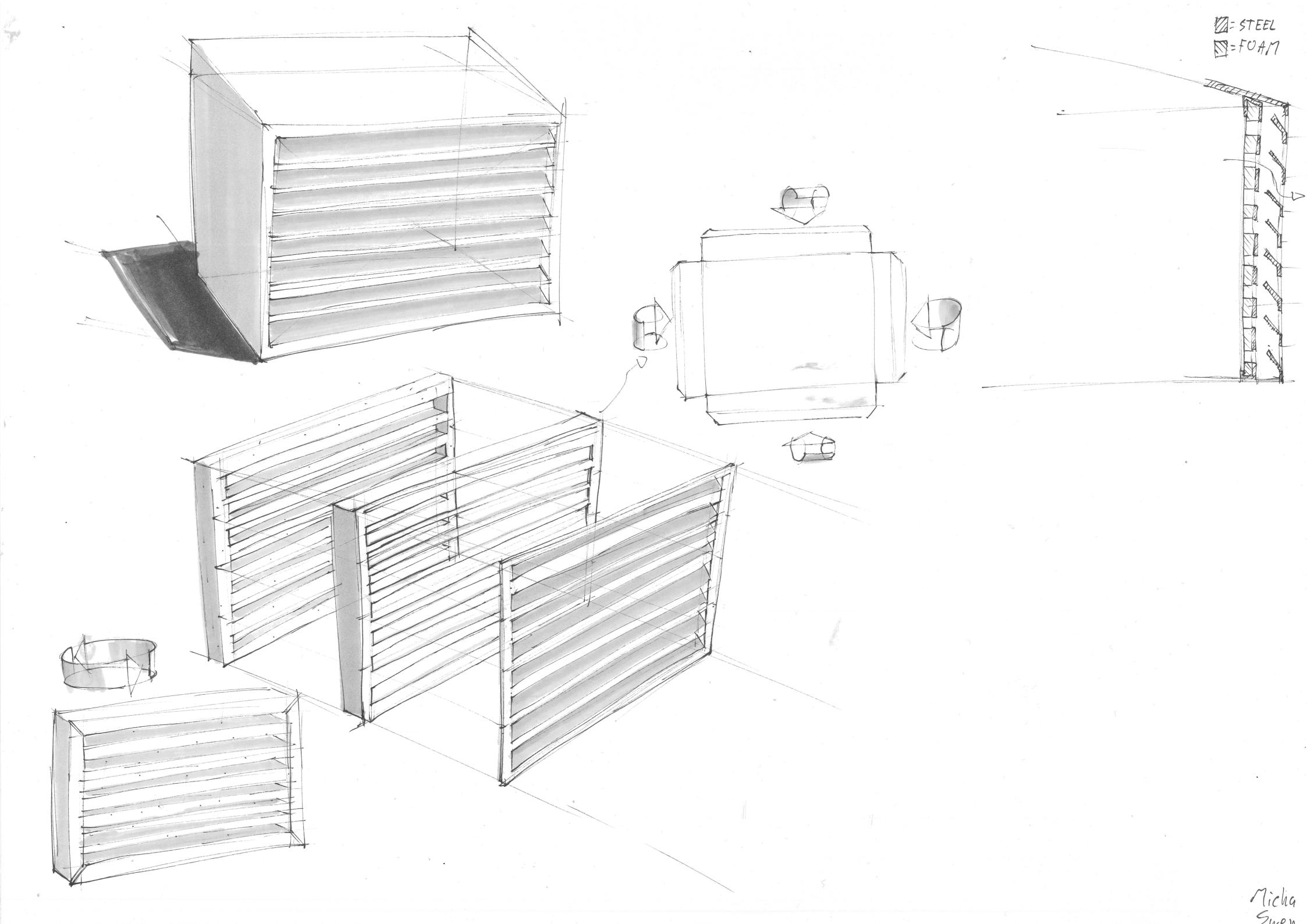
MAGNETS



TEST WITH INSTALLERS DURING DEVELOPMENT









SHEET METAL
FOAM

GVENTI




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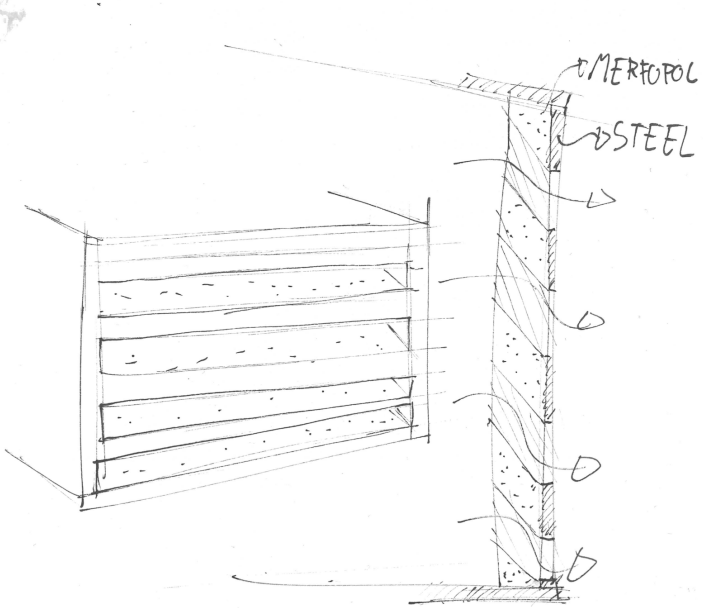
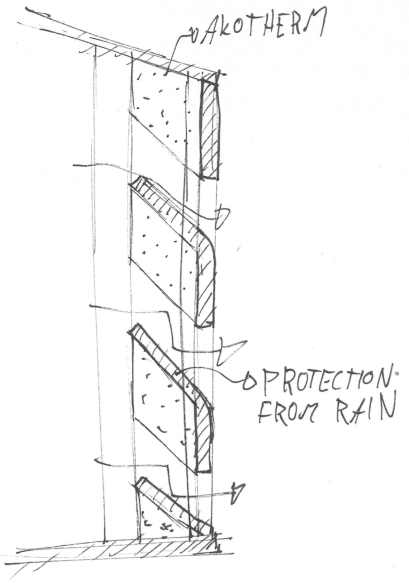
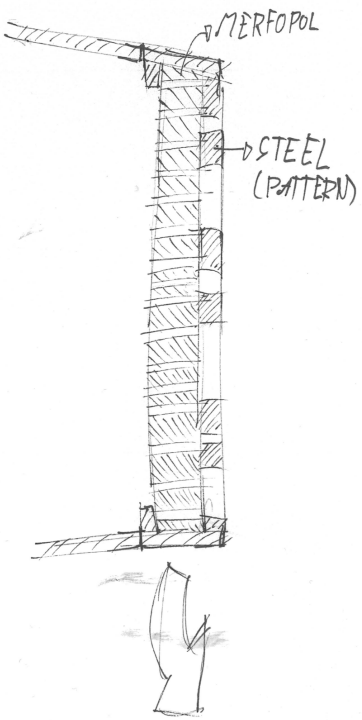
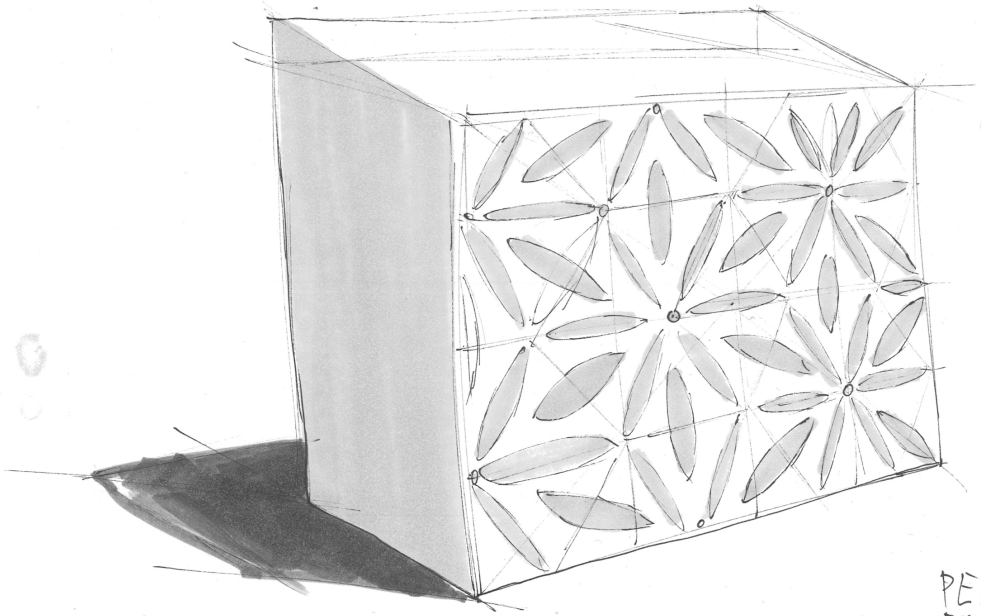
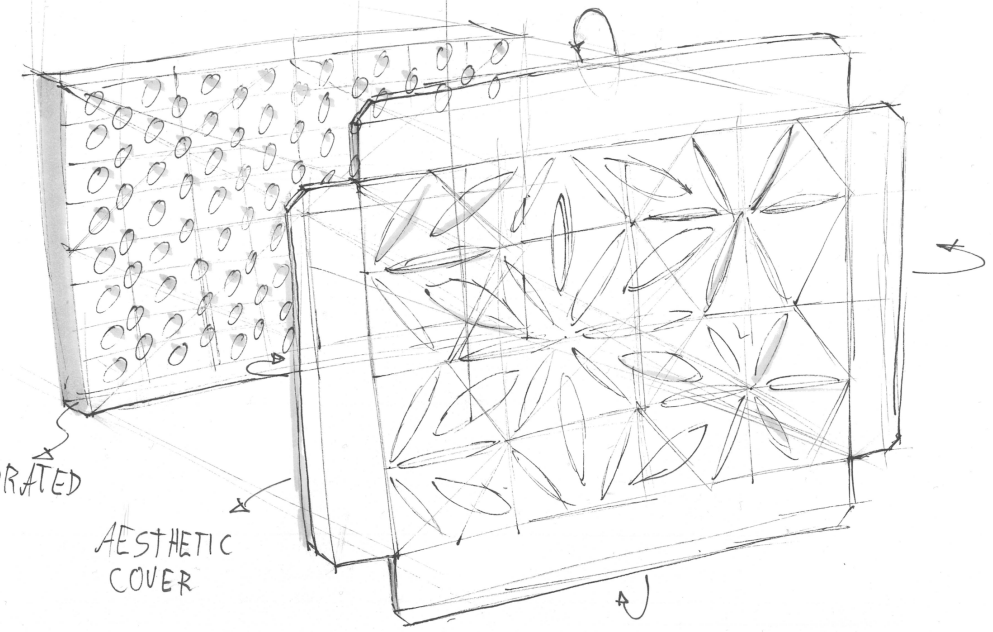
Swen

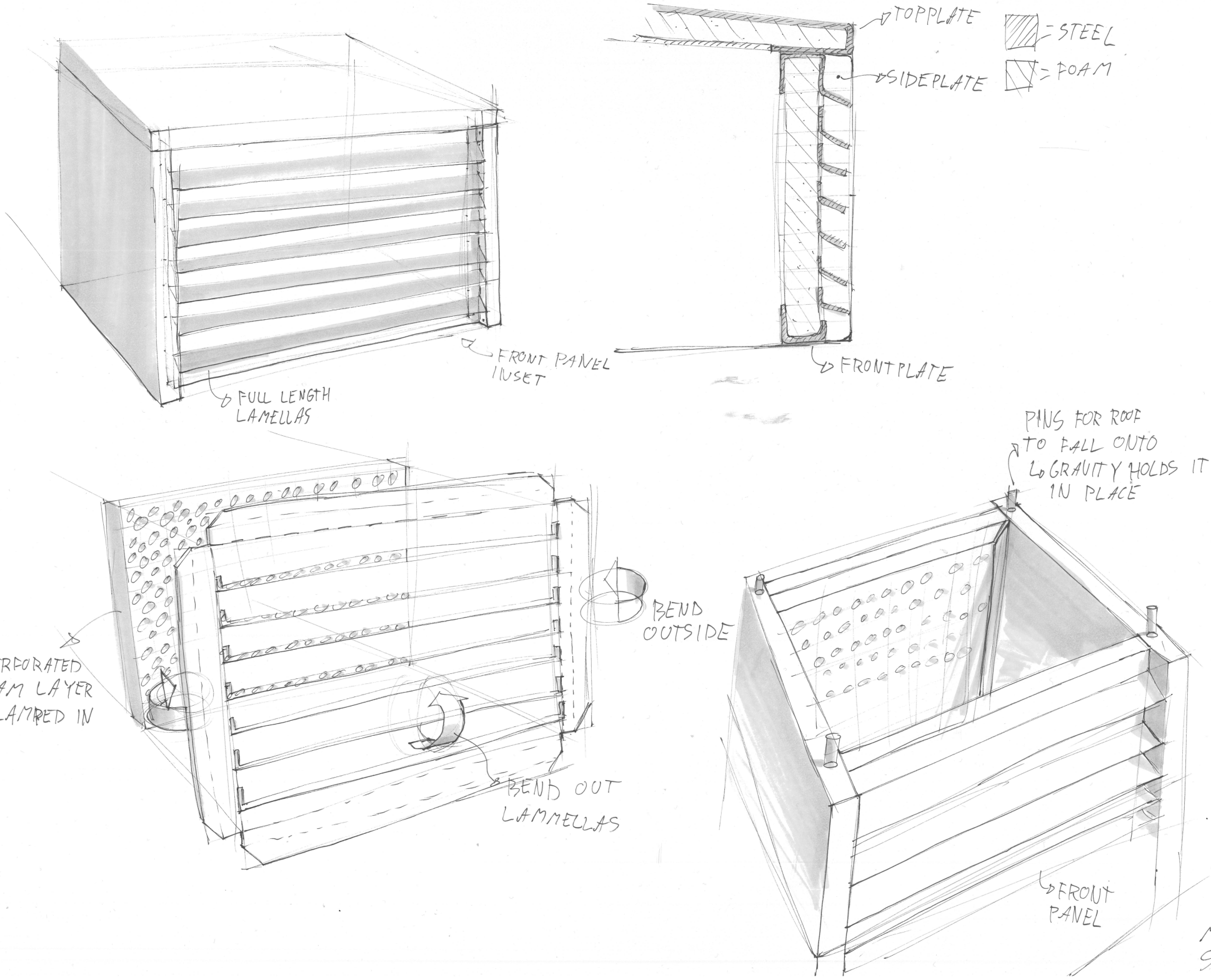

MERFOPOL
STEEL


AKOTHERM
PROTECTION FROM RAIN

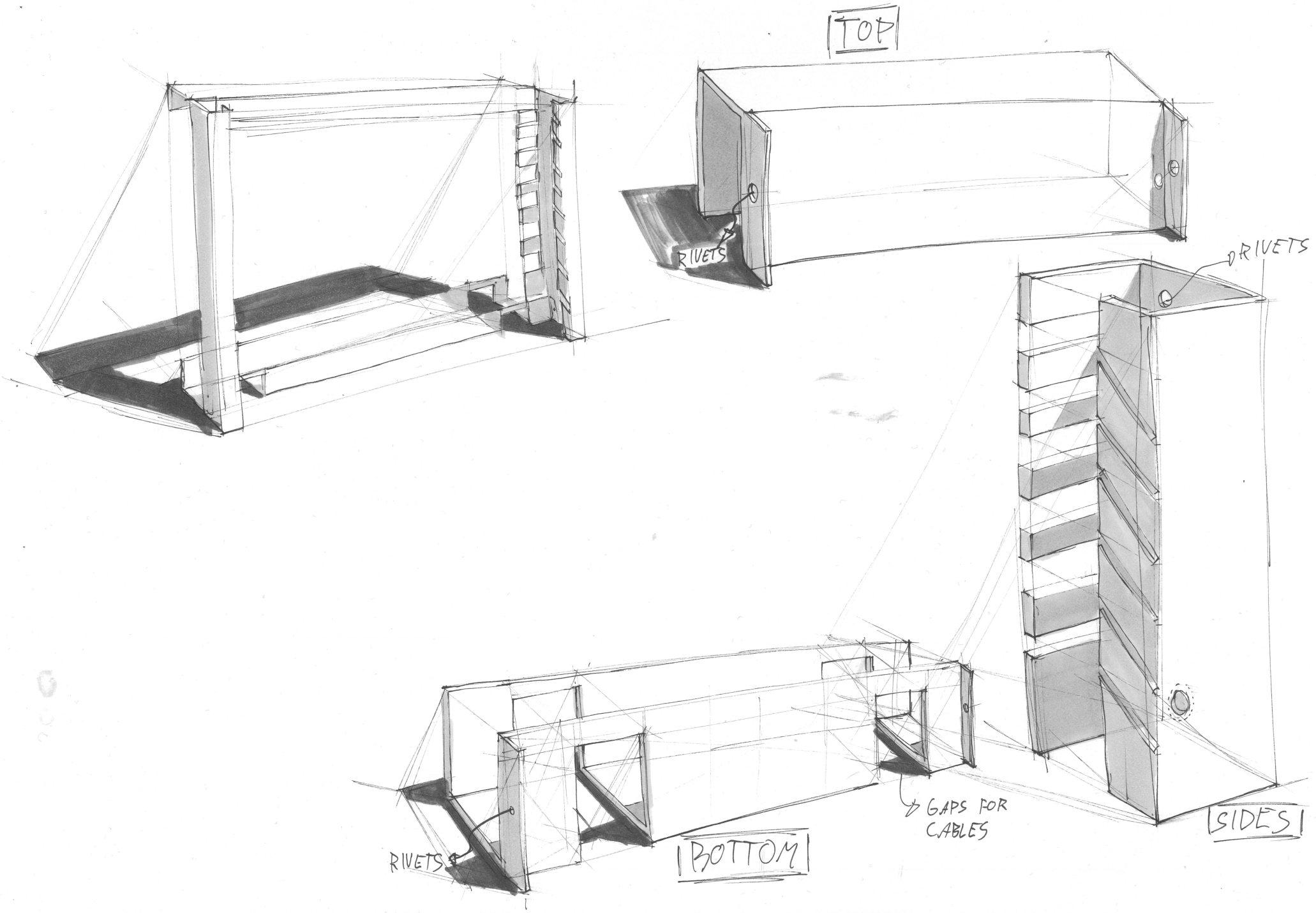

MERFOPOL
STEEL (PATTERN)




PERFORATED FOAM
AESTHETIC COVER


TOPPLATE
SIDEPLATE
= STEEL
= FOAM
FRONT PANEL INSET
FULL LENGTH LAMELLAS
FRONTPLATE
PINS FOR ROOF TO FALL ONTO
GRAVITY HOLDS IT IN PLACE
PERFORATED FOAM LAYER CLAMPED IN
BEND OUTSIDE
BEND OUT LAMMELLAS
FRONT PANEL

Micha Sven



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Swen

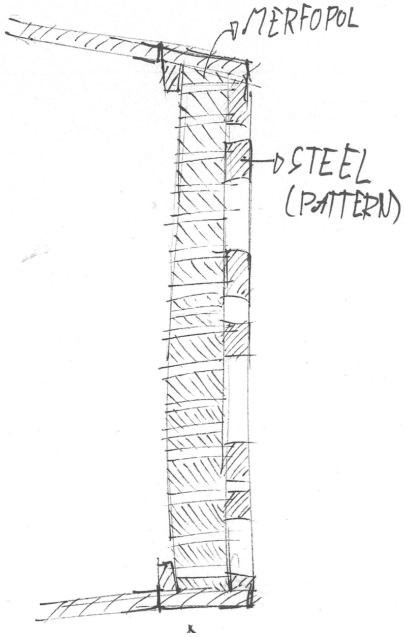
Appendix 6 - Embodiment Iterations

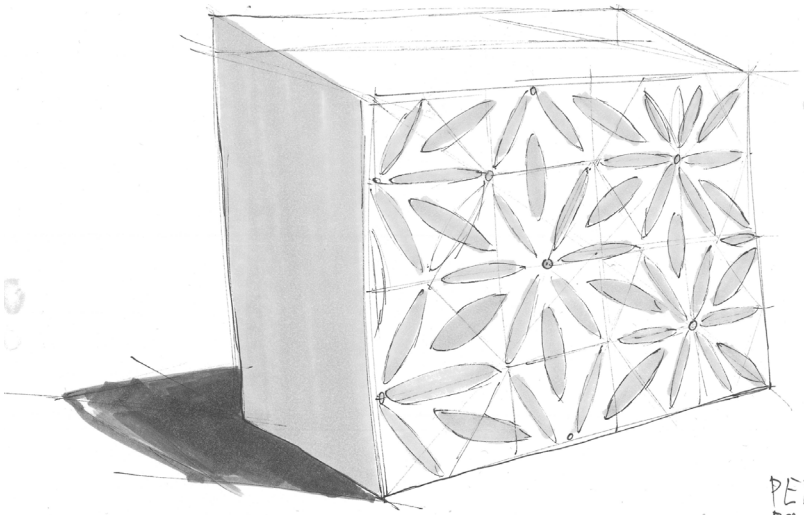
Iteration 1: One sheet frontpanel

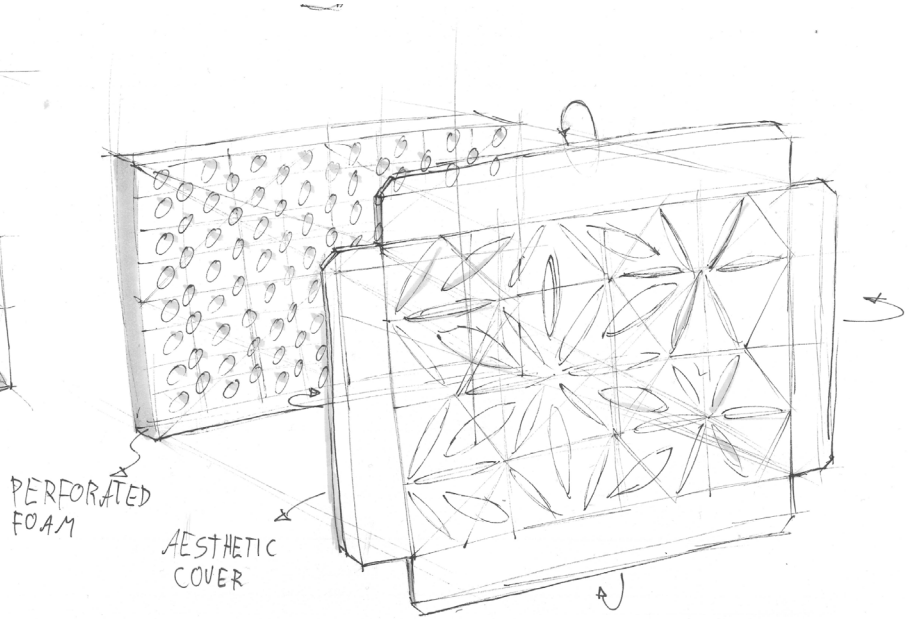
A frontpanel made up from one sheet of metal with a perforated foam layer clamped in. The metal has cut out slits for airflow.

+ A lot of aesthetic freedom
+ Low cost

- If the slits are wide enough for the airflow, the foam will be visible.
- Can not bend potential lamellas inward.





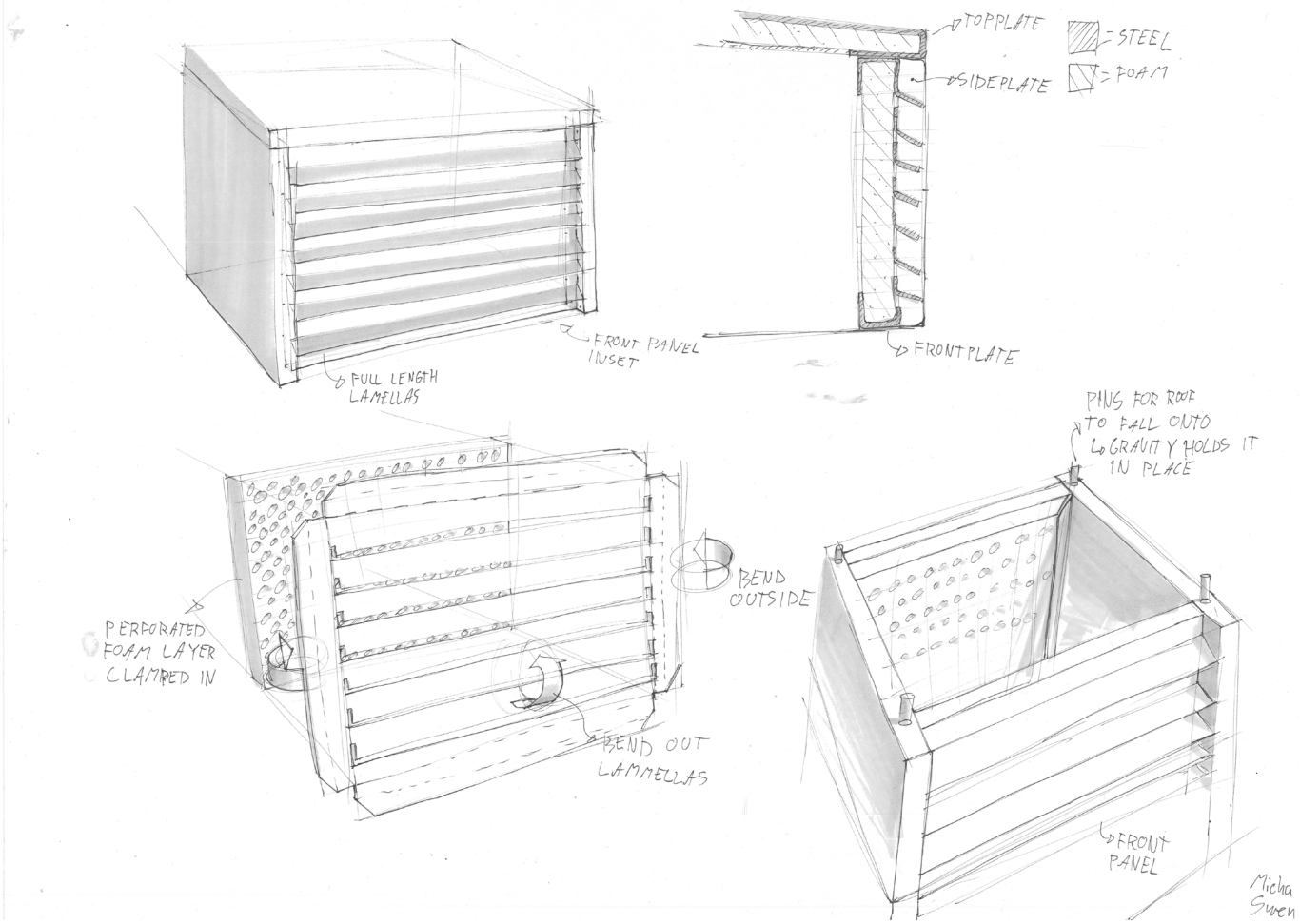


Iteration 2: Inset front

The frontpanel is slightly inset backwards. This means the lamellas can bend outwards without breaking up the flush aesthetic of the front.

+ Foam is concealed
+ Inset front creates flush front side

- Making the panel out of one part turned out to be very expensive and not flexible. This method of manufacturing panels is more suited for small aluminium parts that are mass produced and always have the same size.

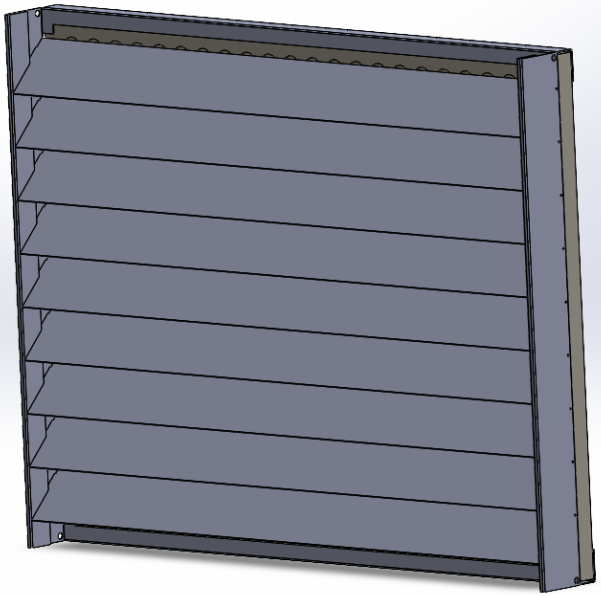


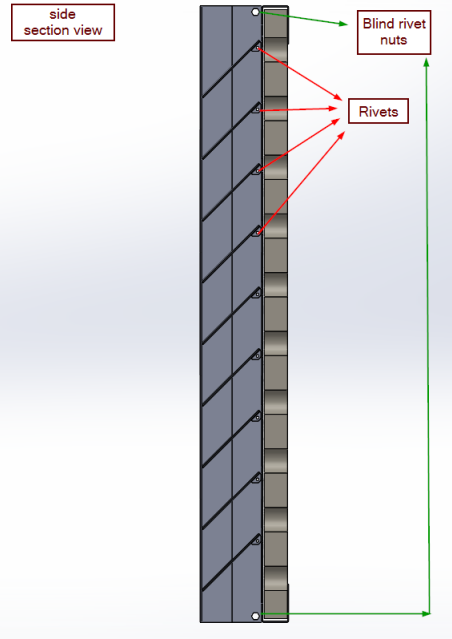
Iteration 3: Individual lamellas

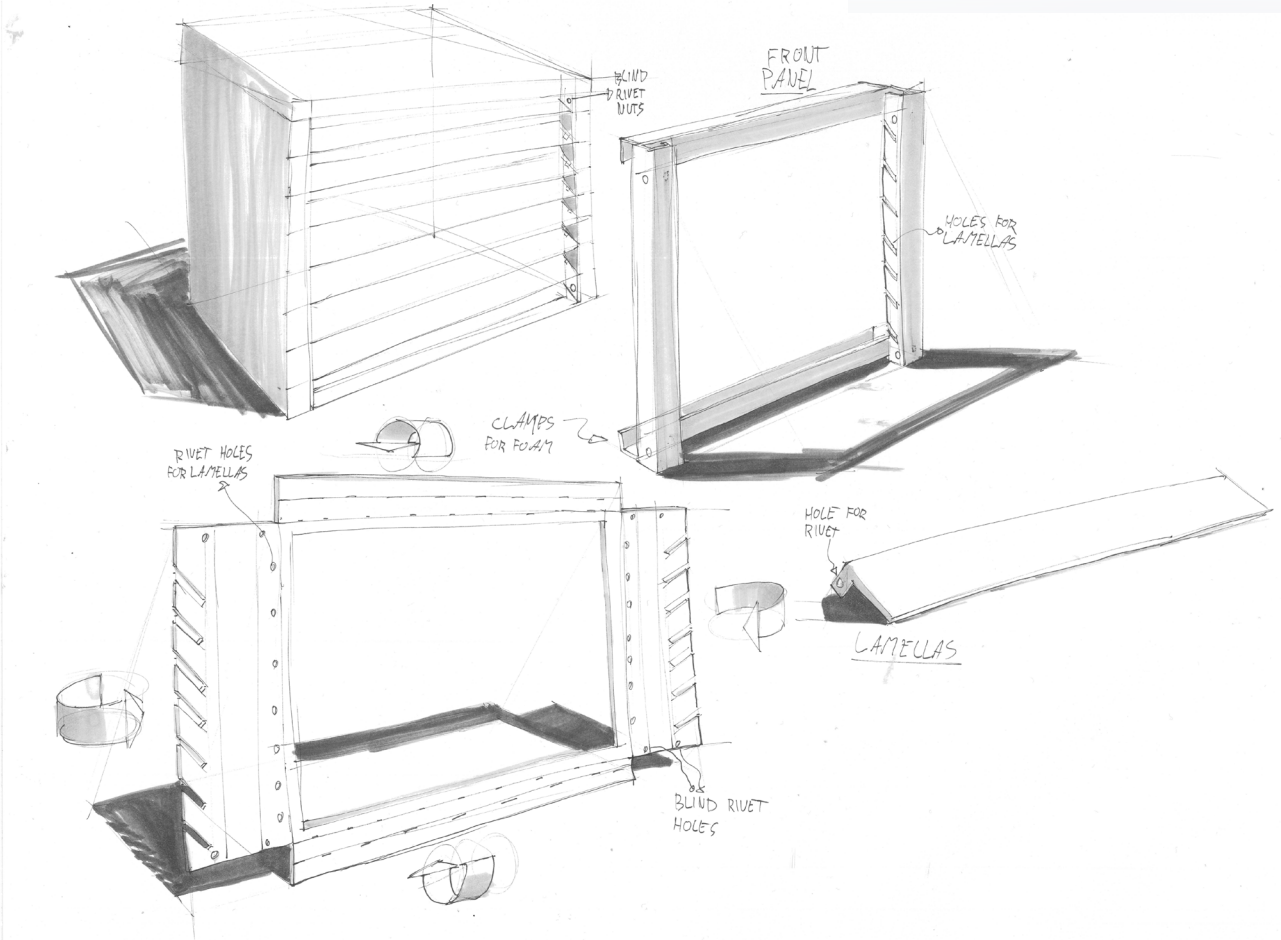
The lamellas are now made individually and then riveted to the main frame.

+ Better suited manufacturing method
+ Better for flexible sizing
+ More low cost

- Making the outer layer of the front part from one sheet introduces a lot of waste material, as the cut-out square in the middle can not be re-used for any other part of the design







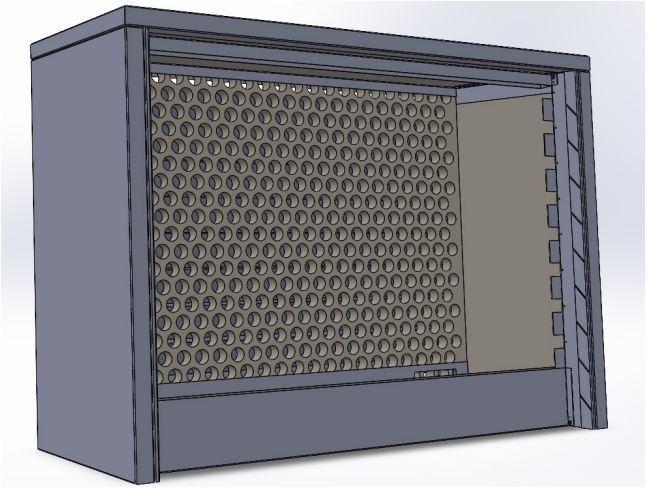
Iteration 4: Four-part frontpanel

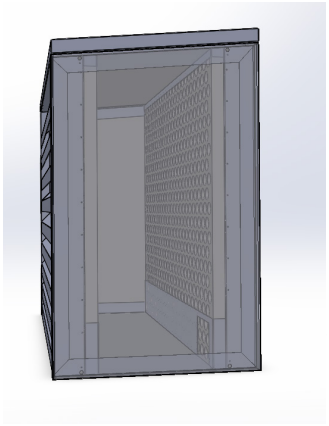
The frontpanel consists of four frame parts which are riveted together. This iteration also introduced the cable slots: There is a cut-out in the back frame. This allows the user to cut the foam from the bottom to allow space for the cables of the heat pump to go through. This means the user can place the cover without disconnecting the heat pump.

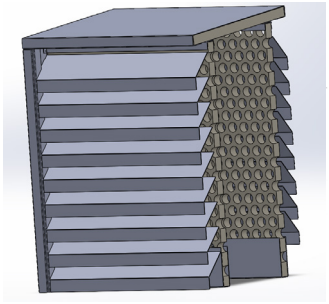
This iteration also introduced a vertical flange on the end of the lamellas. This covers the foam better visually, helps with sound reduction and improves the aesthetics of the front panel, as it is more flush as a whole. Furthermore, this makes the design fit better in the Qventi style, as it makes it more similar to the existing aesthetic covers.

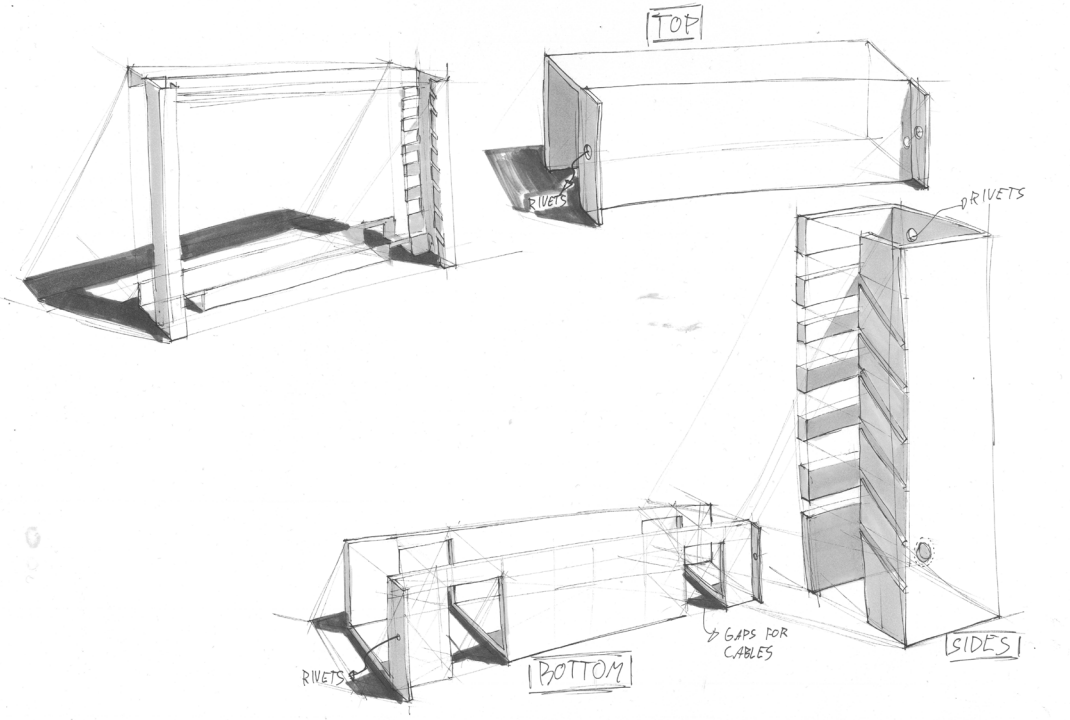
Finally, this iteration introduced the usage of blind rivet nuts, allowing for an easy installation by the end user, as they now only have to screw in a total of eight bolts.

+ Less material waste
+ Easier assembly with blind rivet nuts
+ Don't have to disconnect heat pump for installation anymore
+ More flush aesthetics







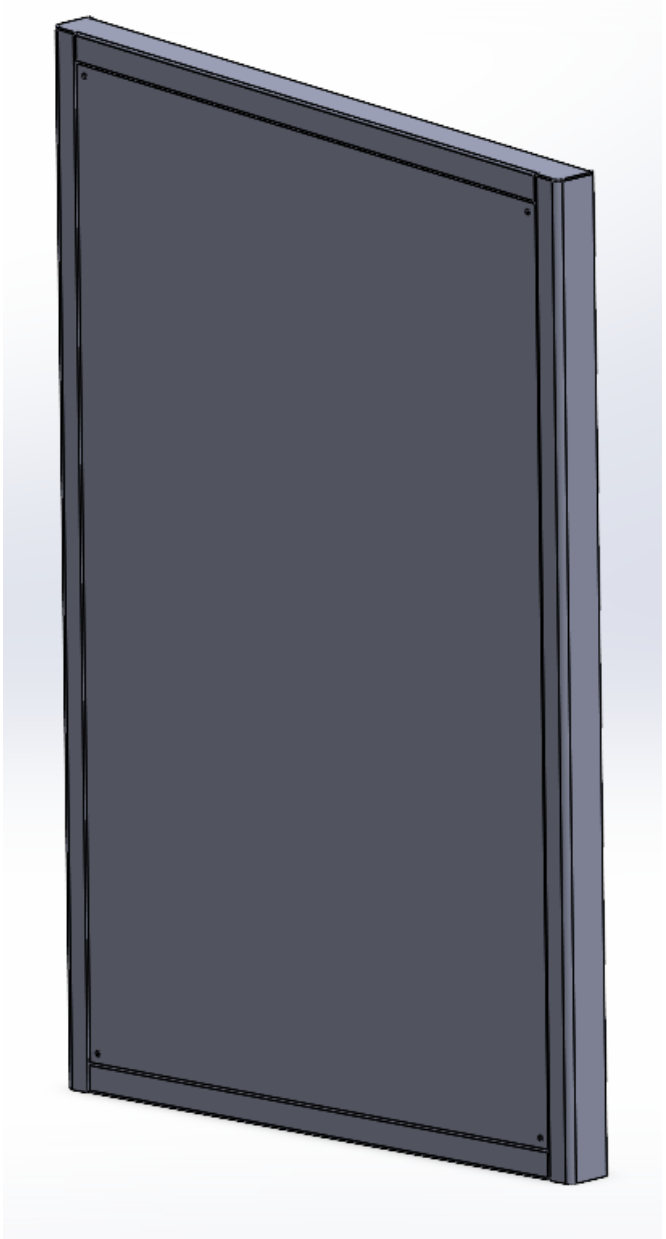


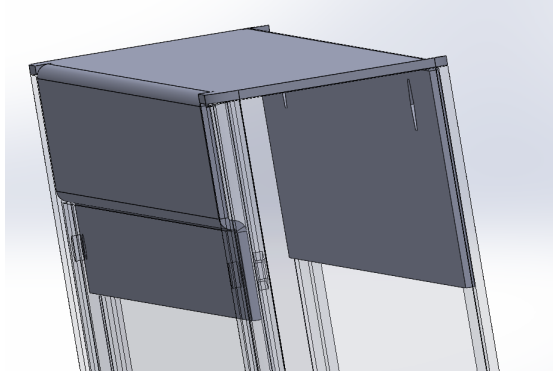
Iteration 5: Four-part side doors

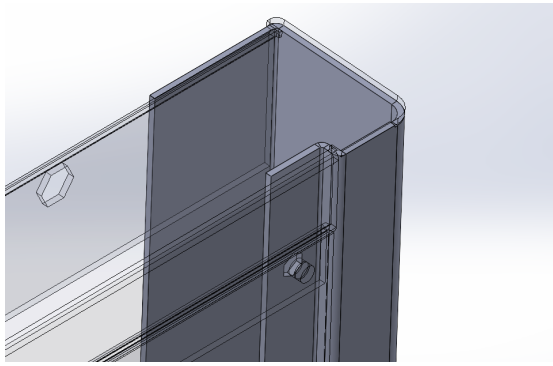
The sidepanels now have an integrated door. The frame consists of four parts which have a jog inwards. This ensures the door stays flush with the panel. The door has four bolts which are attached with blind rivet nuts. After removing the door the user can pull out the foam and access the heat pump for maintenance.

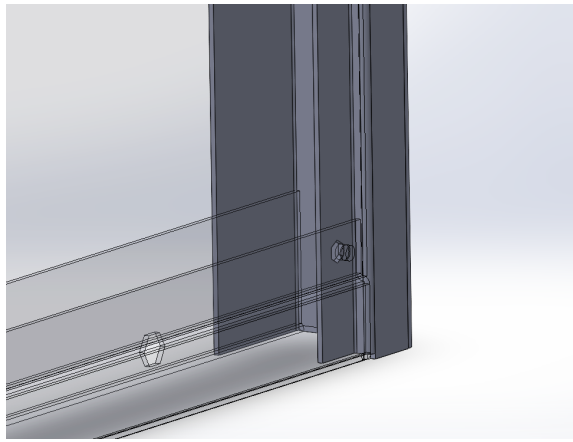
+ Access for maintenance
+ Flush door is aesthetically sound
+ Little material waste

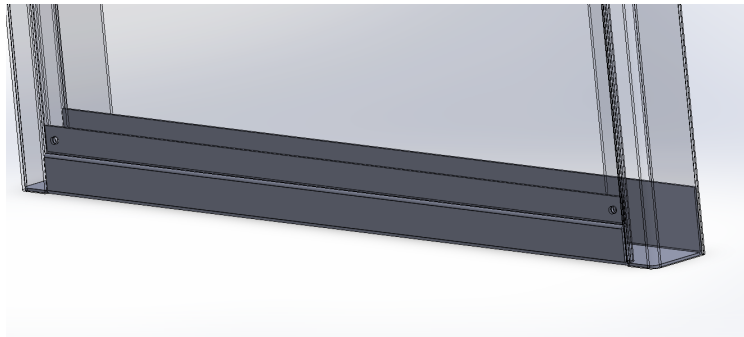
- This design is extremely expensive, as many bending- and fastening operations are needed









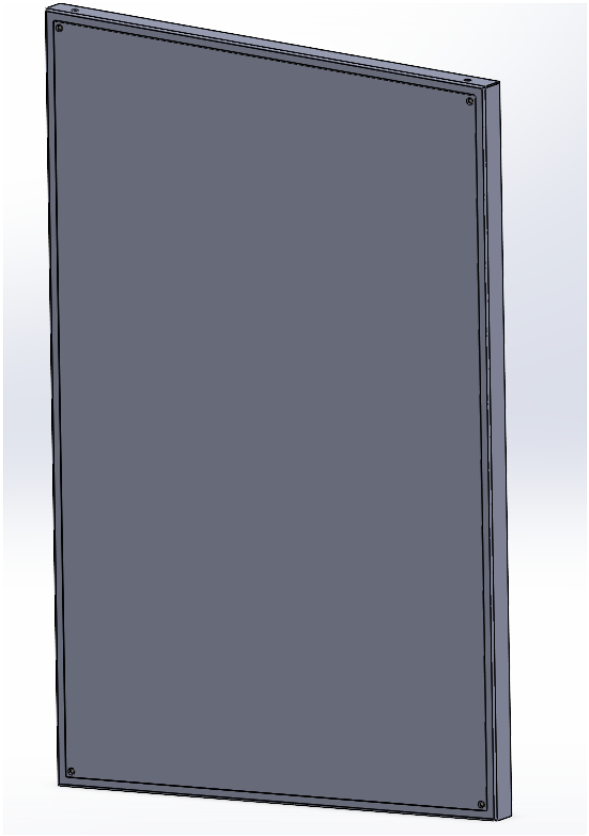


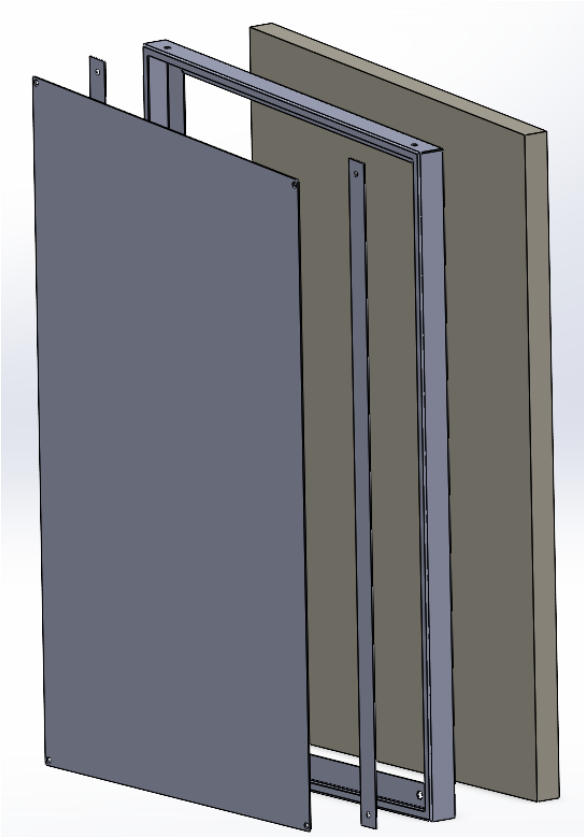
Iteration 6: Simple side doors

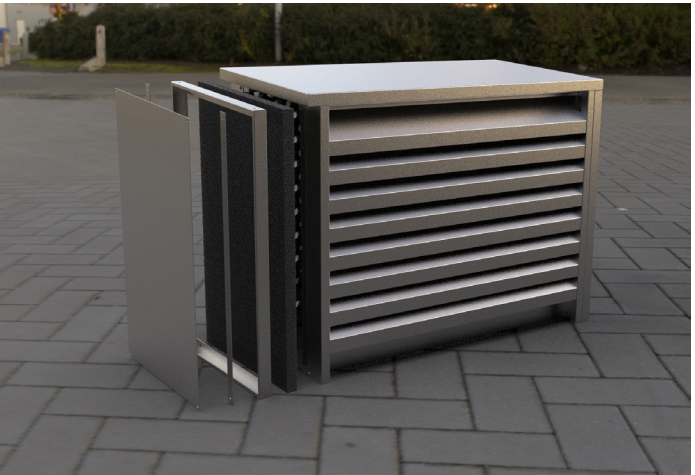
The main frame is once again made from one part. The door is now cut out from the middle. Two metal strips are placed inside of the frame for the door to rest against.

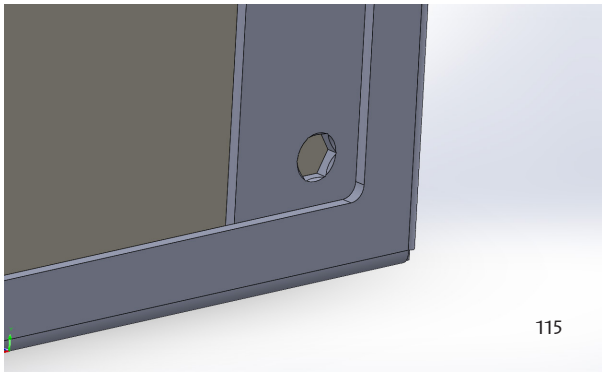
This iteration also split the bottom of the back frame into two, as this allows more flexibility for cable management and it is easier to manufacture with less waste.

+ Little material waste, as door is cut out from the frame
+ More low-cost, less bending operations





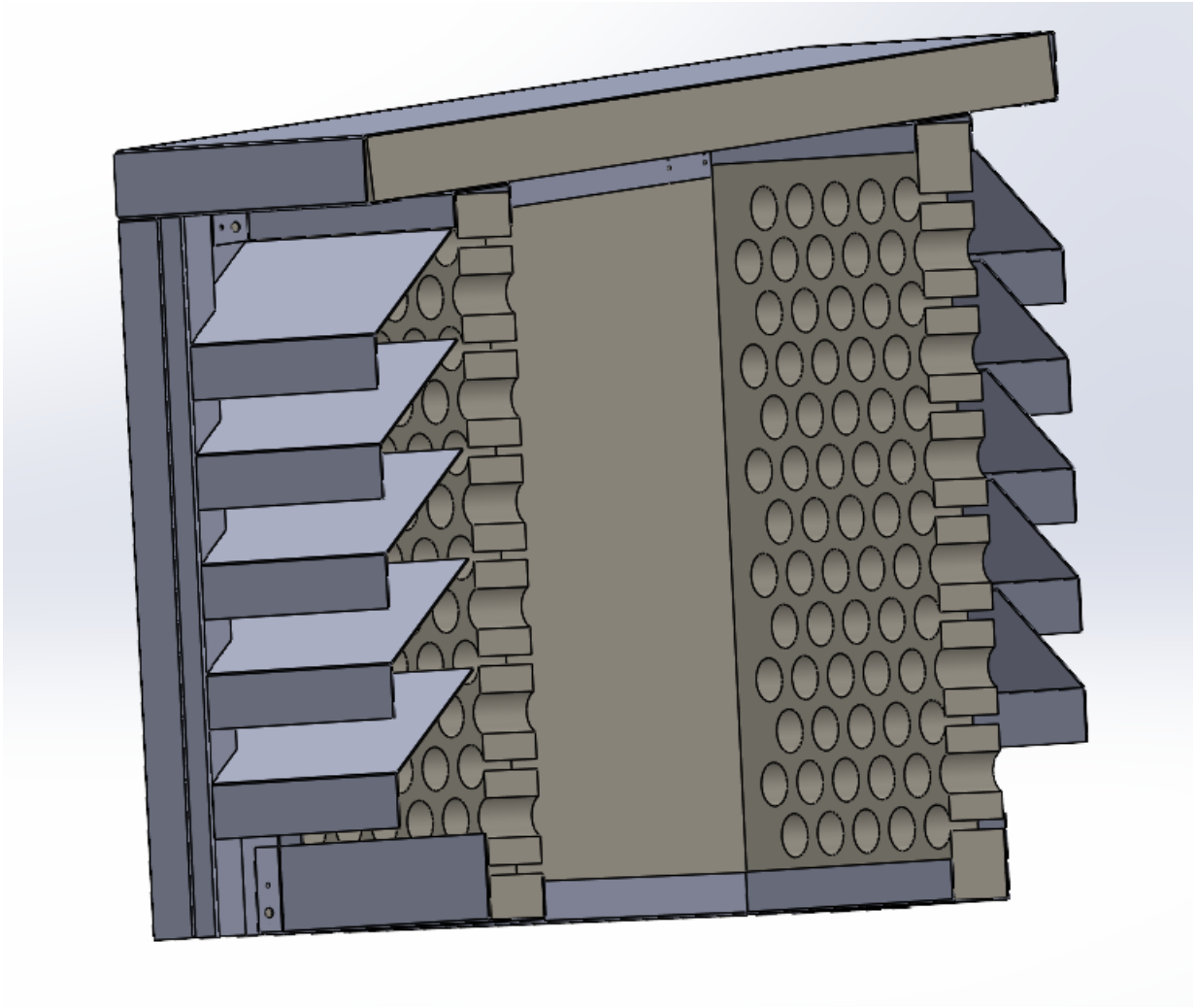




Iteration 7: Optimised sound reduction

Following a meeting with manufacturers and distributors of foam, the ideal type and thickness of foam were selected. The ideal thickness was determined to be 60mm. The thickness of the sheet metal was also changed to be 1.5mm (from 2mm), as weight-wise the 2mm would not yield a significant increase in sound reduction.

+ Better sound reduction



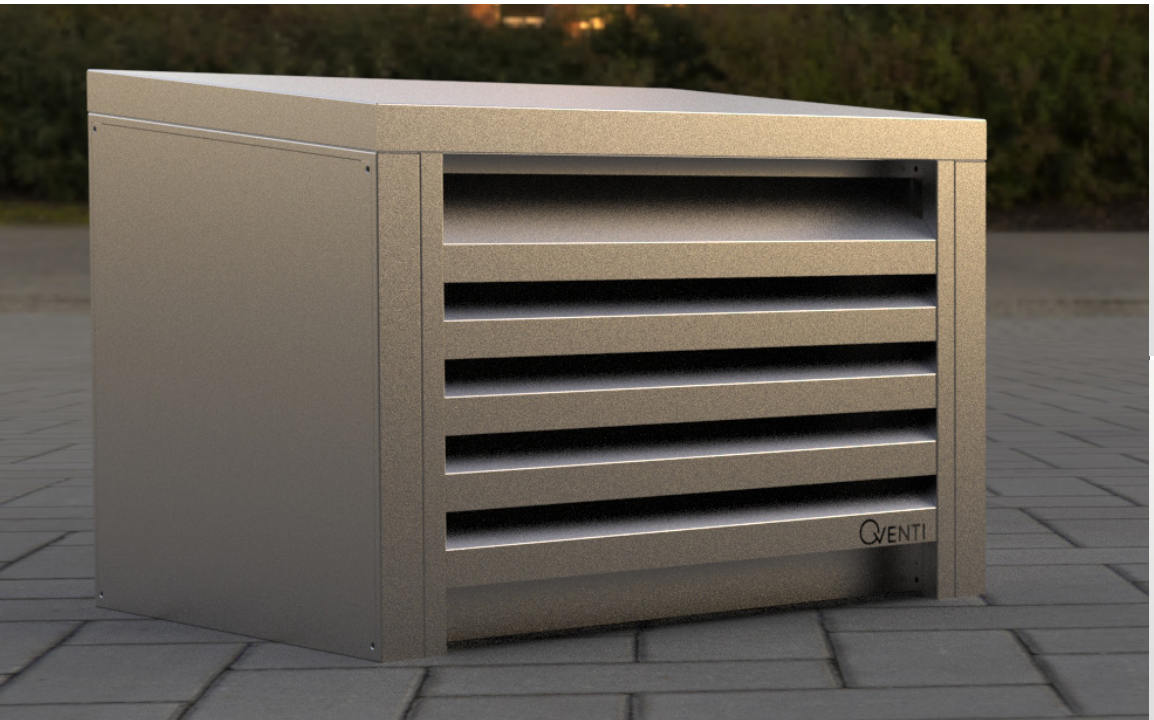
Iteration 8: Even better connections

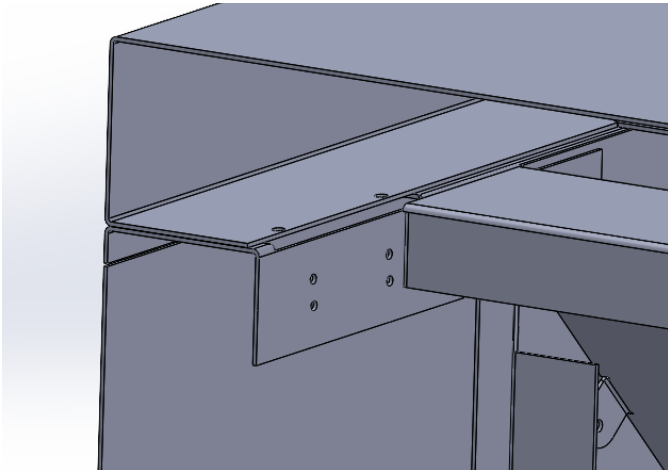
Holes for blind rivet nuts were changed to be pentagonal (from hexagonal). This allows for the use of circular high torque blind rivet nuts. This increases the strength of the connection, gives better aesthetics at the connection point and allows for faster assembly, as the blind rivet nut does not need to be lined up with a hexagonal hole.

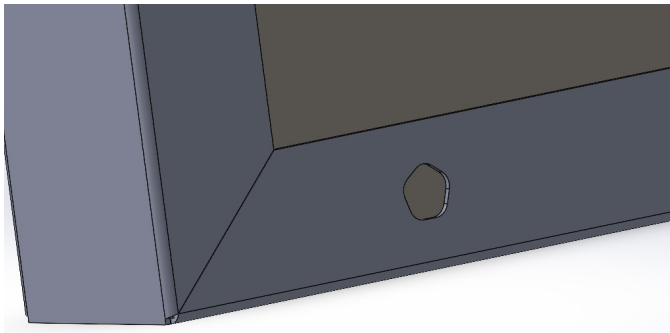
The roof no longer uses pins, but now has a hidden locking mechanism. This makes it easier to align and install the roof and ensures a flush connection between the parts.

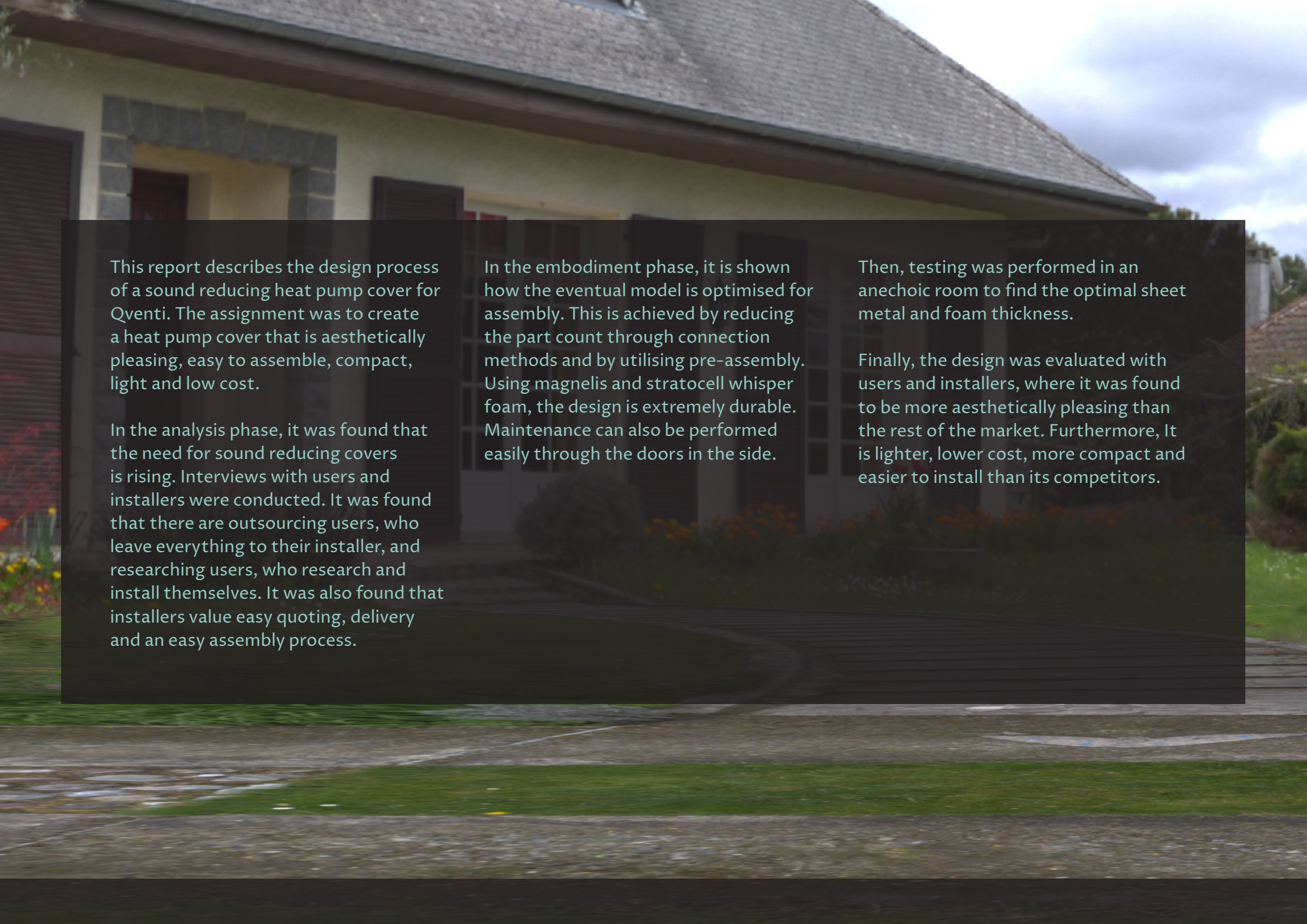
The bottom lamella now has a cut out logo. The branding of the new cover now fits Qventi's existing product language, as the existing aesthetic cover has their logo displayed in a similar way.

+ Easier pre-assembly
+ More strength of connections
+ Easier roof installation (hidden locking mechanism)
+ Consistent branding with logo









This report describes the design process of a sound reducing heat pump cover for Qventi. The assignment was to create a heat pump cover that is aesthetically pleasing, easy to assemble, compact, light and low cost.

In the analysis phase, it was found that the need for sound reducing covers is rising. Interviews with users and installers were conducted. It was found that there are outsourcing users, who leave everything to their installer, and researching users, who research and install themselves. It was also found that installers value easy quoting, delivery and an easy assembly process.

In the embodiment phase, it is shown how the eventual model is optimised for assembly. This is achieved by reducing the part count through connection methods and by utilising pre-assembly. Using magnelis and stratocell whisper foam, the design is extremely durable. Maintenance can also be performed easily through the doors in the side.

Then, testing was performed in an anechoic room to find the optimal sheet metal and foam thickness.

Finally, the design was evaluated with users and installers, where it was found to be more aesthetically pleasing than the rest of the market. Furthermore, It is lighter, lower cost, more compact and easier to install than its competitors.