FEA analysis of the Tree Heat Pump

Joost Remmerswaal

TU Delft
Delft University of Technology

THUISBAAS

Table of Contents

What you can find in this report
and where to find it.

0.1 Introduction

A small introduction into this graduation project. Focussing on why heat pump design is needed.

A new heat pump

The amount of Heat pumps in the Netherlands is on the rise mainly because of the climate accords that hope to abolish the use of natural gas. [1] This project aims to improve upon the current design of Heat pumps to answer to this increased market. This is done in collaboration with ThuisBaas and more specifically Errico Garofalo who created the concept design The Tree.

Figure 1 : The tree concept

The original design

The concept created by Errico Garofalo, and inspired by the Dyson bladeless fans, focusses on creating a low pressure that creates an airflow into the heat pump using a turbine. The advantages of this are: a hidden turbine instead of an open fan blade, as wel as an incapsulated compressor. This in turn will allow the sound the heat pump makes to be more effectively dampened. Which is currently still one of the main stumbling blocks in current heat pump design. The aim of this report is therefore to examine if these techniques work in decreasing sound and increasing heat pump efficiency.

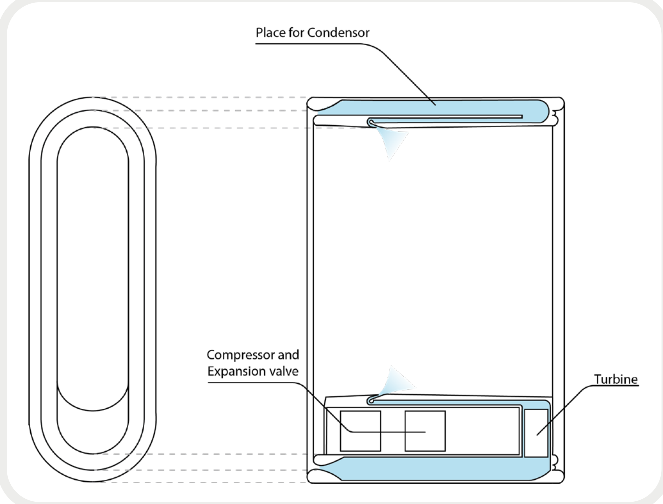


Figure 2 : The tree internal

0.2 Synopsis

How this report is structured and how the chapters fit together. Giving a brief overview of the full report.

Project setup

This project sets out to find proof of concept for the Tree heat pump design created by Errico Garofalo. It does so in several steps. First of all the functionality of heat pumps is described and explored. Secondly the two airflow effects the design makes use of (the venturi and coanda effects) are described and tested.

These effects are then implemented in a design which is in turn compared against a heat pump that is currently on the market. This comparison is done through the use of SolidWorks airflow simulation.

The created design is then tested on aesthetic value through the use of a user survey. It is compared in both an aesthetic vaccuum as well as in real world context. This whole process has resulted in the design shown on this page.

Figure 3 : Final design render

Chapter 1

Heat Pumps

This chapter is all about explaining the basic principles of heat pumps

1.1 What is a Heat Pump

Before we dive in to all of the intricacies of a heat pump this page shows the basic principles needed for them to work

The transfer of Energy

As the name implies a "heat pump" pumps heat from one place to another. It does this using basic principles of heat transfer. These principles are:

1. Anything above -273 C (0 K) has heat energy in it.
2. If two substances exchange heat, the colder of the two substances will absorb the heat from the warmer substance.

With these principles a heat pump can be created and explained. a heat pump works by creating an object that is either warmer or colder than the substance that you want to warm up or cool down. It does this using a refrigerant cycle. This cycle uses a refrigerant that usually changes phases in a heat pumps' system. Changing phase happens at two different places in the heat pump system as can be seen on the following page (Figure 4):

1. An expansion valve expands the refrigerant which lowers the refrigerants temperature
2. A compressor compresses the refrigerant which increases the refrigerants temperature.

But how and why?

To make a basic heat pump one additional part is needed, a heat sink. This heat sink can act as both a condensor and an evaporator. And two are needed to create a functioning heat pump (Figure 5). They are parts with high surface areas that allow the heat to flow from or to the substance we're trying to heat or cool. This is usually done using a metal grate with the refrigerant pipe flowing through it. (Figure 4) In a heat pump this part can function both as a condensor and an evaporator, depending on where the heat needs to flow. If the house needs to be cooled the heat sink inside the house will be made cooler than the air, and vice versa for heating the house.

Figure 4 : An Expansion valve, Compressor and Heat sink respectively

1.2 Schematic of a Heat Pump

How do the parts of the heat pump work together to create temperature changes?

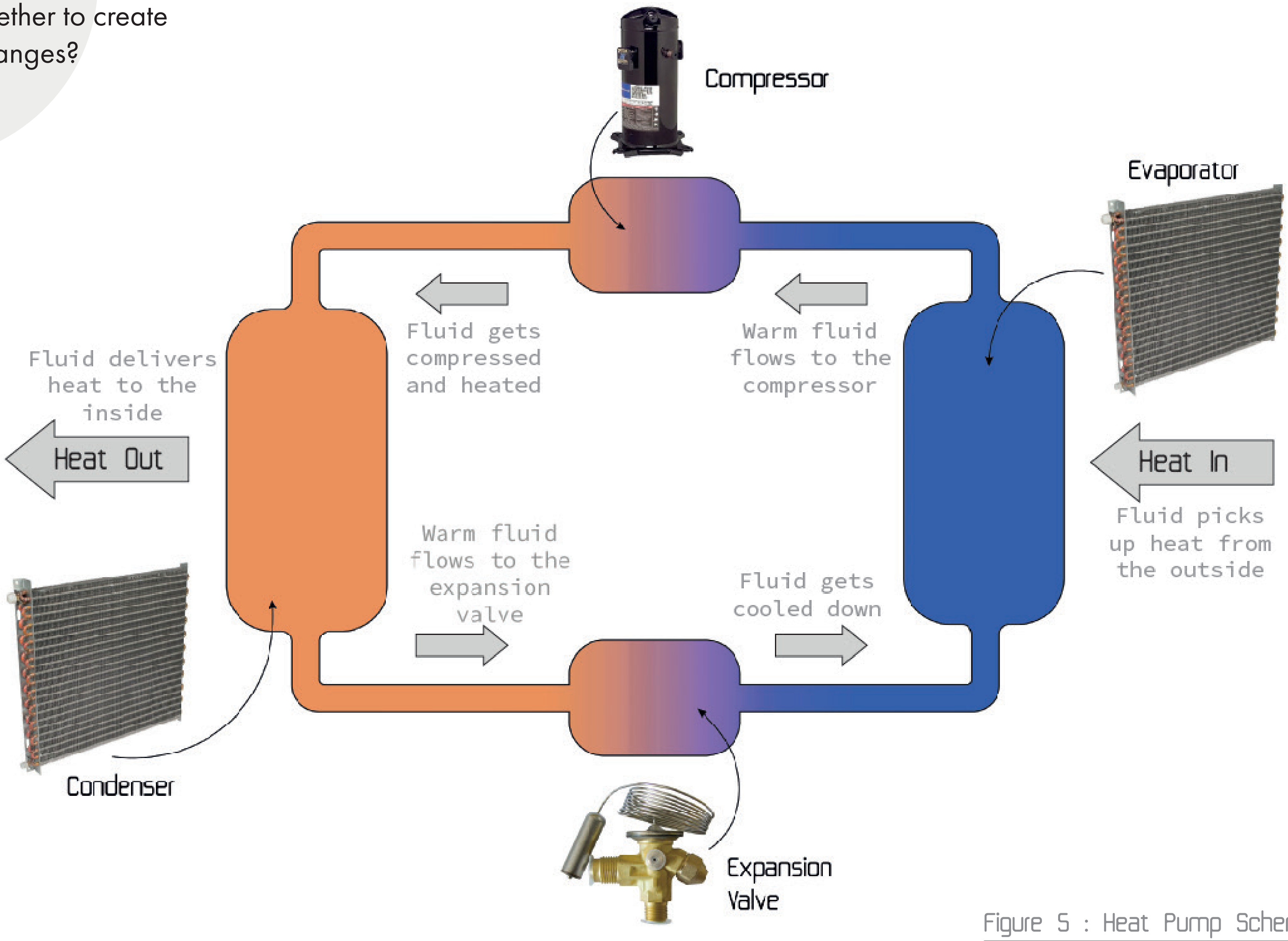


Figure 5 : Heat Pump Schematic

1.3 Air/Air Heat pumps

There are several kinds of heat pump on the market. The one used in this design is explained here.

What is it?

Air/Air heat pumps are, as the name implies, a kind of heat pump that pumps heat from air to air. This is usually achieved by creating an airstream over both the condensor and evaporator. This can be done in two different ways:

1. Single block: both the condenser and the evaporator are in a single unit that is placed inside the house. This option therefore needs a hole in the wall for air to enter the unit.
2. Split block: The evaporator and condensor are seperated and placed inside and outside respectively. They are connected via the refrigerant cycle (usually through copper tubing).

Air/Air heat pump systems don't exchange air from the outside to the inside which can be favorable based on the quality of the air in the geographical region.

The heat pump design of this report is a split block heat pump. This not only gives more versatile design options, But also uses as little space as possible inside the house since half the unit will be placed outside.

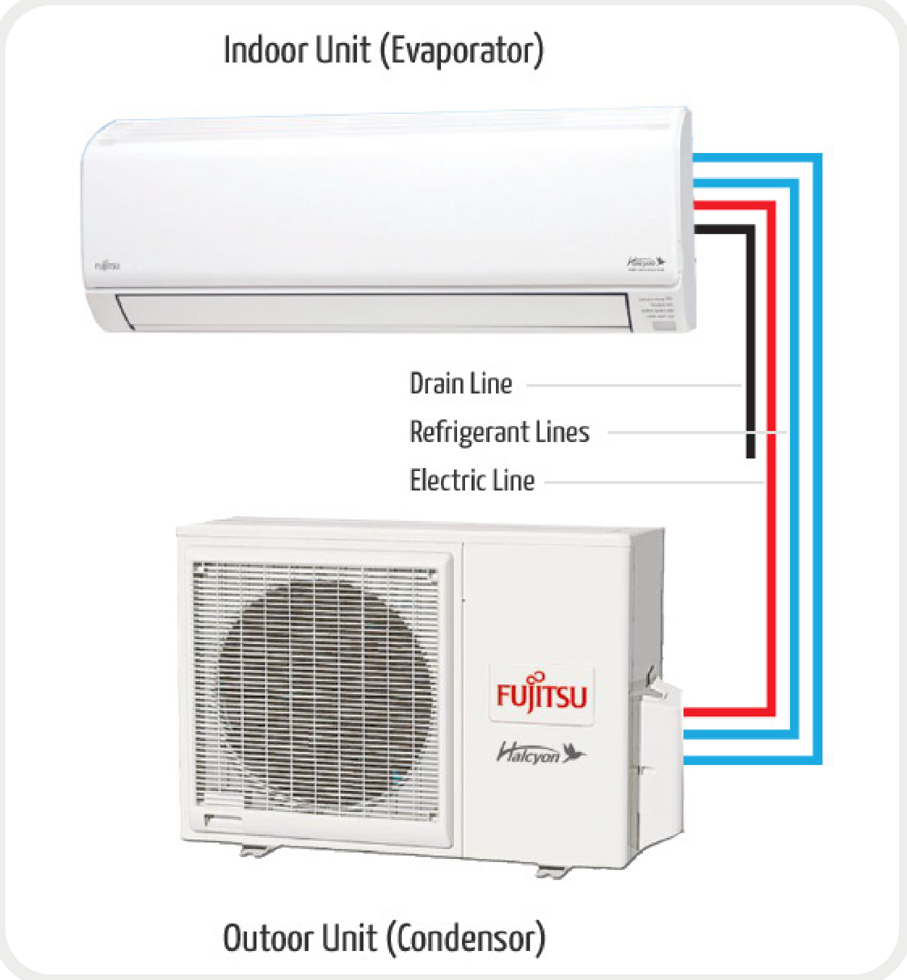


Figure 6 : Example of a Split block heat pump system

1.4 Current Heat pumps

To get a feeling of current heat pump design a couple of them will be shown here.

Designs

The current heat pump market consists of mainly box-like shapes. The rectangular nature of these products is most likely based in the cheap cost of these shapes. Not much forming has to be done in order to achieve these looks. However this does create a disconnect with the environment they are usually placed in (gardens etc.) and they fall out of style to a point where several services have popped up advertising concealment options for the current heat pump designs. [2]

Figure 7 : Current aesthetic of heat pumps

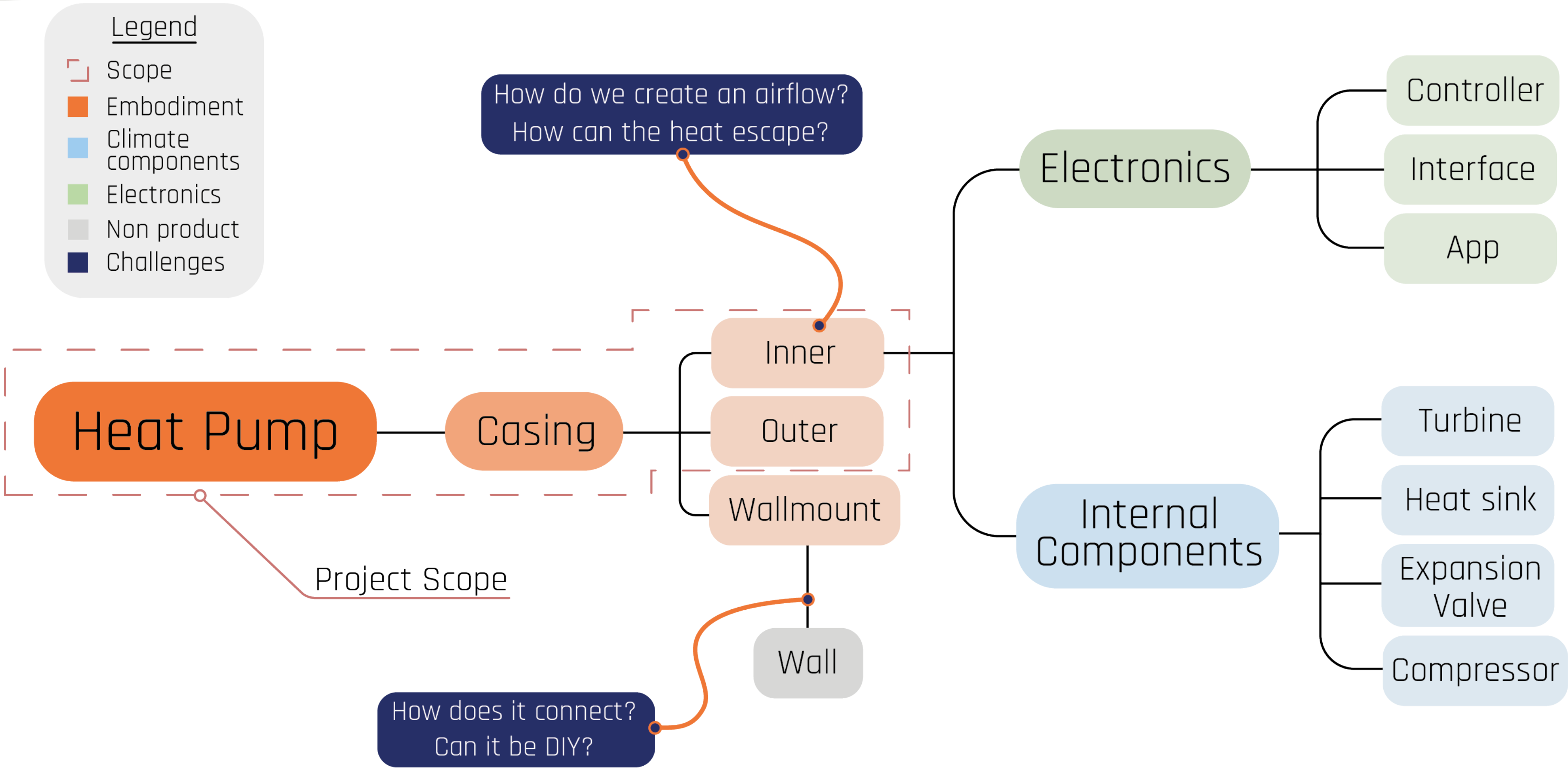
Chapter 2

Scope and Principles

This chapter is all about the framework of the project and the principles used in the design

2.1 Scope of the Project

An overview of what parts of the product have been designed. And what parts need to be considered but not designed.



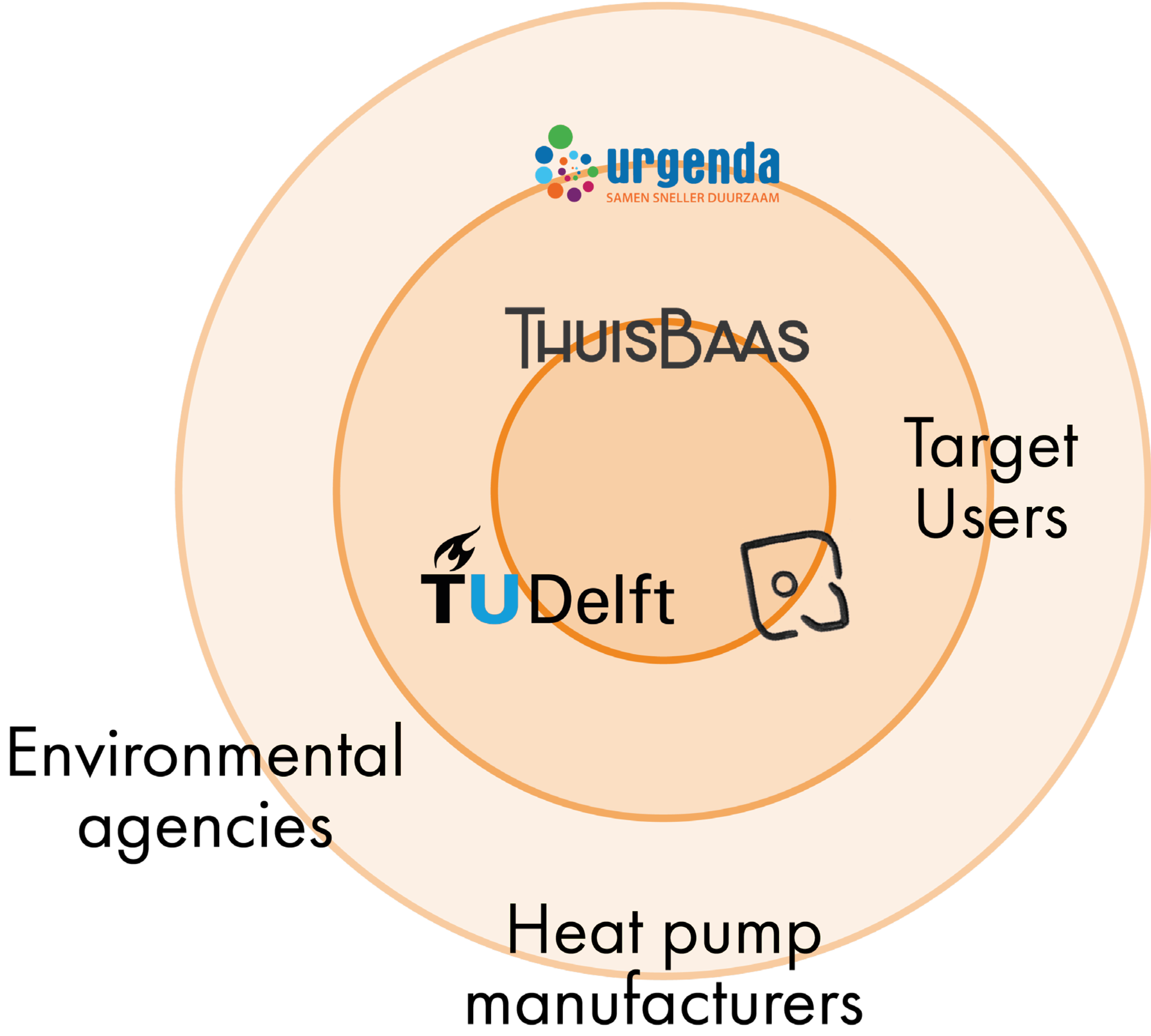
2.2 Stakeholders of the Project

Who has an interest in this project and on what level are they interested?

Interests

The following visual shows the interested parties for this project. The closer they are to the center the higher their interest in this project. The three main stakeholders are:

- ThuisBaas (Errico Garofalo)
- TU Delft
- The Designer (Me)



2.3.1 The Venturi Effect

How does the design create an airflow into its system and how can we use this effect?

What is it?

The venturi effect is the name of the reduction in pressure when a fluid flows through a constriction (also known as a choke).
This principle can be explained using Bernoulli's principle. The equation that will explain the effect is the following:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

in which P is the pressure, ρ is the density of the fluid, v is the speed of the fluid, g is the gravitational constant and h is the height of the pipes the fluid flows through.

This equation yields the basis for the venturi effect when we look at the relation between the pressure and the velocity of the fluid. A constriction in a pipe system will increase the velocity of the fluid flowing throught that constriction. Bernoulli's equation tells us that in turn this will result in a decrease in pressure in this constriction. The venturi effect becomes usefull when a hole is made somewhere along the constriction. Because the pressure in the constriction is lower than the outside pressure this will generate a flow into the constriction (Figure 6).

Why do we care?

This effect seems to create a higher airflow by allowing air from the atmosphere to be introduced in its system. This extra air will increase the velocity of the air in the system slightly as well as introduce more air particles and will help to increase the heat flow from the air to the heat sink or vice versa. This will in turn increase the efficiency of the heat pump.

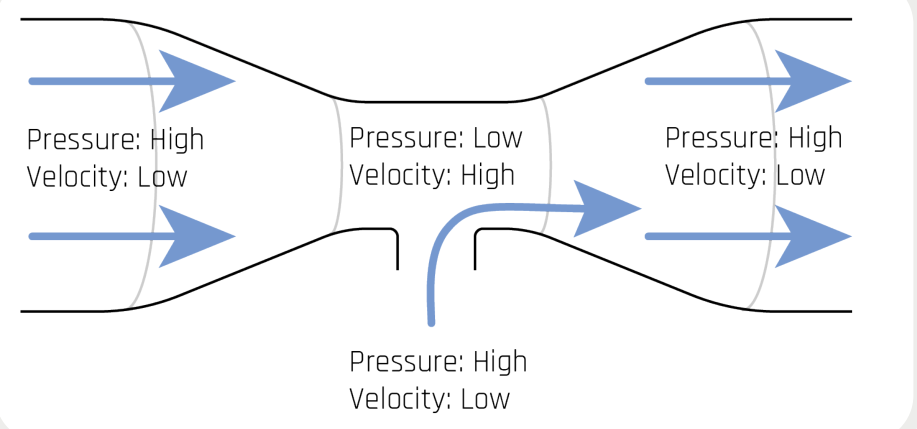


Figure 8 : Venturi Tube

2.3.2 How do we apply it?

How do we apply the venturi effect in the design of a new heat pump?

The effect in a Heat pump

Using the venturi effect in a heat pump can create an increased airflow from the atmosphere over the heat sink. Thereby decreasing the time it takes for the air to heat or cool. This means energy used to create the airflow creates a bigger airflow than traditional heat pump fans, which in turn saves energy that would otherwise be used to propel the air.

Decreasing the electrical energy used in a heat pump is key to increase the COP (Coefficient of Performance) value of that heat pump. The COP value is a reference value for the efficiency of a heat pump and is found through the following formula:

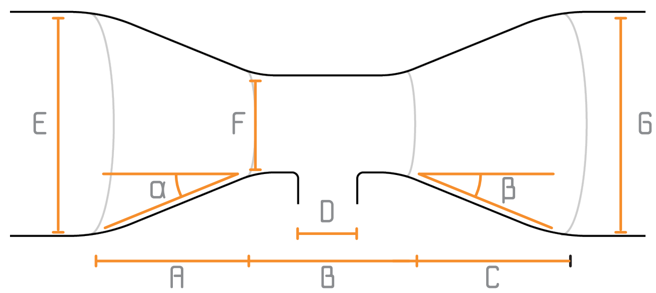
$$\frac{\text{Supplied heat in Watt}}{\text{Electricity used in Watt}} = \text{COP}$$

Using this formula in its most rudimentary form shows us that the higher the COP the more efficient a heat pump is. The venturi effect can hopefully decrease the Electricity used in Watt and will therefore help increase the COP of heat pumps.

Restrictions

The restrictions for this effect is ofcourse the form of the air channel. There are several parameters that have to be accounted for the efficiency of the venturi effect. [3] These are:

- Throat Contraction Ratio = F/E
- Venturi Tube lenght diameter ratio = B/D
- The velocity of the air coming in to the system
- the entrance and exit sloping = α and β respectively



2.4.1 The Coandă-effect

There is a second effect at work in the design. This effect and how it is used will be explored here.

What is it?

The coanda effect occurs when a liquid or gas meets a convex surface. The liquid or gas flows over the convex surface and sticks to it instead of following its original path after clearing the first part of the surface. This increases the speed of the airflow over the convex surface and creates a force vector pointed downwards instead of horizontal. This in turn creates a low pressure area above the convex surface (Figure 9).
This effect is an important part of the creation of lift on an airplane wing but can be used in many other ways, including creating an airflow from a heat pump into a room.

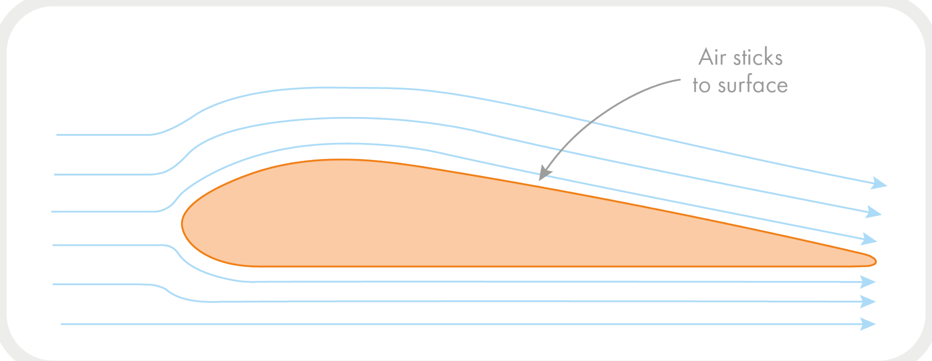


Figure 9 : Coanda Effect

Why do we care?

This effect is already used to great effect in the dyson bladeless fans. In these fans it creates an increased airflow into a room by creating low pressure in the center of the product. This low pressure is created by blowing air out of small slits near the begining of the "wing" of the fan (Figure 10). This idea of propelling air into a room is a great solution for heat pumps as well since they need to distribute the created hot or cold air throughout the room they are in. The question that remains then is how are we able to combine this effect with current heat pump technology?

Figure 10 : Dyson Bladeless Fan

2.4.2 How do we apply it?

How do we apply the coanda effect in the design of a new heat pump?

The effect in a Heat pump

As stated before the coanda effect can increase the efficiency of a heat pump by allowing more air to flow into the room with the same amount of electric energy used. It does this by creating a low pressure area that pulls in air. In the design the airflow that is needed to achieve this can be created by a turbine within the product that lets air flow through the wing and out a small slit (Figure 11). Creating the desired effect by blowing the air past the convex surface.

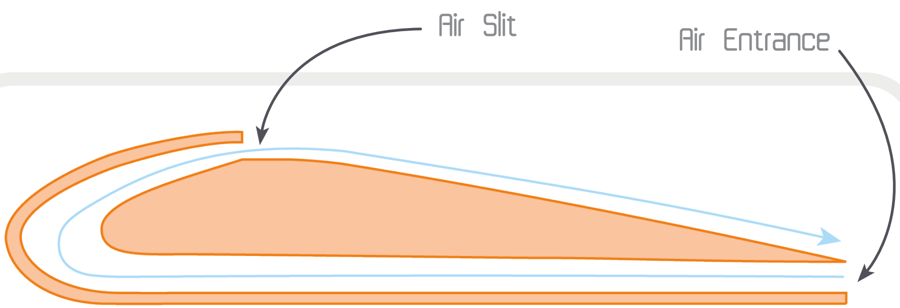


Figure 11 : Flow through the wing

Restrictions

Since the low pressure area needed can only be created by a "set of wings" (Figure 12), the question remain if this effect is worth the form restriction of the design. The dimensions of the air slit have the biggest impact on the flowrate out of the wing and have to be carefully considered. The smaller these dimensions the higher the flow velocity. [4]

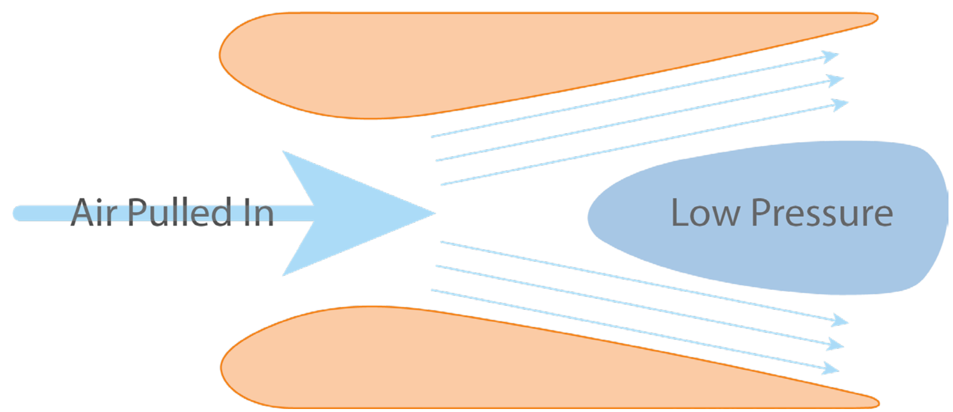


Figure 12 : Coanda Effect

2.5 Physical prototype test

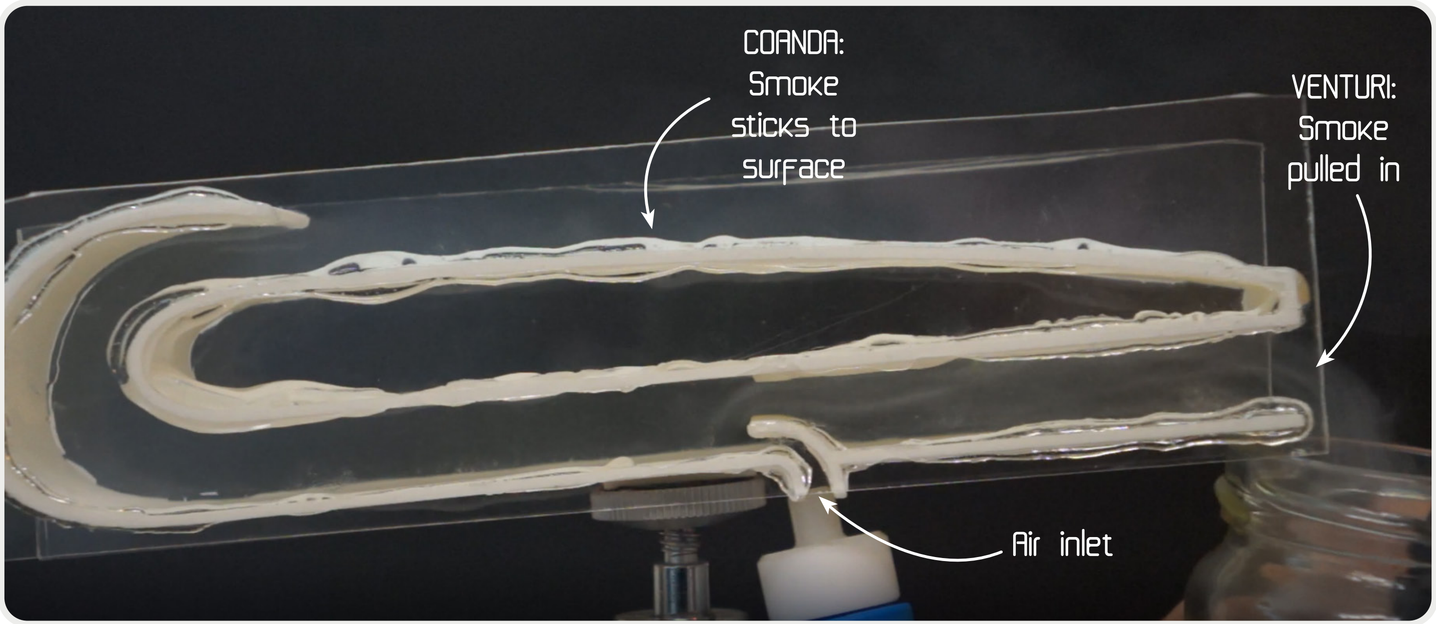
A physical prototye was created to test the 2 effects combined in a real world example. The test setup is found in Appendix 8.5

Visualisation

The still image on this page shows the best representation of the working principle in the prototype. As stated before the video in the data package will give a better overview of the physical test.

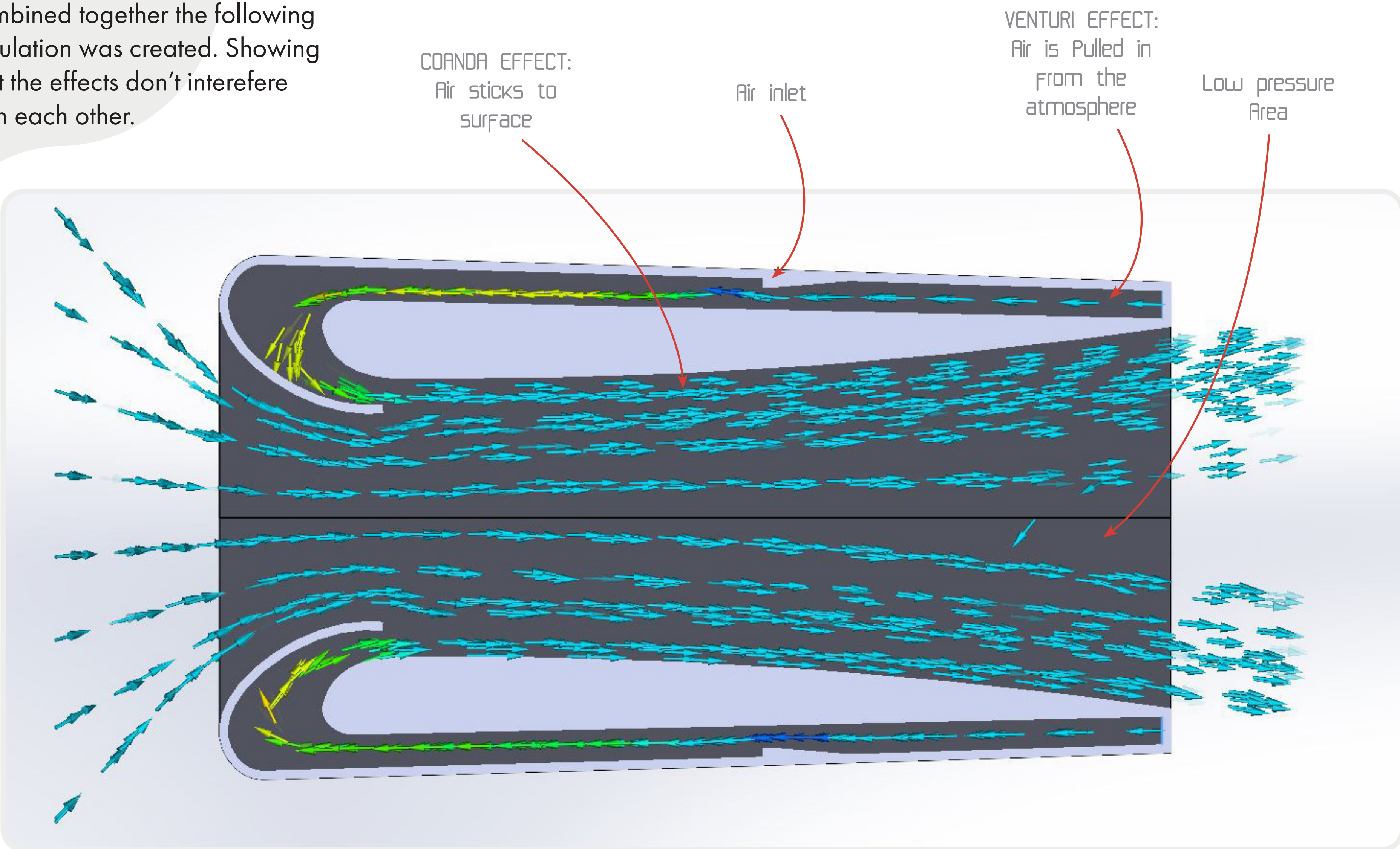
Conclusion

The physical prototype shows the same attributes and airflow as the previously created simulations. Therefore for the application of this project the simulations are a valid way of interpreting the airflow through the design.



2.6 Can the effects be combined?

To test if these effects can be combined together the following simulation was created. Showing that the effects don't interefere with each other.



Chapter 3

Defining the product

This chapter is all about focussing the search fields for a product solution.

3.1 Method

How will the new design be created? And how will it be researched and validated?

SolidWorks Simulations

The way the proof of concept is tested is mainly through Solidwork simulations. These simulations focus on testing the efficiency of the proposed design against the efficiency of an existing heat pump. These simulation require the following conditions to function:

- A 3D model of the product
- Initial air flow conditions
- A heat source

The simulations can be found on page 27-34. They are shown as clearly as possible in 2D but will probably require some extra information to be fully understood. This information can be found in the introduction and the comparison on page 21 and 35 respectively. The visualisations will be done through the use of both isosurfaces and streamlines.

Validation

The validation of the proposed design will be based on 3 variables. Those variables are:

- Efficiency
- Cost
- Aesthetics

As stated earlier the effieciency of the design will be validated through SolidWorks simulations. This leaves both cost and aesthetics to be discussed. The cost of the product will be validated through estimating the costs of all the components of the design and comparing it against current heat pump pricing.
Lastely the aesthetics of the design will be validated through a user test comparing current heat pump aesthetics with the design.

3.2 The Characteristics of a Heat Pump

How can we quantify what a heat pump does and how can we test these behaviours?

Area of Effect

This is the area a heat pump can effectively heat up or cool down. This is usually described as an area in square meters which assumes a ceiling height of roughly 2.6 meter. Increasing this ceiling height will ofcourse have an effect on the effectiveness of the heat pump and will therefore have to be considered when choosing the heat pump for a room. The size of the heat pump will have to be determined based on how big of an area of effect it should have.

CoP

the CoP (Coefficient of Performance) of a heat pump is determined by comparing the heat output of the condensor (Q) with the power supplied to the compressor (W) resulting in the following formula:

$CoP = Q/W$

Condensor Area

A condensor is made of 2 main parts, a tube (usually copper) which holds the refrigerant and ribs (usually aluminium) that serve to create as big a surface for the air to touch. The bigger the area of these ribs the better a condensor is able to transfer heat energy to the air. Therefore it follows that the bigger the area the heat pump should be able to heat up or cool down the bigger the Condesor Surface Area should be.

Sound volume

The sound a heat pump makes is usually based on two seperate sound emiting devices. First of all the compressor in the refrigerant cycle and secondly the rotating fan blade creating an airflow through the heat pump. Both these sources of sound will have to be considered in the design of a heat pump.

3.3 Validation metrics

What metrics will the design be tested on? And what do these encompas?

Efficiency

The efficiency of the design will be tested through the use of SolidWorks simulations and will mainly focus on the airflow. This will include the airspeed through the design, the direction of the airflow and the temperature of the air through the design. All of these factors will then be compared to a model of a similar type of an already existing heat pump. This wil result in an overview of the performance of both the existing heat pump as well as the design which are based on the same initial parameters (air speed and initial heat) allowing for fair comparison.

Cost

the cost comparison will be based on the cost of existing heat pumps and estimating the costs of the design. This will be achieved by creating an overview of all the components of the design and estimating the costs of all these components based on current market prices. This will result in an overview of all the components as well as give an indication of both the costs of creating the design as well as an indication of a possible retail price.

Aesthetics

the aesthetics of the design will be tested through the use of a user test. This user test will be purely focussed on the aesthetic of the design. To achieve this a visual of both the design and an existing heat pump will be shown in both a context setting and without one and participants will be asked to rate these visuals based on aesthetics. The full survey can be found in Appendix 8.9 and 8.10. an example of the visuals used is shown below.

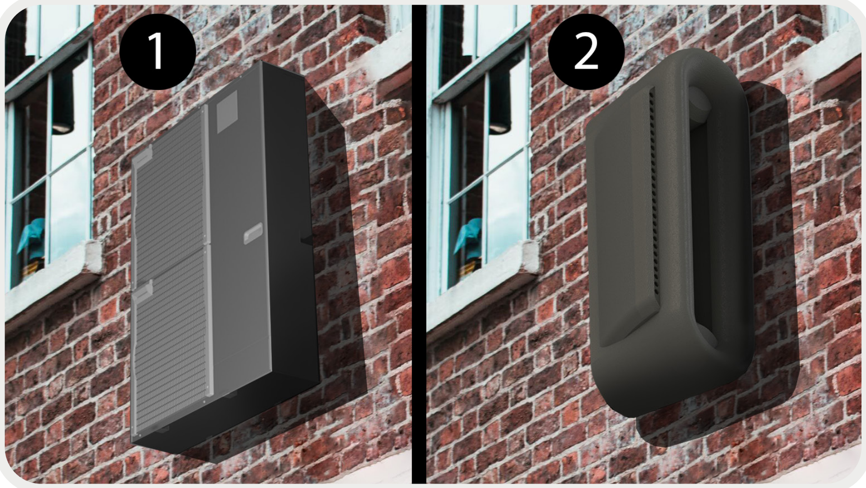


Figure 13 : Survey example

3.4 Program of Requirements

With the parameters of a heat pump cataloged, the following requirements and wishes can be determined

Requirements

- 1. The product should have a CoP equal to current heat pumps
- 2. The product has to be wall or ceiling mounted
- 3. The product should not be bigger than current heat pumps
- 4. The product should not emit sounds louder than 50 dB
- 5. The sound emited should be below 60 Hz
- 6. The weight of the product must not exceed 100 KG
- 7. The heat pump must effectively heat a room of at least 35 m2
- 8. The condensor surface area should be at least 3/4 of the Mitsubishi

Wishes

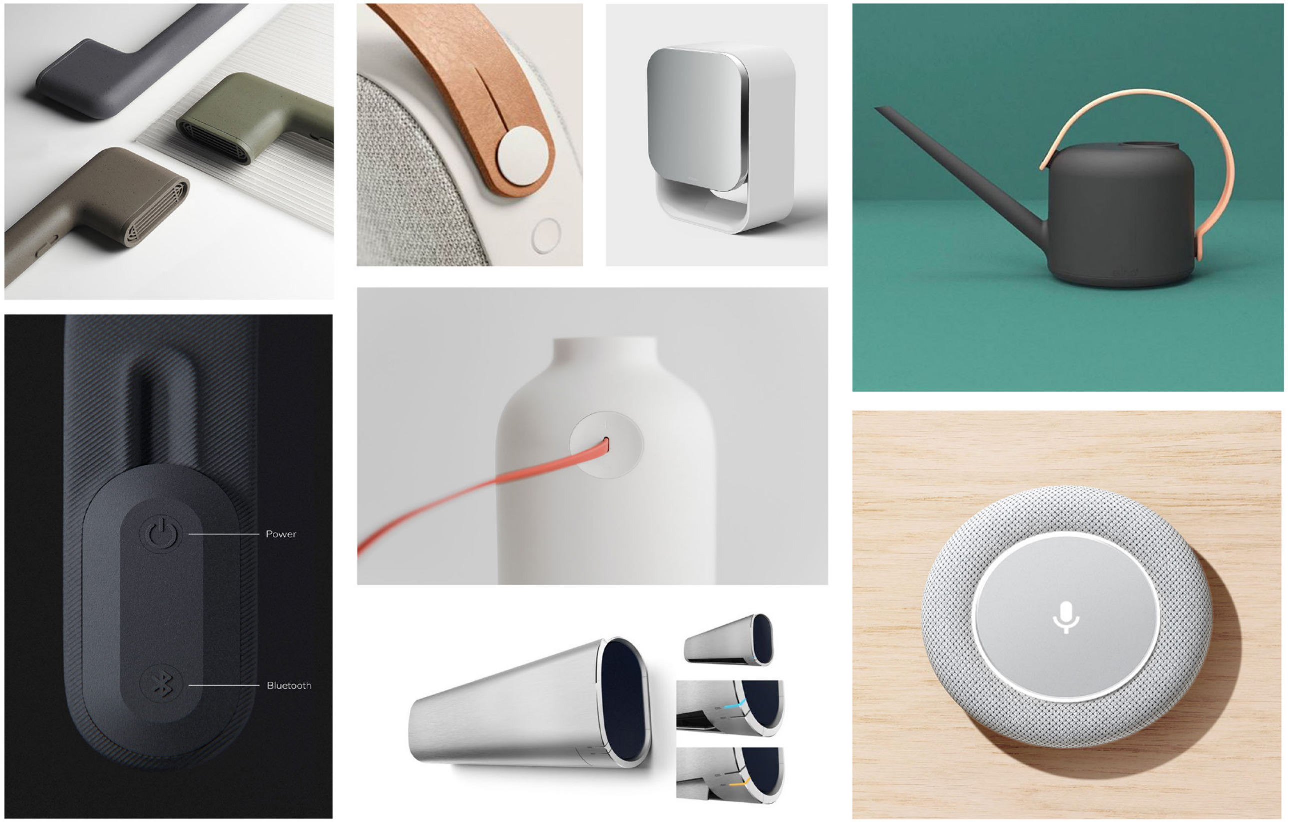
- 1. Fits in the context it is placed (outer walls)
- 2. Can be implemented in small appartments
- 3. Unique form language in the market
- 4. Parts are able to be individually coloured
- 5. Able to create different sizes of the product
- 6. Close to the visual style collage (page 19)

3.5 Visual Style Collage

What feeling do I want the product to have? This page gives an idication through the use of a moodboard.

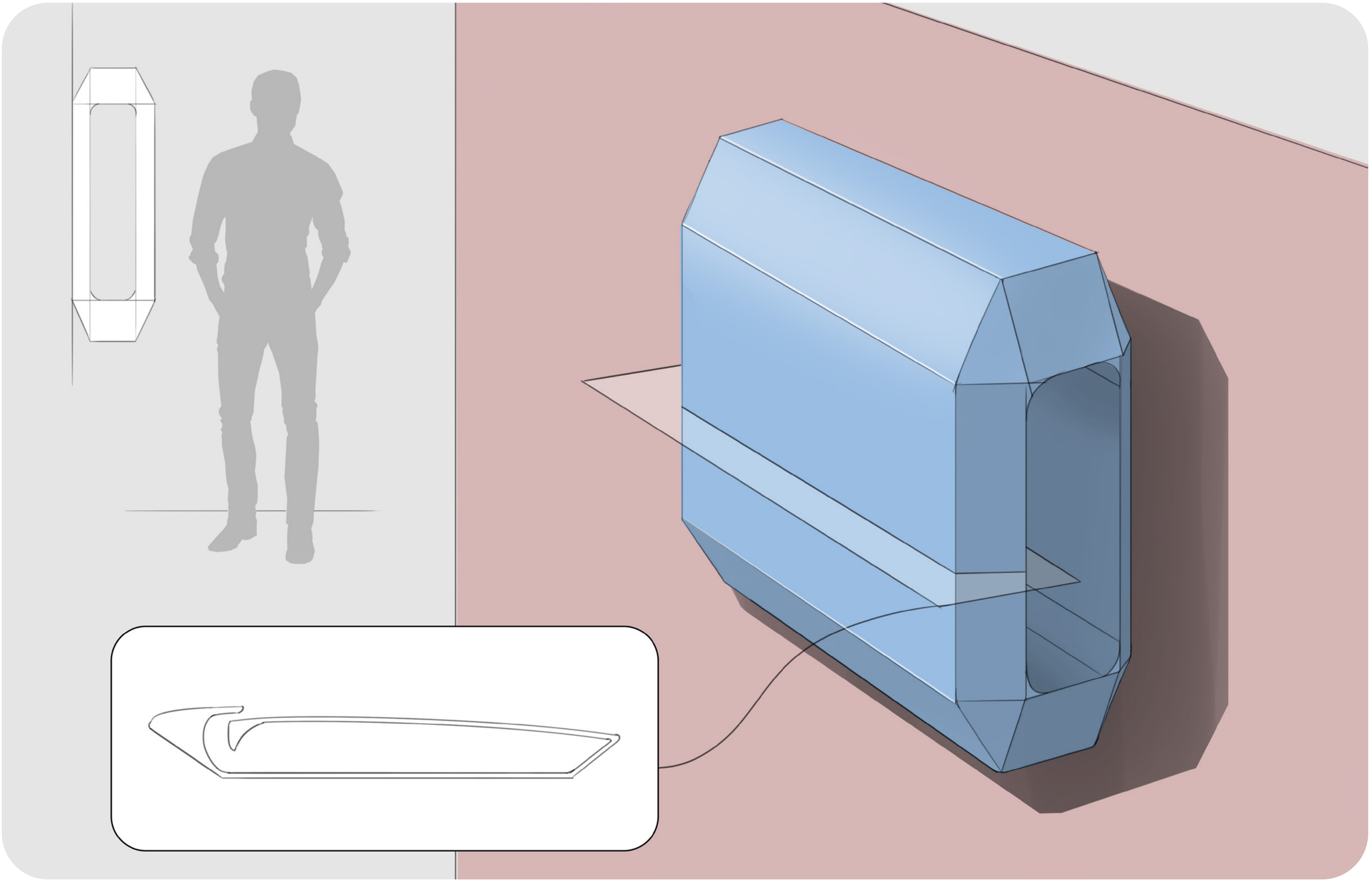
Current Trends

The trend of upcoming products has been steadily going away from hard transitions into smoother shapes. This combined with a movement towards matte products shows the most prevelant design trends of 2021. Some examples of this style are presented here. A focus on this style could lead to an aesthetically desireable product for the years to come. However this style is very distinct and will most likely be overshadowed in 5-10 years by new trends. For now this is the best option for creating an aesthetically desireable product but if a further future is to be focussed on, basic shapes will be a more secure choice. Finding a balance between these two options has been the main priority of the aesthetic design.



3.6 Concept Drawing

A concept drawing page based
on the visual style collage.



Chapter 4

Validation

This chapter is all about simulating the airflow of a current heat pump and the design.

4.1 Simulation introduction

A small introduction into the 3D air and heat simulations that were done.

Data package

As stated before the best way to experience flow simulations is through animation. This chapter sets out to show the simulations on paper as best as possible but if more information is required the animations in the data package will provide a better overview. (The information for this can be found in Appendix 8.12).

There are 3 main questions the following simulations aim to answer:

- Do the Coanda and Venturi effects work in 3D?
- How does a design with these effects look?
- How does the design compare to current heat pumps?

To compare the simulations all of them will have the same initial conditions where possible. The heat sink is 60 C ° and the initial airspeed is 20 m/s in each simulation. This will ensure the simulations can be compared to get the proof of concept the design works as intended. The dimensions of the models used in these simulations can be found in the Appendix.

Simulation visuals

The way the simulations are visualized in this report is in a 2D sideview highlighting parts of the simulations (for instance a central plane or a plane through the heatsink etc.). A preview of these simulations can be seen in figure 11. This figure shows the legend, the 2D plane as well as where this 2D plane is located in the 3D model.

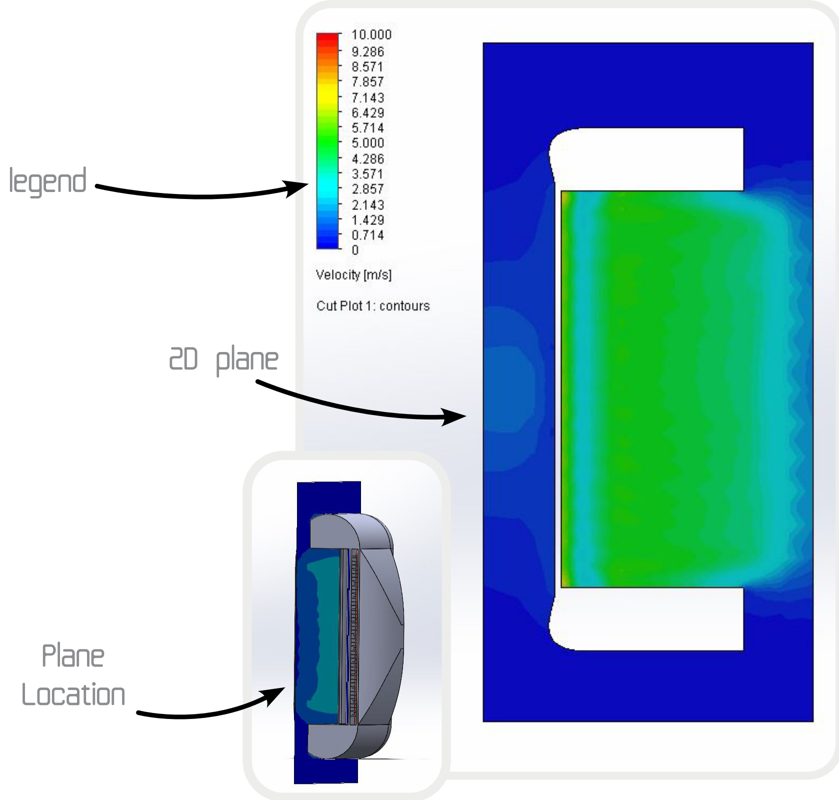


Figure 14 : Simulation Preview

4.2 Model introduction

The lessons learned from the 2D representation of the previous chapter will help to create full 3D simulations.

Two different models

The aim of this chapter and in extension the whole project is to find out if the principles from chapter 3 can be used to create a heat pump that is at least as efficient as current heat pumps. To accomplish this a comparison between a current heat pump and a new design with these principles included has to be made. Since the new design is not yet a physical prototype the choice was made to create a virtual 3D model of a current heat pump. Since a physical version of a Mitsubishi MXZ5C42NA heat pump (figure 15) was available to be be examined and measured this heat pump was chosen for the virtual comparison model. The newly designed heat pump will therefore be compared to this mitsubishi heat pump. Both the mitsubishi and the new design have been modelled in SolidWorks and have been be simulated with the same initial conditions where possible to ensure a fair comparison. Both simulations have a focus on the following variables:

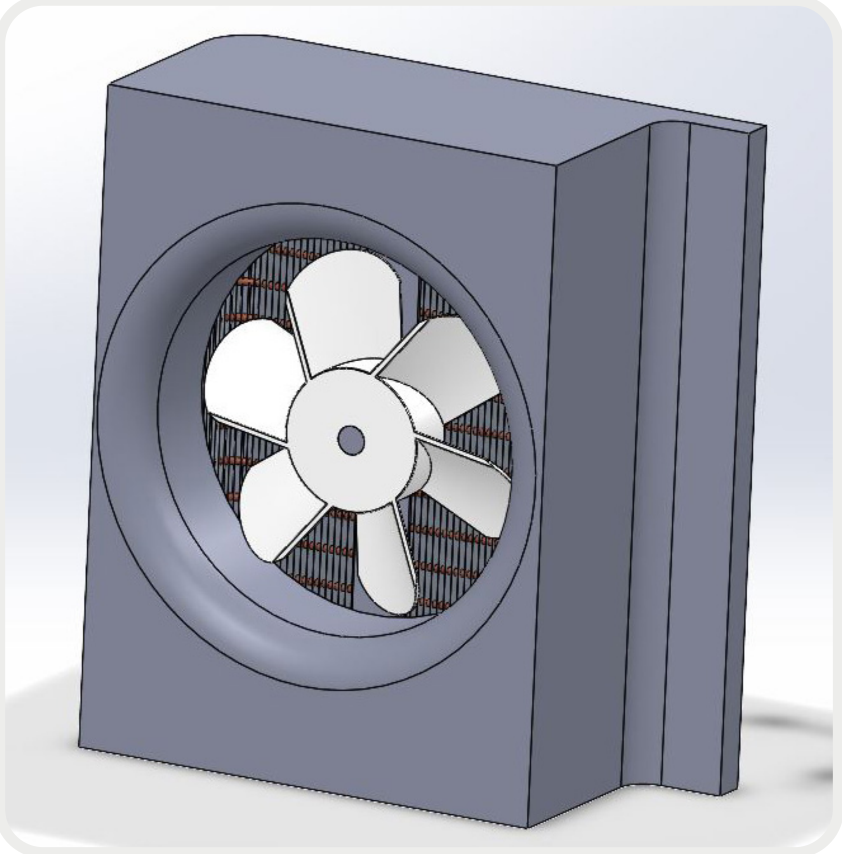
- Air speed and flow through the heat pump
- Heat transfer from heat sink to air
- Energy input

Figure 15 : Mitsubishi Heat Pump

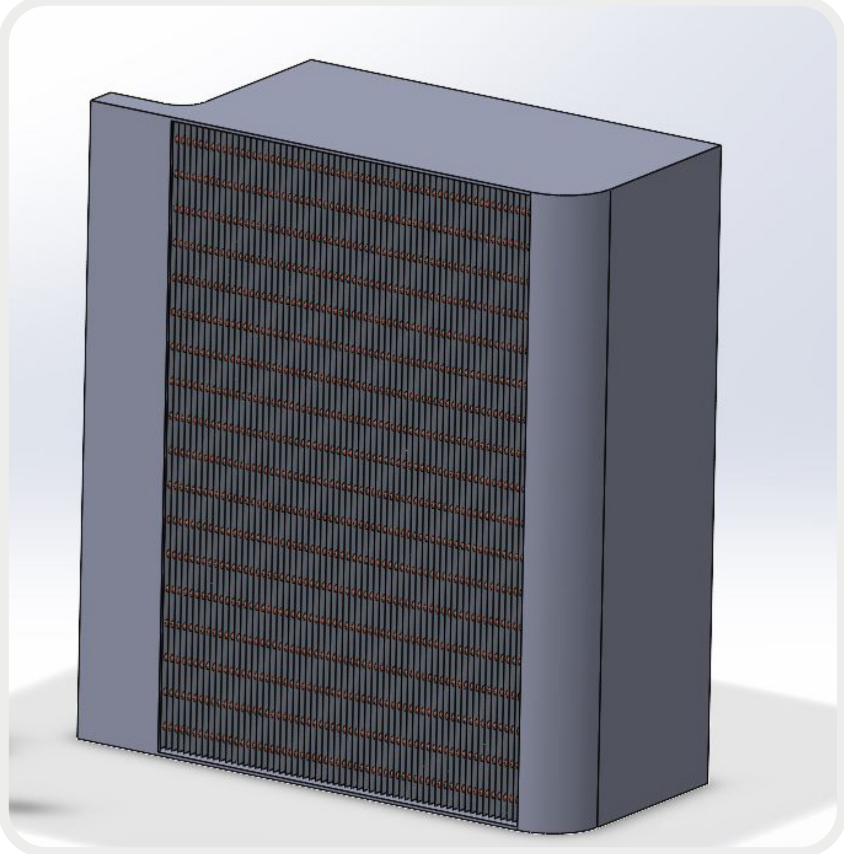
4.3.1 Mitsubishi Model

An overview visual of the mitsubishi model the full SolidWorks model including simulations can be found in the data package

Front view



Back view



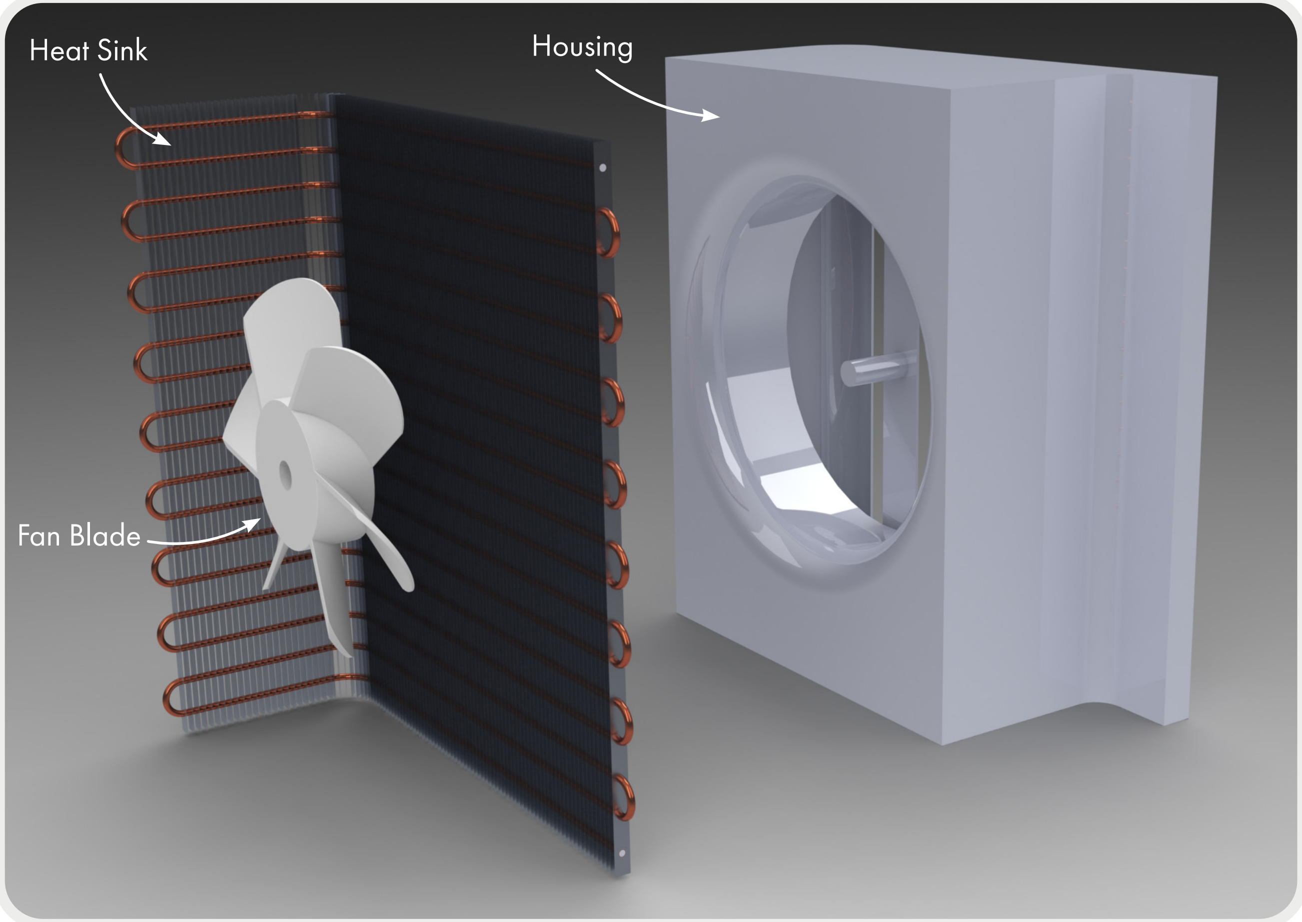
4.3.2 Component View

All the components of the mitsubishi are shown here with an explanation of the model included.

The Model

The mitsubishi heat pump has been modelled in 3 seperate parts: The housing, the heat sink and the fan blade. These three components are the parts that are necessary to create a full airflow simulation of the heat pump.
The housing will be one of the initial constricting conditions for the airflow simulation, the heatsink will be used to simulated the air heating up and the fan blade is used to create the airflow simulation.

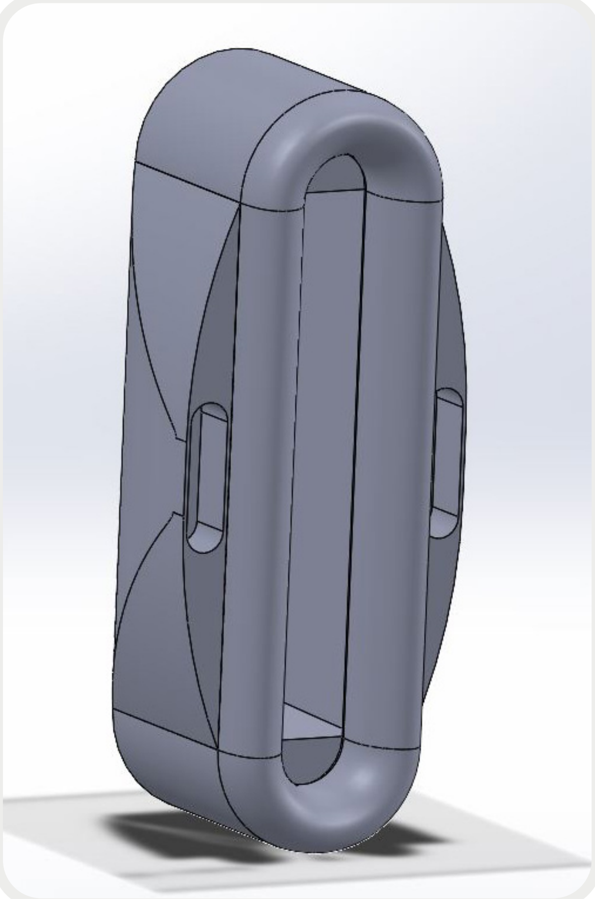
The materials used are: Copper (pipes in the heat sink), Aluminium (heat sink plates and housing) and ABS (fan blade).



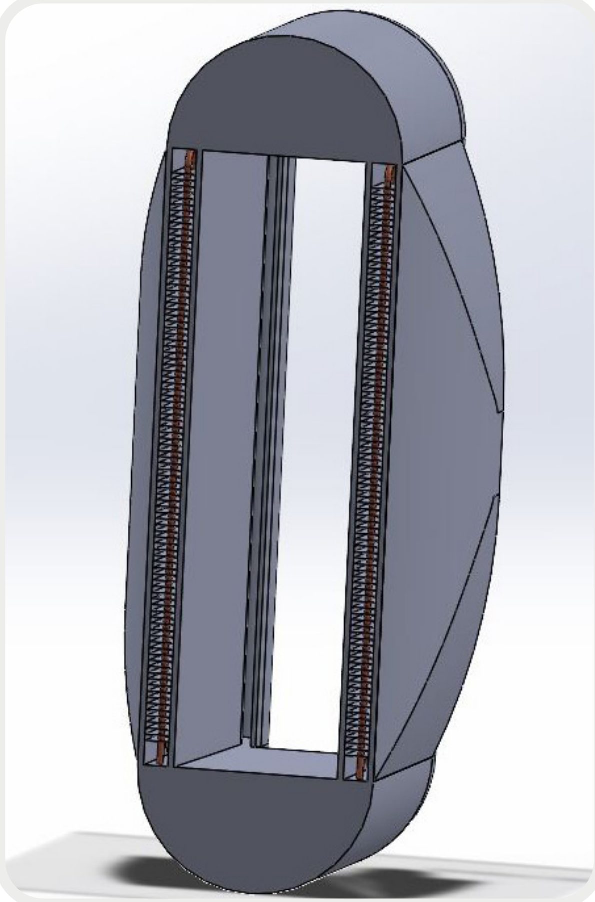
4.4.1 New Design Model

An overview visual of the new design model the full SolidWorks model including simulations can be found in the data package

Front view



Back view



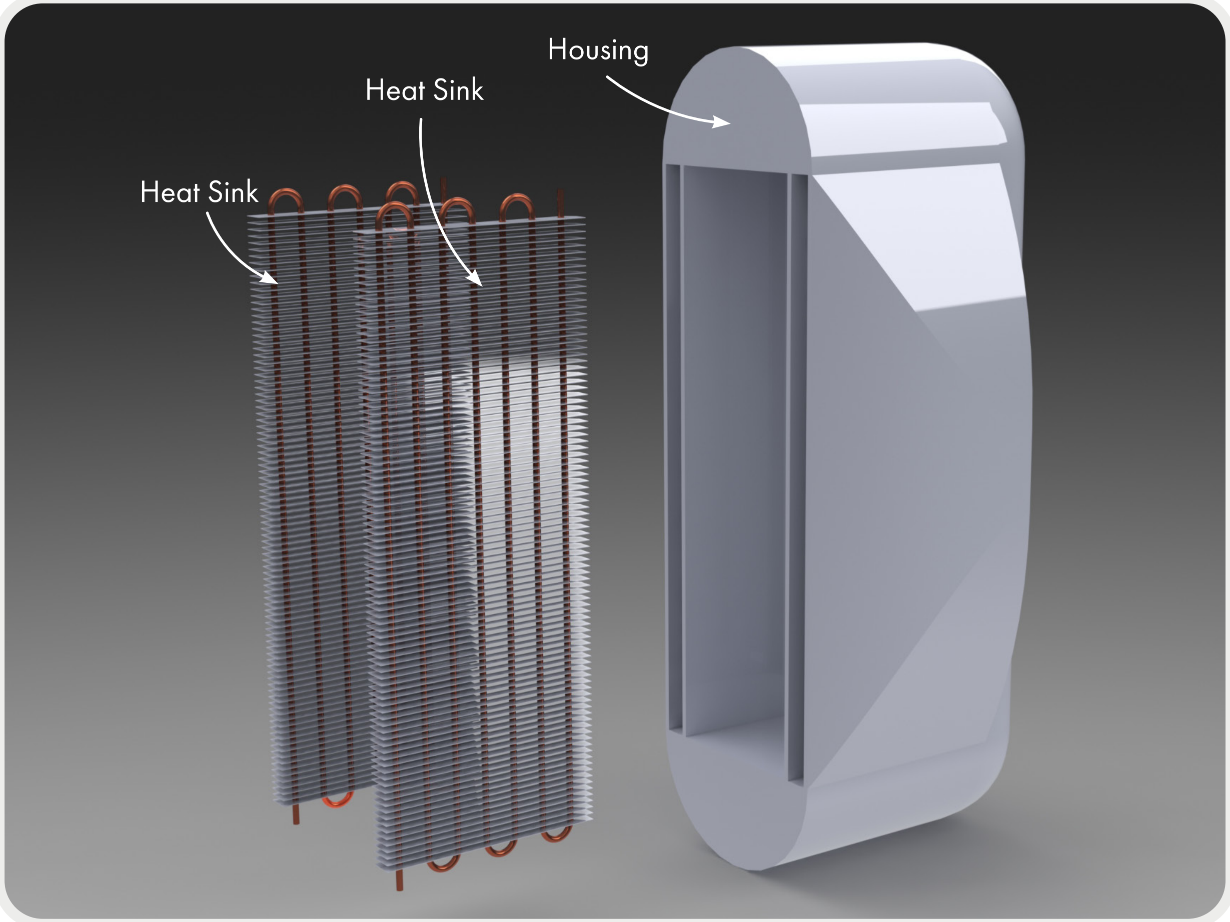
4.4.2 Component View

All the components of the new design model are isolated in several visuals here

The Model

For the Designed model to function on the same level as the Mitusbishi model two different parts were modelled: The heat sinks and the housing. Both these parts were created in the same specifications as the Mitsubishi model to allow for a fair comparison. Therefore the parts will function roughly the same in this model. The housing is again a constriction condition for the airflow and the heatsink will be used to simulated the air heating up

The materials used are: Copper (pipes in the heat sink), Aluminium (heat sink plates and housing)



4.5.1 Mitsubishi Airflow

A page all about the airflow of the mitsubishi model.

Airflow

The airflow simulations of the mitsubishi heat pump resulted in two noteworthy results. First of all the flow through parts of the heat sink is restricted by a significant part of the housing, resulting in a less direct airflow past those regions of the heat sink (Figure 16 and 17). This restriction in aiflow decreases the efficiency of the heat pump since part of the heat sink does not have a good airflow through it.

Secondly the Coanda effect takes effect in this model and helps the spread of air through the area (Figure 18). This creates a better airflow away from the heat pump which ensures there is less recycling of air that just went through the system. This in turn increases the efficiency of the heat sink.

The initial conditions of this simulations are a rotation of 240 rpm with a fan blade of 500 mm. Resulting in a velocity of 4.2 m/s at the max of the simulation. This is based on 1/4th of the capacity of commonly used heat pump fan motor (900-1000 rpm) [Appendix]. These results will be used to compare this heat pump to the proposed design.

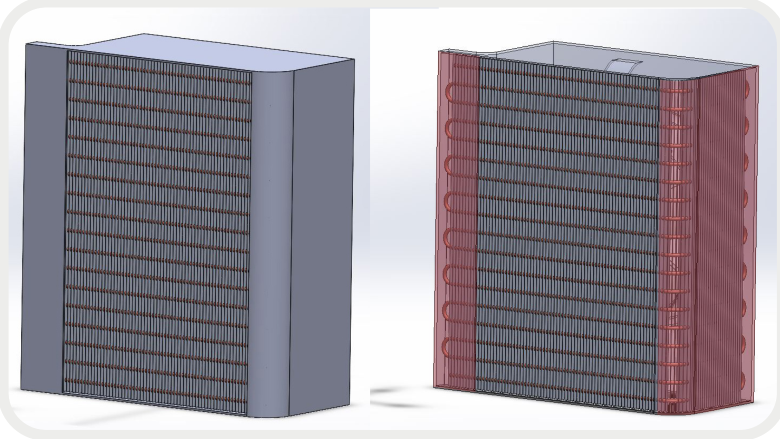


Figure 16 : Heat sink cover

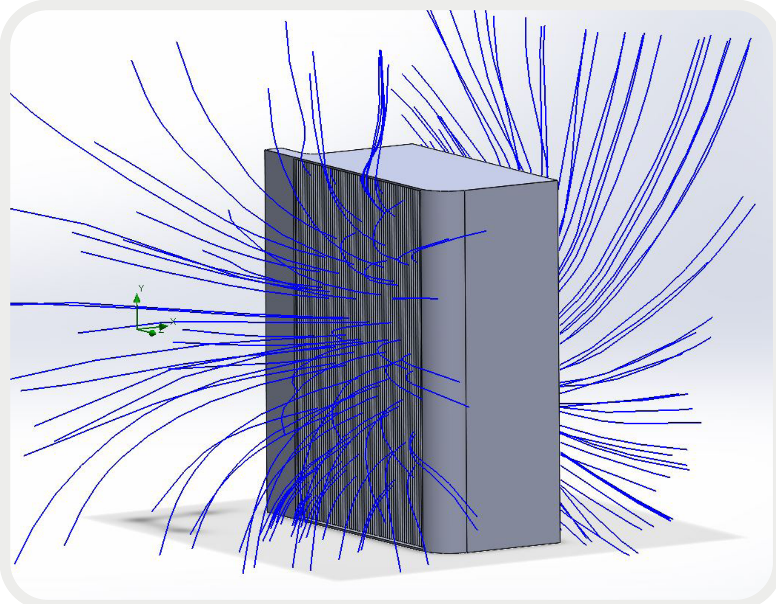


Figure 17 : Airflow lines

4.5.2 Mitsubishi Airflow Simulation

A page showing the velocity of the air in the simulation of the Mitsubishi

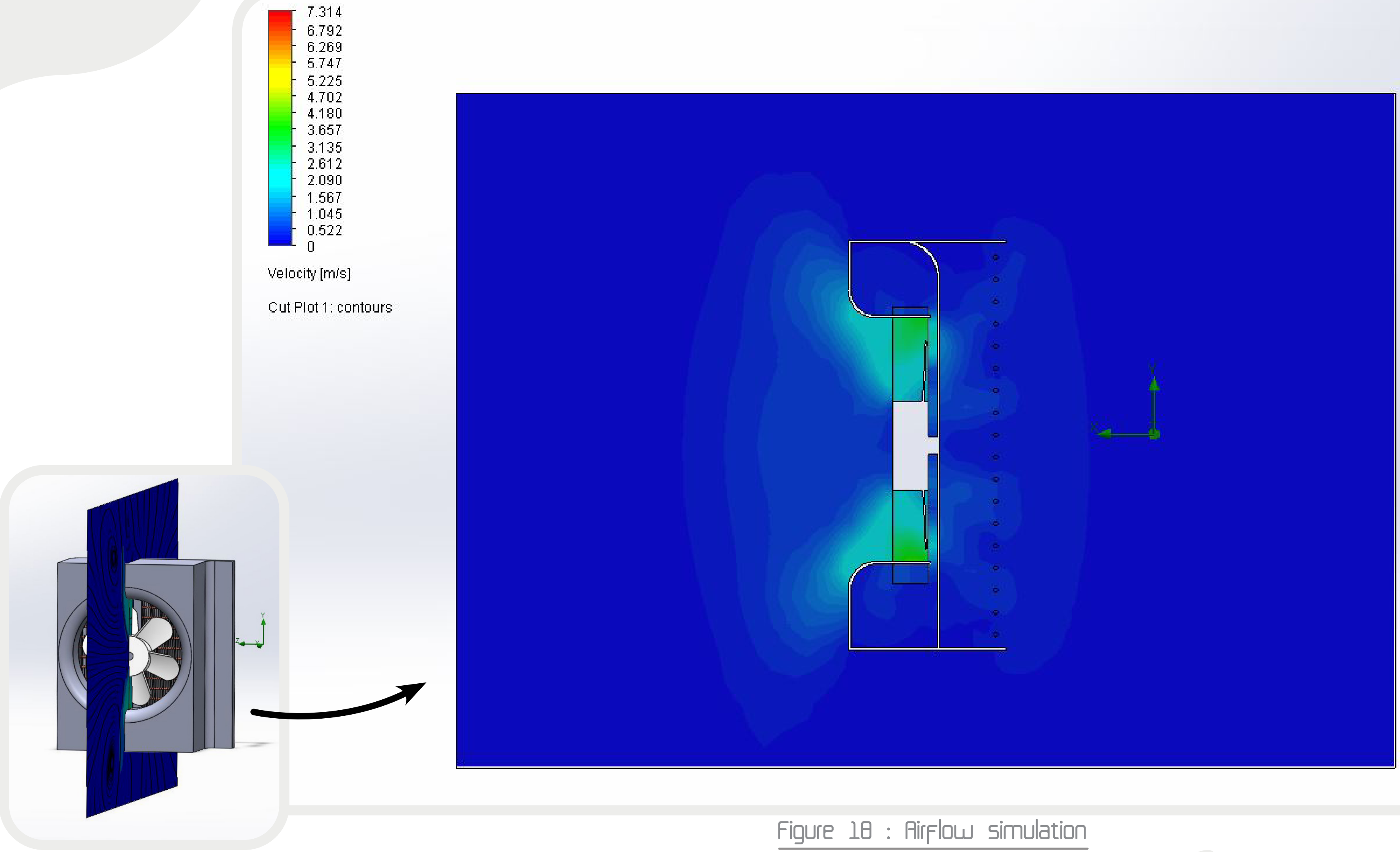


Figure 18 : Airflow simulation

4.6.1 Mitsubishi Heat

A page all about the heat maps
of the mitsubishi model.

Heat

The heat map of the mitsubishi model follows what is expected based on the airflow simulation. The heat sink is simulated at 60 °C based on normal heat pump use. This heat gets transfered to both the air and the aluminium housing of the heat sink. The air then gets blown out of the heat pump by the fan and follows the curvature of the housing (Figure 21)

In this simulation the air that comes out of the system is roughly 28 °C (Figure 21) showing the heat pump works as intended. An interesting finding here is that the housing becomes relatively hot (60 °C) since it is close to the heat sink as well as it being made of a material with a relatively high thermal conductivity (Thermal Conductivity Aluminium: 0.57). (Figure 19 and 20)

This is mainly due to the forced convection of the air which creates a constant stream of air into the system and therefore refreshes the air around the heat sink. This ofcourse does not happen in the aluminium of the housing making it heat up more.

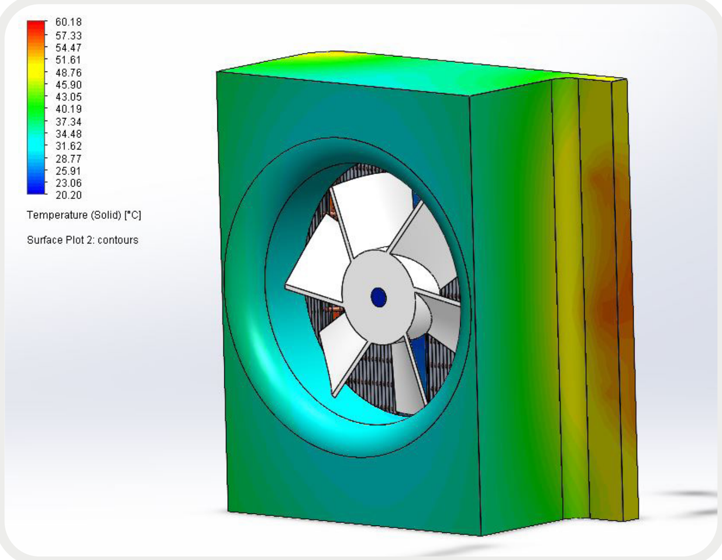


Figure 19 : Heat map front

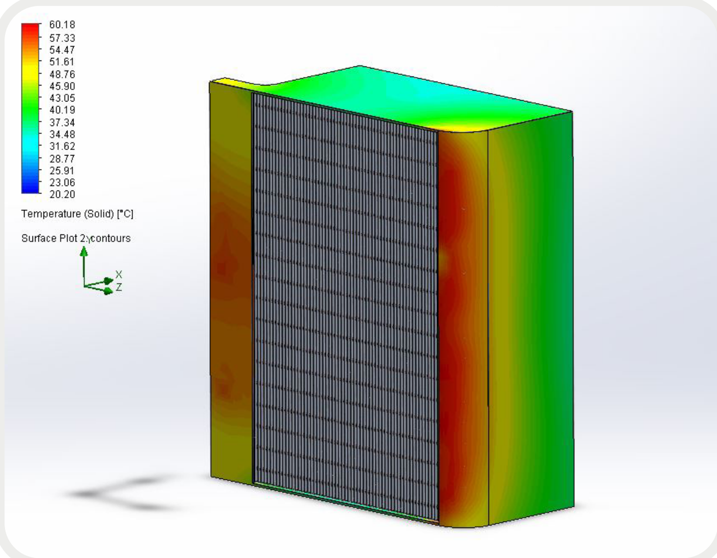


Figure 20 : Heat map back

4.6.2 Mitsubishi Heat Simulation

A page showing the temperature of the air in the simulation of the Mitsubishi

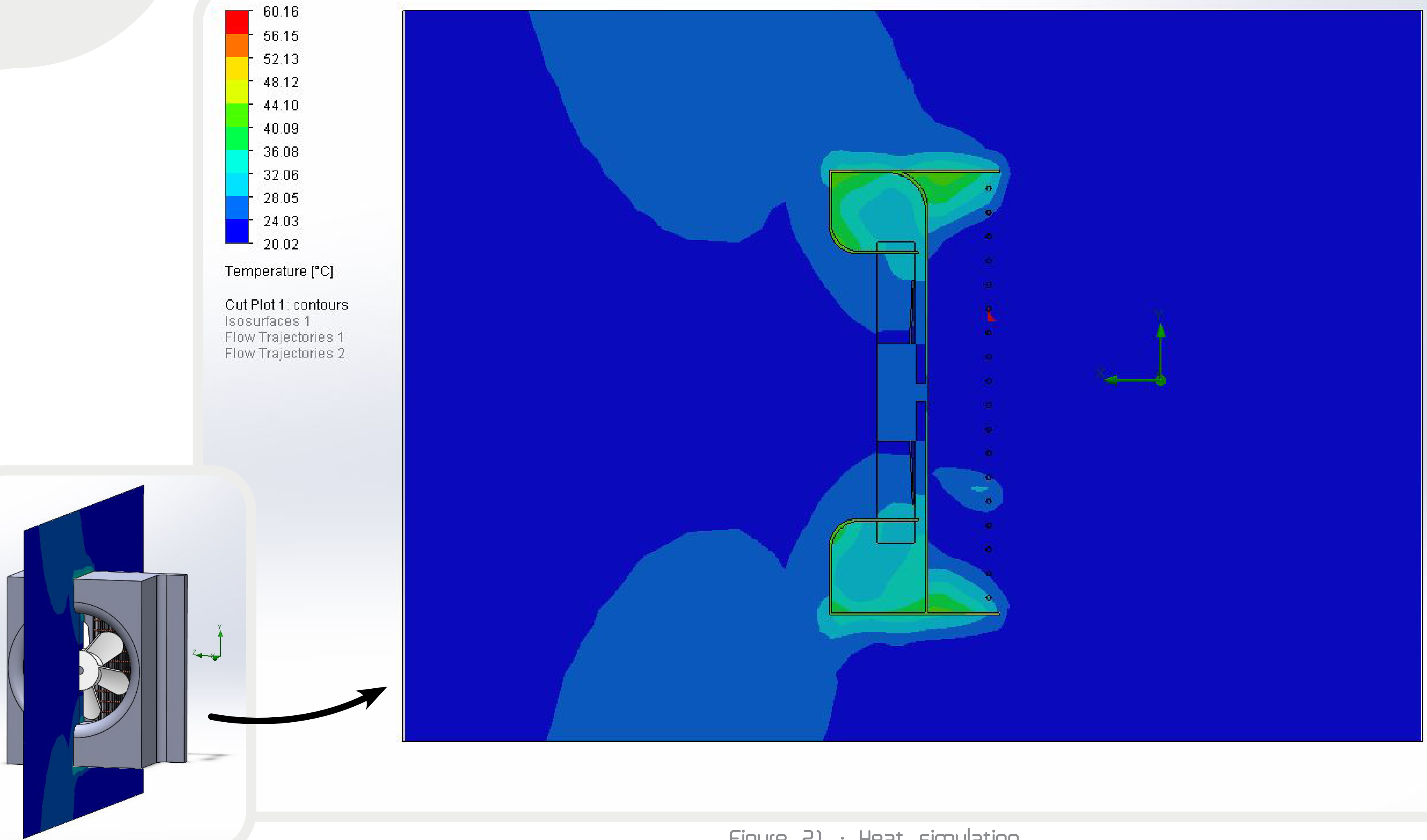


Figure 21 : Heat simulation

4.7.1 New Design Airflow

A page all about the airflow of the proposed design.

Airflow

The airflow of the design can be divided into three parts. First of all the air going going over the heatsink, secondly the air being pulled into the intake, (Figure 22) and thirdly the air flowing out and through the center of the design. (Figure 23)

The air flowing over the heat sink will be discussed later in the report so the focus here will be the air intake and exit. The air will be pulled in through two holes in the sidepanels of the design (Figure 22). The velocity of the air going in to the design is relatively high (20 m/s). This is achieved with a turbine that's fitted inside the housing of the design (Figure 24).

The exit of the airflow is located in the inner side of the housing (Figure 23). Air flowing through the turbine flows into the chamber housing the heat sink and then flows out of the design (Figure 24). The air flowing out the design has a velocity of roughly 5 m/s. This decrease from the higher velocity exiting the turbine is due to the increase in surface area in the the chamber that houses the heat sink.

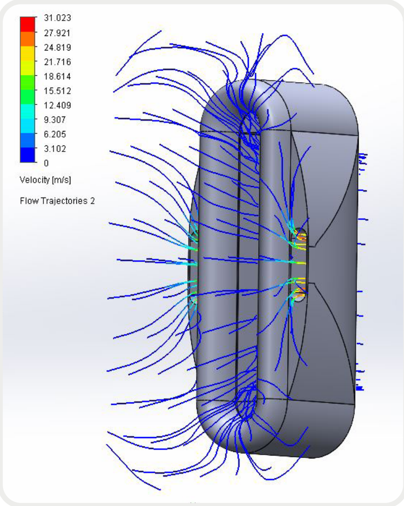


Figure 22 : Intake flow

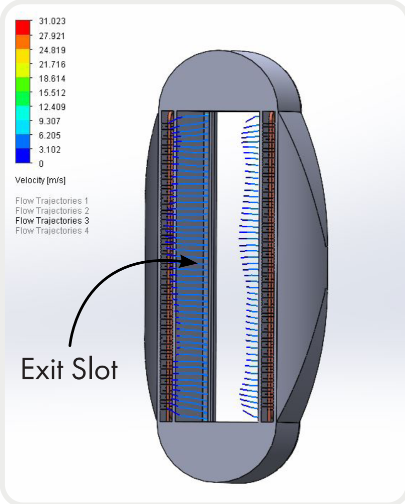


Figure 23 : Exit flow

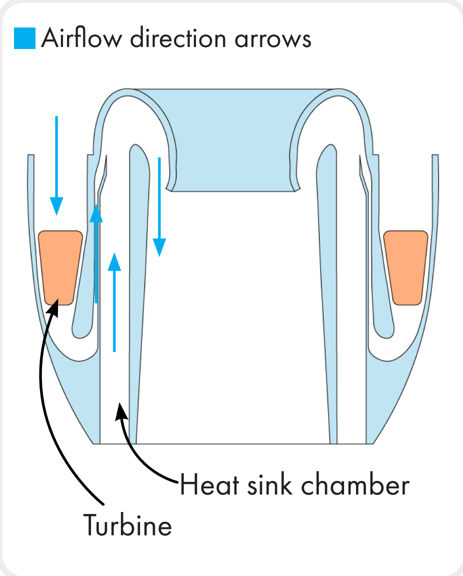
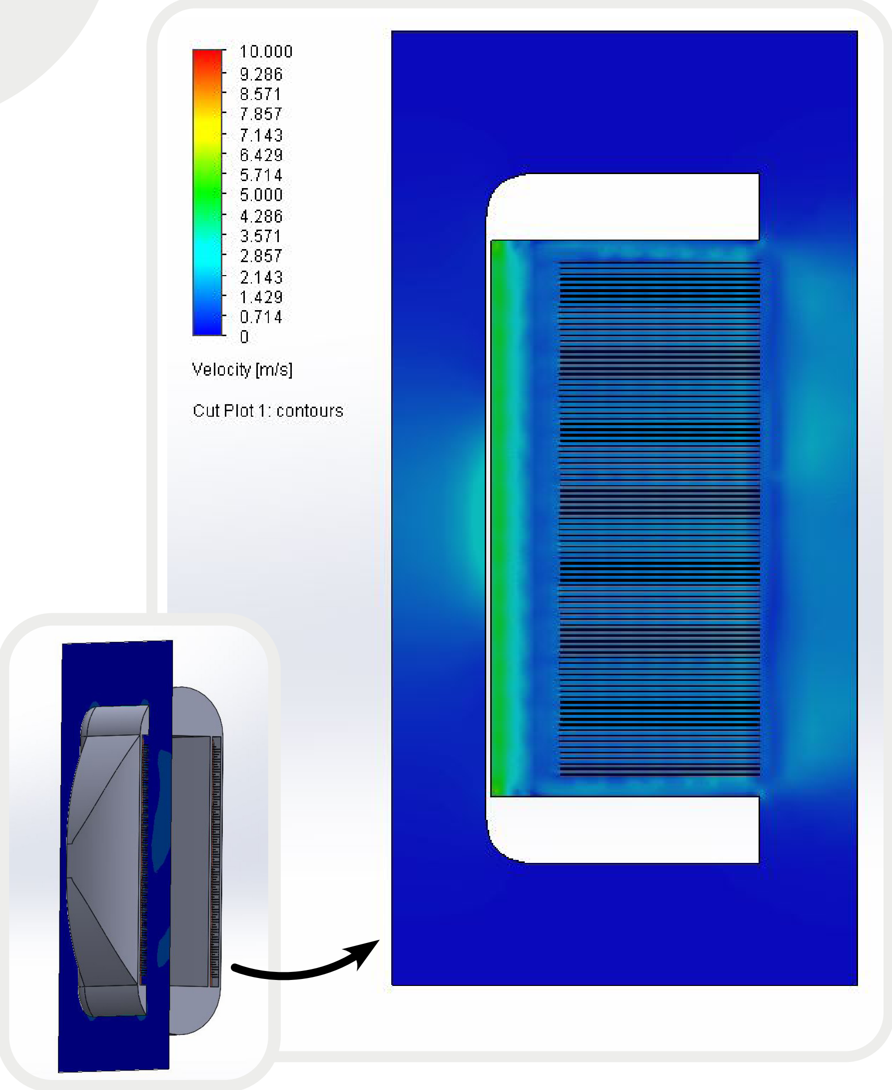
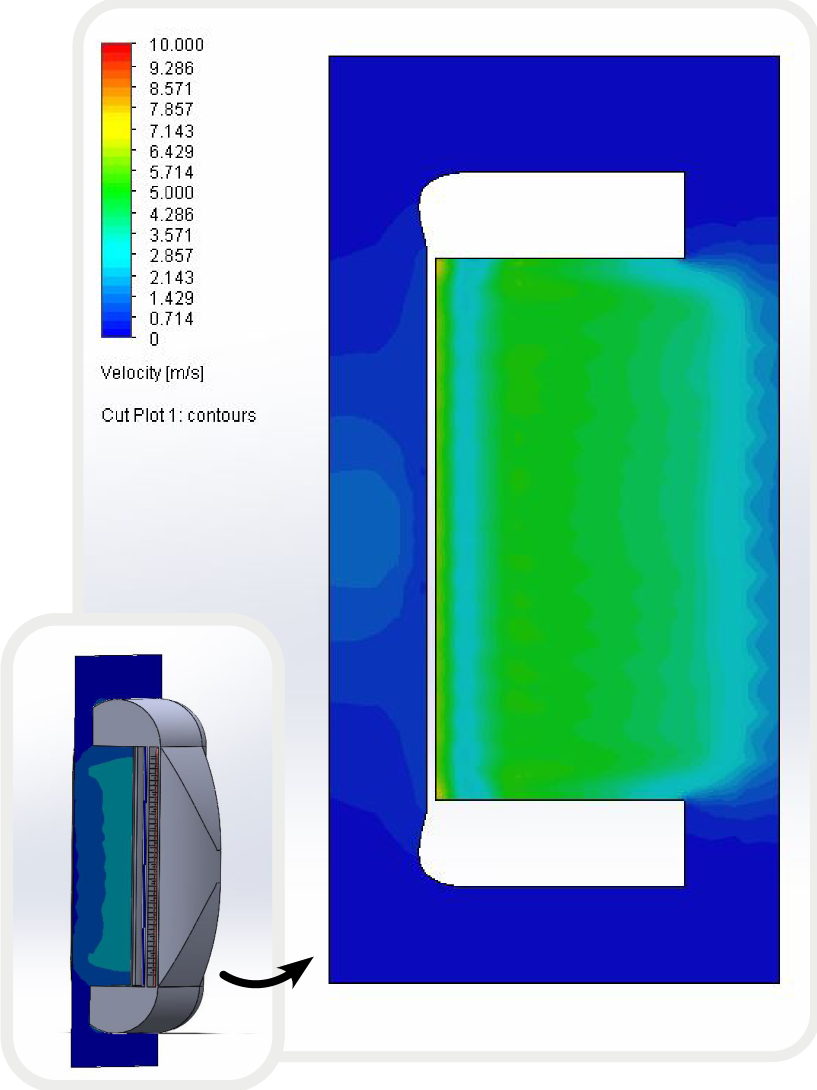


Figure 24 : Section view

4.7.2 New Design Airflow Simulation

A page showing the velocity of the air in the simulation of the design





4.8.1 New Design Heat

A page all about the heat maps
of the proposed design.

Heat

The heat maps of the design show two interesting results, First of all the air around the heat sink becomes relatively hot and secondly the air coming past the heat sink cools down when it mixes with the air coming from the turbine.

The high heat of the air flowing along the heat sink is due to two different things. First of all since the air is flowing due to the venturi effect in the chamber it moves slower than the air through the turbine. This gives the air more time to heat up since it's in contact with the heat sink for a longer period of time. Secondly the heat sink is situated in parallel to the flow of the air, thus increasing the time each air particle is in contact with the heat sink. These two effects result in the increased temperature of the air along the heat sink. (Figure 25)

Since the air flowing through the turbine comes from the atmosphere it has a temperature that's the same to the environment the design is in. (20°C in these simulations) This air gets mixed with the relatively high temperature coming from the heat sink resulting in the medium temperature flowing out of the design. (Figure 26)

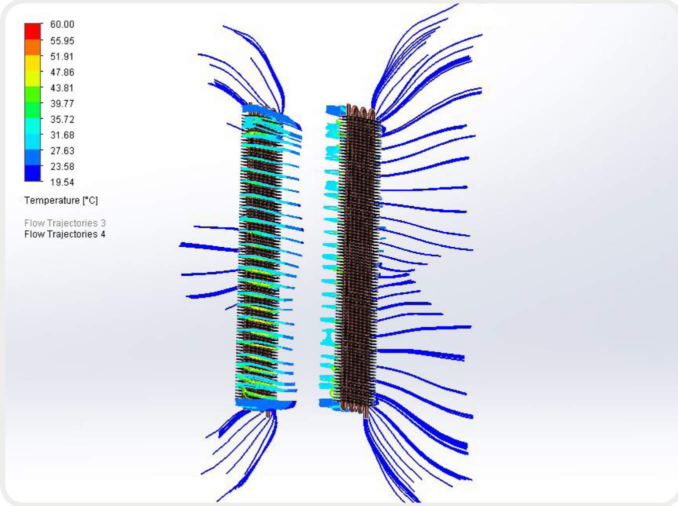


Figure 25 : Heat flow heat sink

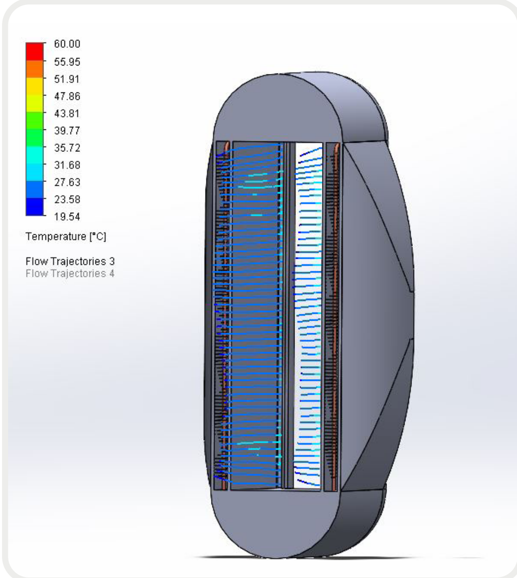
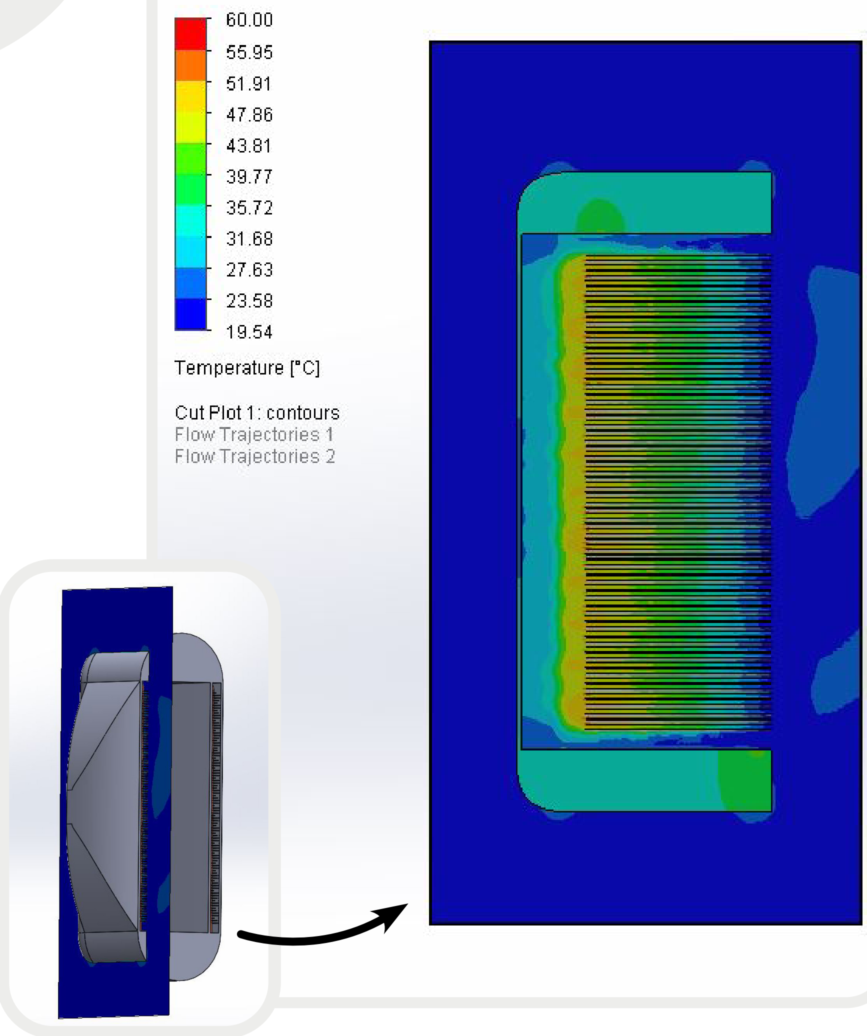
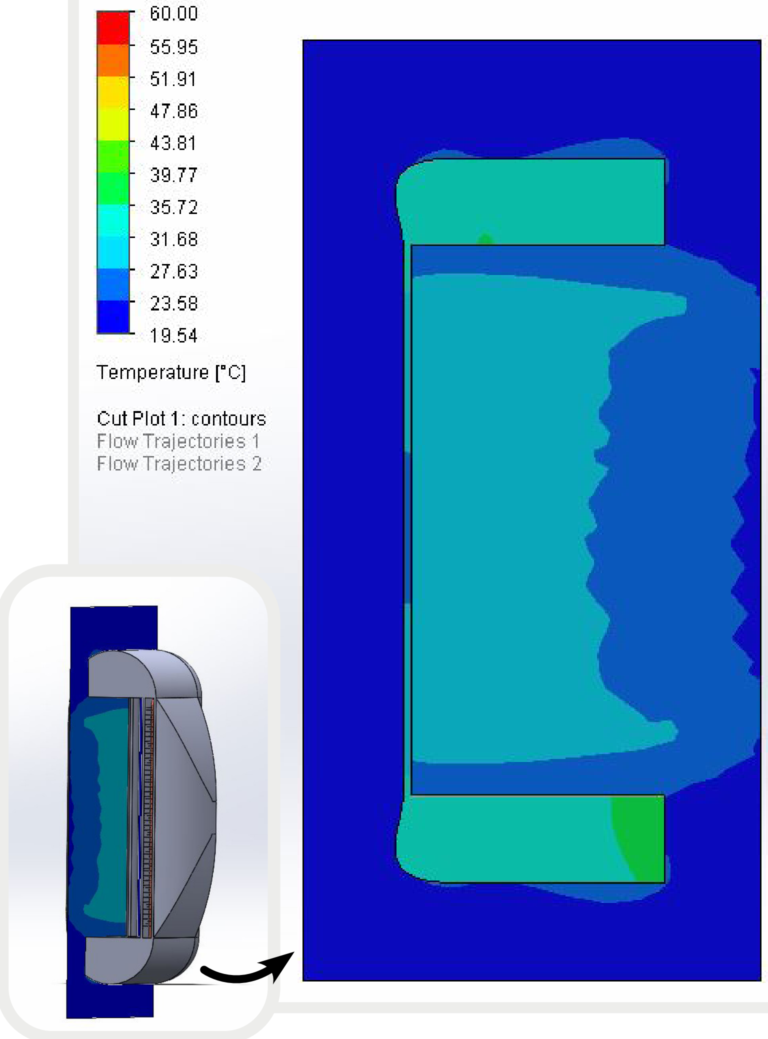


Figure 26 : Section view

4.8.2 New Design Heat Simulation

A page showing the temperature of the air in the simulation of the design





4.9 Simulation Comparison

How do the models and their simulations compare to each other.

Differences

To compare the variables that matter between the Mitsubishi heat pump and the design the focus should first be on the differences between the two models. Mainly in the way the air is being propelled in each of the heat pumps. The Mitsubishi has a relatively big fan blade which will both increase the air that it propells as well as increase the size of the motor needed to make move. to create the same air velocity coming out of the design the turbines have to create a a higher air velocity. (20 m/s for the design against 5 m/s for the mitsubishi). This increased velocity in the air requires smaller motors with a higher rpm.

These motors have a relatively high power consumption compared to their size. (Appendix 8.7)Because of this only two of these motors will have the same power comsumption as the motor used in the mitsubishi model despite their relatively small size. However the total energy consumption of the Mitsubish heat pump is around 4000 W (Appendix 8.6). Meaning that the energy consumption of the heat pump lies mainly in the refrigerant cycle. This is due to the high energy consumption fo the compressor as well as the electrical engineering of the control systems.

Comparison

The proposed design uses the same heat sinks and refrigerant cycles as current heat pumps. Therefore the only possible difference in energy input can be the energy used by the fans of the heat pumps. Since the motors used to propell the turbine in the design can be roughly the same wattage as the Mitsubishi heat pump, the energy input of both the Mitsubishi as the proposed design will be roughly equivalant.

A further step in comparing the design to current heat pumps can come from the creation of a functioning prototype which will be discussed in the recommendations. An overview of the simulation comparison can be found in the following table:

	Mitsubishi	Design
Fan Motor	1000 rpm	4000 rpm
Fan Motor Consumption	200 W	2X100 W
Air velocity at fan	4 m/s	20 m/s
Air temperature	32,06 °C	31,60 °C

4.10 Aesthetic Survey

Two aesthetic surveys were conducted and can be found in full in Appendix 8.9 and 8.10 respectively

Surveys

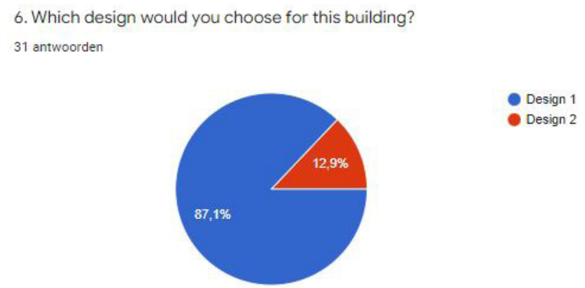
These aesthetic surveys have resulted in two different and interesting results. Both the design and comparison heat pump were shown in both the context they would be placed and an aesthetic vaccuum. In the aesthetic vaccuum the proposed design seems to be the clear favourite but this changes when it is placed in the context of a current building.

When both the design and the comparison heat pump are put in context the design stands out more than current heat pump designs. When asked to focus on heat pumps in their context the comparison heat pump is preferred over the design because it fits most buildings it is placed on. This feeling increased due to the fact that in the context survey attention was placed on the heat pumps. (Quote 1)

This suggests that people prefer heat pumps to blend in to the environment they are placed in and that current heat pump design does this better than the proposed design. (Quote 2) However the result of the aesthetic vaccuum survey suggests that the proposed design does have aesthetic values that are liked by the interviewees. A further step in this research can be to find what specific traits of the design create this discrepancy between vaccuum and context. This will be discussed in the recommendations.

Results

A small collection of the results are shown here, the full results can be found in Appendix 8.9 and 8.10 respectively.



Quote 1: "I almost never notice machinery like that on buildings in real life, and when my attention is drawn to that sort of thing, I'm pretty ambivalent to its nature."

Quote 2: "I think the shape of heat pumps is fine as they are. Making them rounded would call attention to them."

Chapter 5

Conclusions and Recommendations

This chapter shows all the conclusions this project has brought

5.1 Efficiency

The conclusion of the efficeny of the proposed design based on the flow and heat simulations.

Overview

The mitsubishi and the proposed design have different methods of propelling the air over the heat sink (Figure 27 and 28). This makes the comparison between them harder. This was accounted for by finding the regions within both designs that are comparable. The results of this method are shown below.

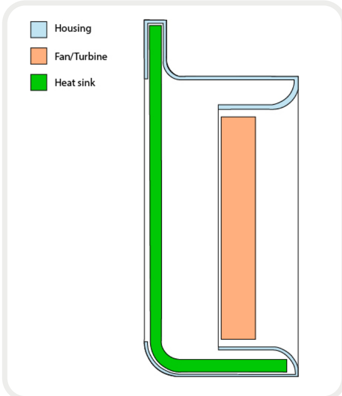


Figure 27 : Mitsubishi

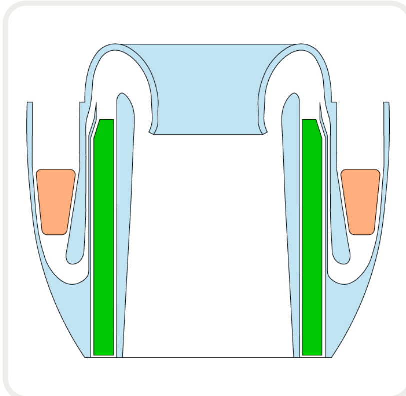


Figure 28 : Design

Results

The main goal of this project is to find out if the proposed techniques and effects to manipulate the air through the proposed design work as expected. In this regard both the Venturi effect as the Coanda effect have been proven to work as intended in the design.

The question that follows this result is: Do these effect create a heat pump that is at least as effective as current heat pumps? This answer is harder to find due to the greater amount of variables involved. To simplify this problem it is split up in two different results. The flow of air through the design and the heat maps of the air.

The simulation of the design give similar results as the Mitsubishi simulations in both airflow and heat. This leads to the conclusion that the proposed design has an efficiency that is comparable to that of current heat pumps. It has not been definitively proven that the proposed design has an increased efficiency based on the current tests. This is due to the fact that the increase in efficiency will mainly come from the difference in fan motor used. This requires further research to be proven definitively.

Simulation results

	Mitsubishi	Design
Air speed at entry	2 m/s	20 m/s
Air speed at exit	5 m/s	5 m/s
Temperature air over heat sink	± 40 °C	± 50 °C
Temperature air just after exit	± 32,06 °C	± 31,60 °C

5.2 Cost

The conclusion of the cost of the proposed design based on the cost of current heat pumps.

Cost

There are two main factors that could increase the cost of the design relative to current heat pumps. These are the embodiment and the fan motors. Both of these require more research to establish fully. However based fan motors currently on the market these will not increase the price of the design significantly.

The embodiment of the design however is a different beast entirely. The embodiment of current heat pumps is rather simplistic and can be boiled down to aluminium plating that's bent and finished. This is not fully possible in the proposed design due to the more intricate shape of the air ducts that are needed to make the Venturi effect possible.

This increase in complexity will show itsself in the cost of this part of the design. However the cost of the embodiment of a heat pump is relatively small. The higher cost components being the compressor, the electrical systems and the heat sinks. Therefore the full price of the proposed design will be slightly higher than current market heat pumps.

Breakdown

A breakdown of the costs of the Mitsubishi MXZ5C42NA and the proposed design is shown here to give an indication of the price increase the design would need. These prices are an indication of real world prices based on the current marekt value of the components.

Cost Breakdown

	Mitsubishi	Design
Refrigerant cycle	€ 2000	€ 2000
Electrical system	€ 500	€ 500
Fan system	€ 250	€ 250
Embodiment	€ 250	€ 500
Profit	€250	€250
Total	€ 3.250	€ 3.500

This is a very basic cost breakdown of the design and more research is needed to get a more accurate cost analysis.

5.3 Aesthetics

The conclusion of the aesthetics of the proposed design based on the conducted surveys.

Results

The aesthetics of the proposed design has been tested through two surveys. The first of these surveys shows the design in its desired context (against the wall of several differnt buildings). The second survey shows the design in an aesthetic vaccuum (plain dark background). These two surveys have very distinct results.

The first survey shows that people prefer current heat pump design in the context of a building. The main reason for this seems to be that the proposed design fits in less to the environment it is placed in. The rounded corners of the design clash with the straight lines of the walls it is placed on. This makes it stand out on the wall while the current designs blend in more.

The second survey shows that if the design is not shown in the context it is prefered over current heat pump design. This difference between the two surveys raises the question if it is preferable to have a design that stands out instead of one that blends in as much as possible. To find out if this is the case more research will have to be conducted focussing on how current heat pumps are experienced.

Colour

Independent of the outcome of these tests, a great way let the design blend in or stand out is colour. The different parts of this design give a wide range of options to create different colour options. Some options of this are highlighted here.

5.4 Final Render

A final render of the proposed design. Indicating how a final product could look.

Chapter 6

Recommendations

This chapter shows all the recommendations for further research and design

6.1 Recommendations

What can be further steps to take
in this project.

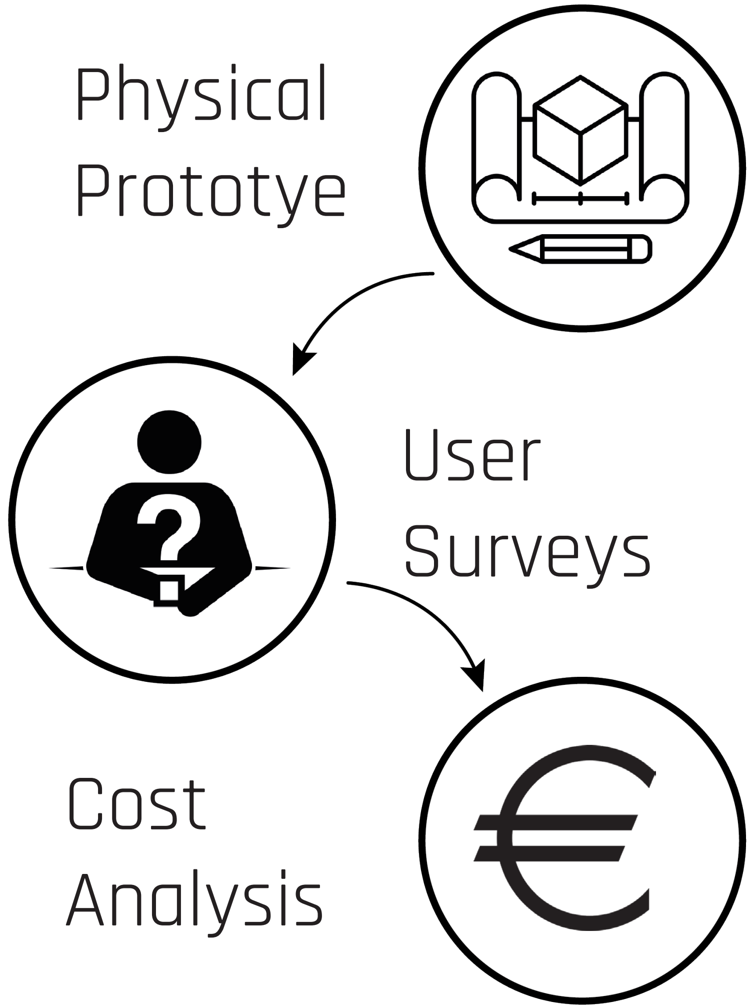
Further steps

There are several steps this project can still take that were not achieved due to time constraints. First of all to fully test all of the effects in the design it will need a full scale physical prototype. This is due to the fact that simulations are only a representation of reality and not reality itsself.

Secondly the surveys that were conducted showed some interesting results that merit a further look. The difference between the aesthetic vaccuum and the context survey raise the question if the design should stand out as much as it does. And if not how does the design need to change to fit the context it is placed in?

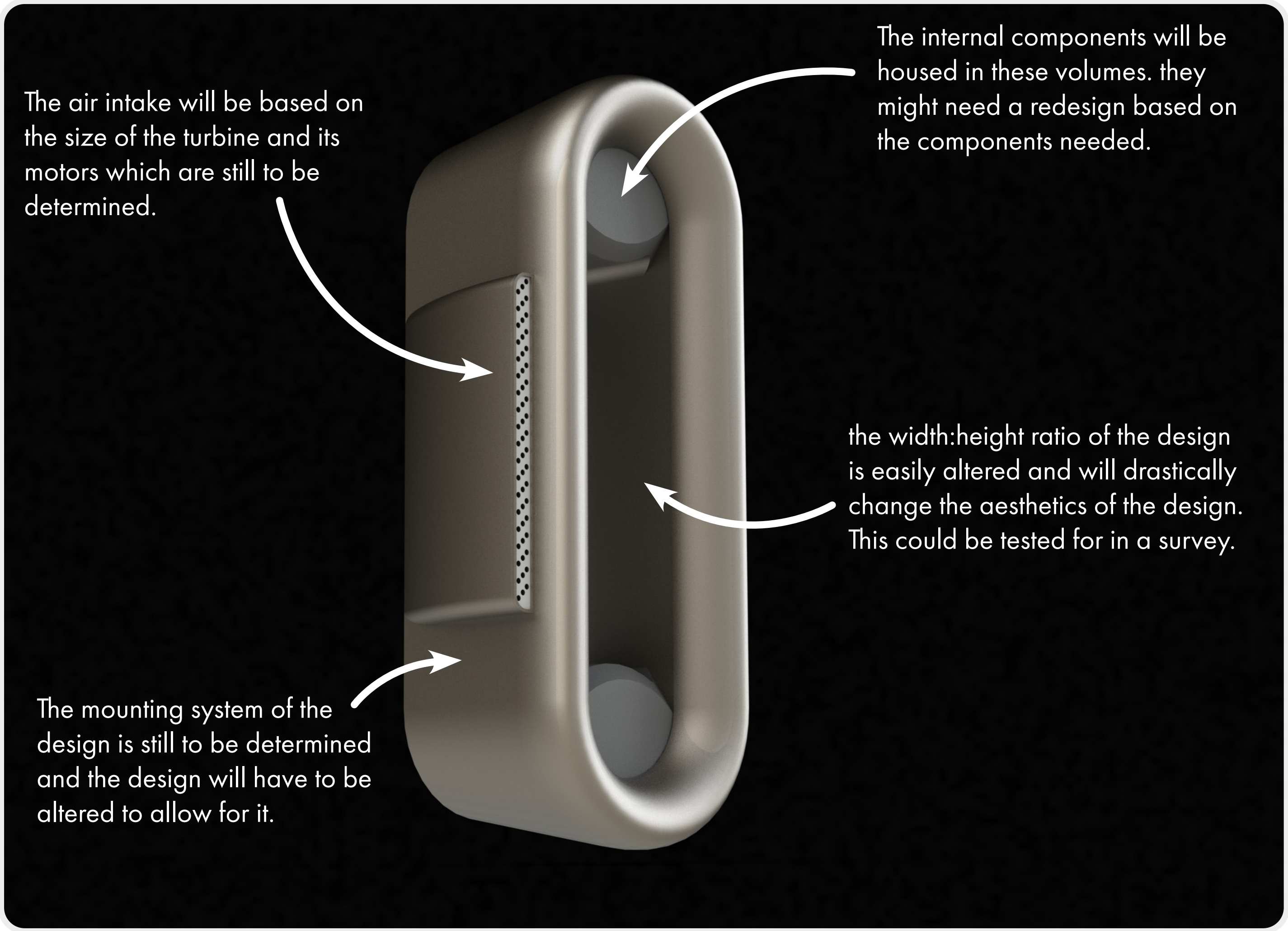
Thirdly creating the physical prototype will give a better view of the costs the final product will have. Therefore increasing the validity of a new cost overview once the prototype is created. This can then be compared to the current market heat pumps

These three steps will bring the design to a point where first steps toward production can start being made. As well as having a base to pitch the project to possible investors.



6.2 Changes to the design

What improvements can already be seen for the design of the product



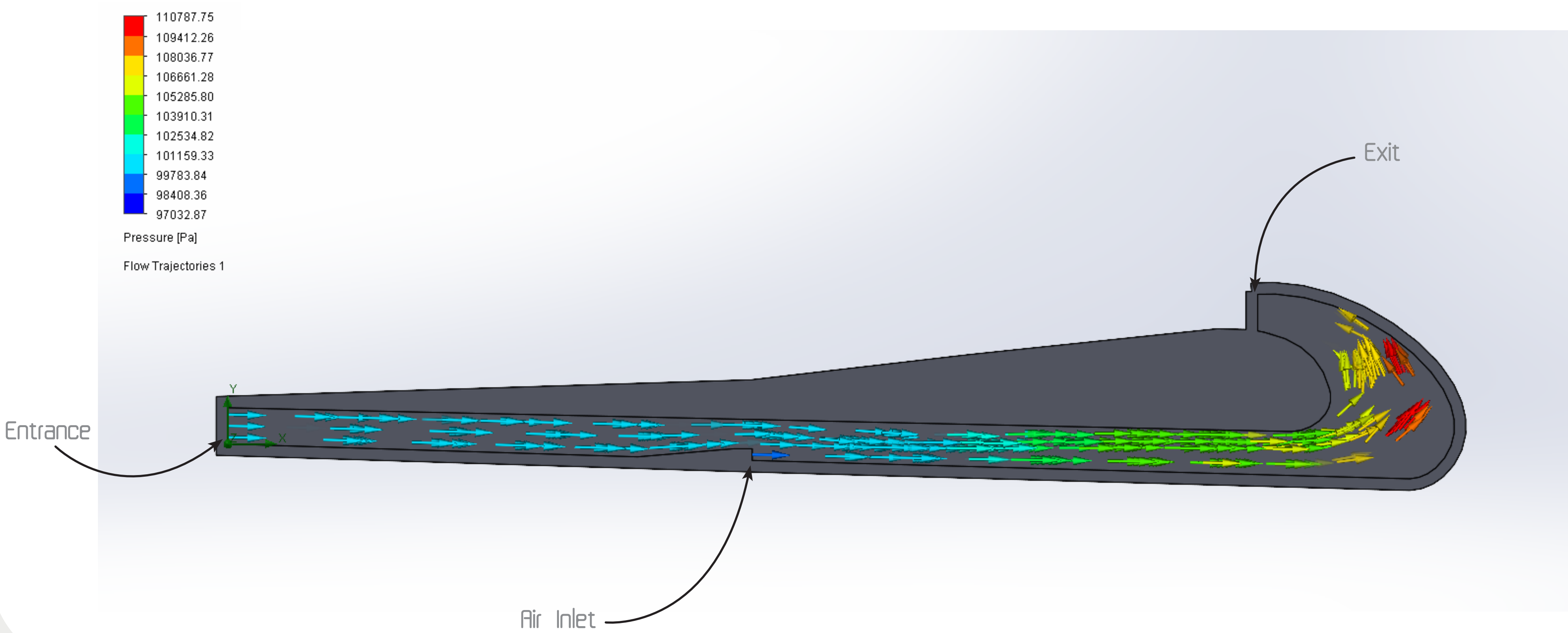
Appendix

This chapter shows all the information that is relevant for reference.

8.1 Simulation - Venturi

The Venturi effect

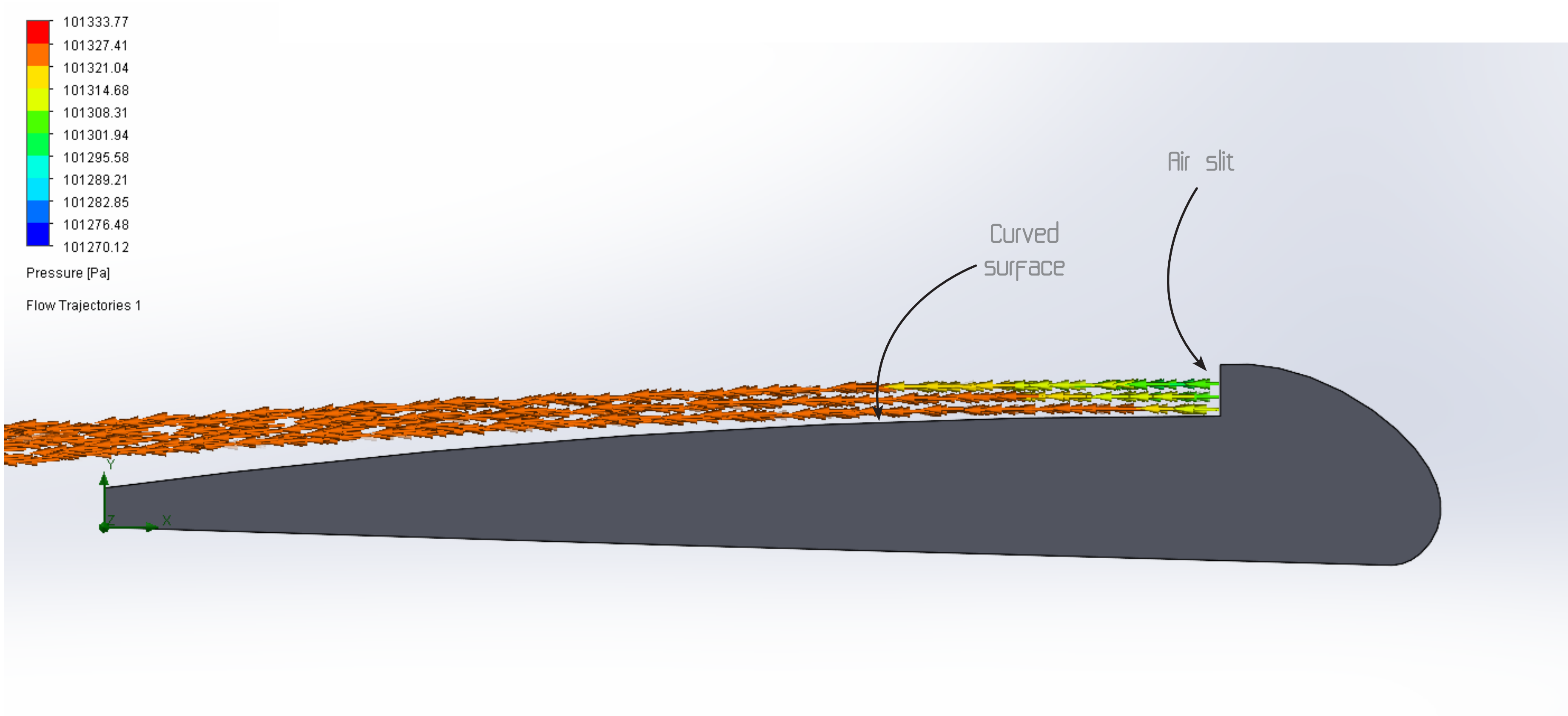
The venturi effect works the way it is intended if the following boundary conditions are met: The entrance and exit holes are roughly the same diameter, The channel the air flows through does not deviate much from this diameter in the flow direction and the air inlet velocity is relatively fast. In this simulation you can clearly see the air from the entrance being pulled in.



8.3 Simulation - Coanda

The Coanda effect

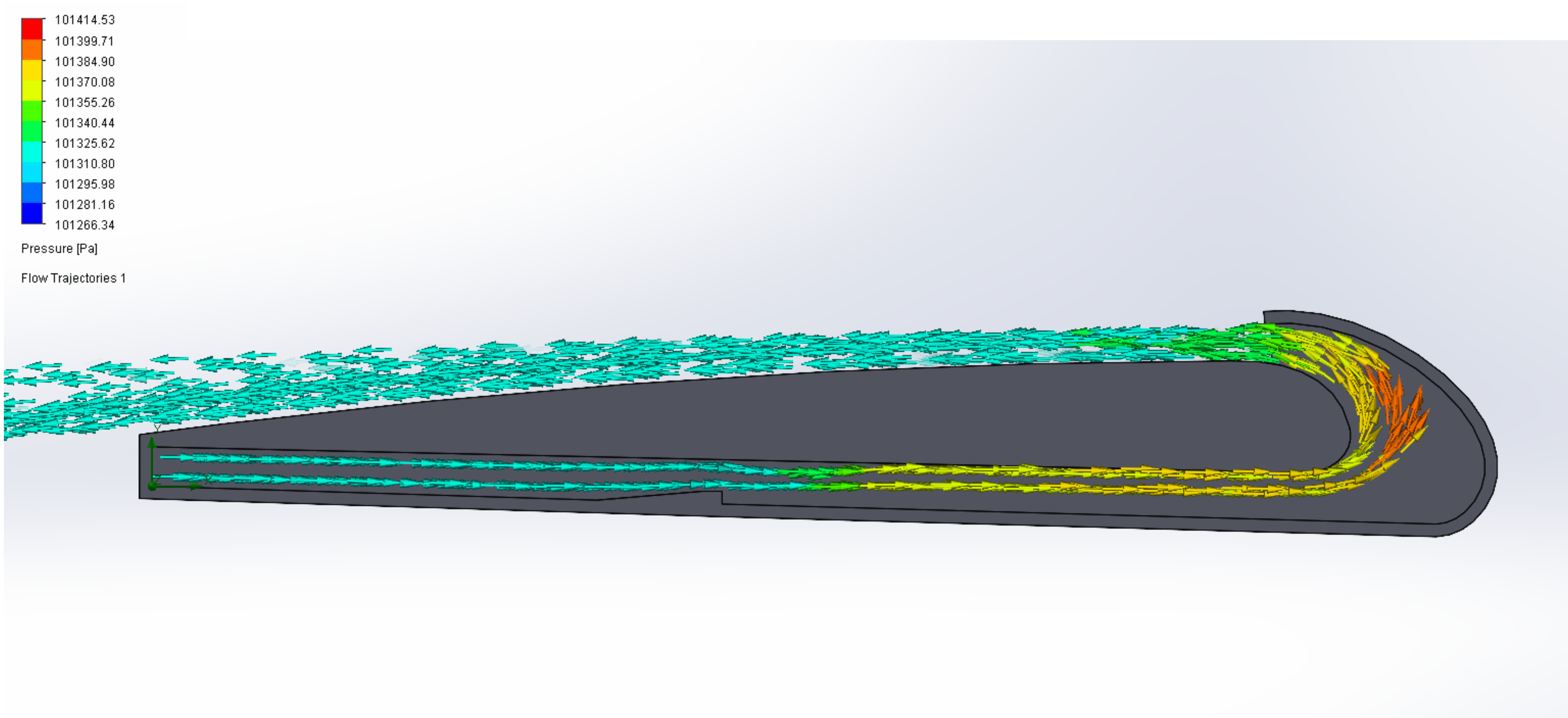
As can be seen the Coanda effects works as intended in the simulations. The flow lines “stick” to the curved surface of the 3D model. This effect however is more apperent if the slit the air comes out of is smaller. This has to be taken into account in the ideation phase and conceptual designs to follow.



8.4 Simulation - Combined

Both effects

These effects combined show that they can work in unison to create the desired effects in a heat pump. Both these effects can therefore be used in the following conceptual designs. After the creation of a 3D model of the concepts these effects will be tested in a 3D space to see if they still work as intended.



8.5 Physical Test Setup

To make sure the simulations can be trusted in the 3D models a physical test was created. This test follows the same setup as the 3D models. These being:

- A 2D representation of the principle
- Streamlines being shown (through smoke)

The test setup consists of the following items:

- The prototype wing
- Stand to place the prototype on
- Incense for smoke creation
- Compressor for air flow
- Camera and appropriate background
- Anemometer

Figure 12 : Test setup items

8.6 Mitsubishi Specifications

Specifications			Model Name
Unit Type			MXZ-5C42NA
Cooling* (Non-ducted / Ducted)	Rated Capacity	Btu/h	40,500 / 37,400
	Capacity Range	Btu/h	6,000 - 43,000
	Rated Total Input	W	4,403 / 4,112
Heating at 47°F* (Non-ducted / Ducted)	Rated Capacity	Btu/h	45,000 / 41,000
	Capacity Range	Btu/h	7,200 - 53,600
	Rated Total Input	W	3,575 / 3,463
Heating at 17°F* (Non-ducted/Ducted)	Rated Capacity	Btu/h	24,400 / 23,000
	Rated Total Input	W	2,943 / 2,869
Electrical Requirements	Power Supply	Voltage, Phase, Hertz	208 / 230V, 1-Phase, 60 Hz
	Recommended Fuse/Breaker Size	A	40
	MCA	A	31.9
Voltage	Indoor - Outdoor S1-S2	V	AC 208 / 230
	Indoor - Outdoor S2-S3	V	DC ±24
Compressor			INVERTER-driven Scroll Hermetic
Fan Motor (ECM)		F.L.A.	1.9
Sound Pressure Level	Cooling	dB(A)	56
	Heating		58
External Dimensions (H x W x D)		In (mm)	41-9/32 x 37-13/32 x 13 (1048 x 950 x 330)
Net Weight		Lbs (kg)	189 (86)
External Finish			Munsell No. 3Y 7.8/11
Refrigerant Pipe Size O.D.	Liquid (High Pressure)	In (mm)	1/4 (6.35)
	Gas (Low Pressure)		A:1/2 (12.7) ; B,C,D,E: 3/8 (9.52)
Max. Refrigerant Line Length		Ft (m)	262 (80)
Max. Piping Length for Each Indoor Unit		Ft (m)	82 (25)
Max. Refrigerant Pipe Height Difference	If IDU is Above ODU	Ft (m)	49 (15)
	If IDU is Below ODU		49 (15)
Connection Method			Flared/Flared
Refrigerant			R410A

8.7 Motor reference

Mitsubishi fan motor

Ecodan ECM motor 1.9 1000 rpm

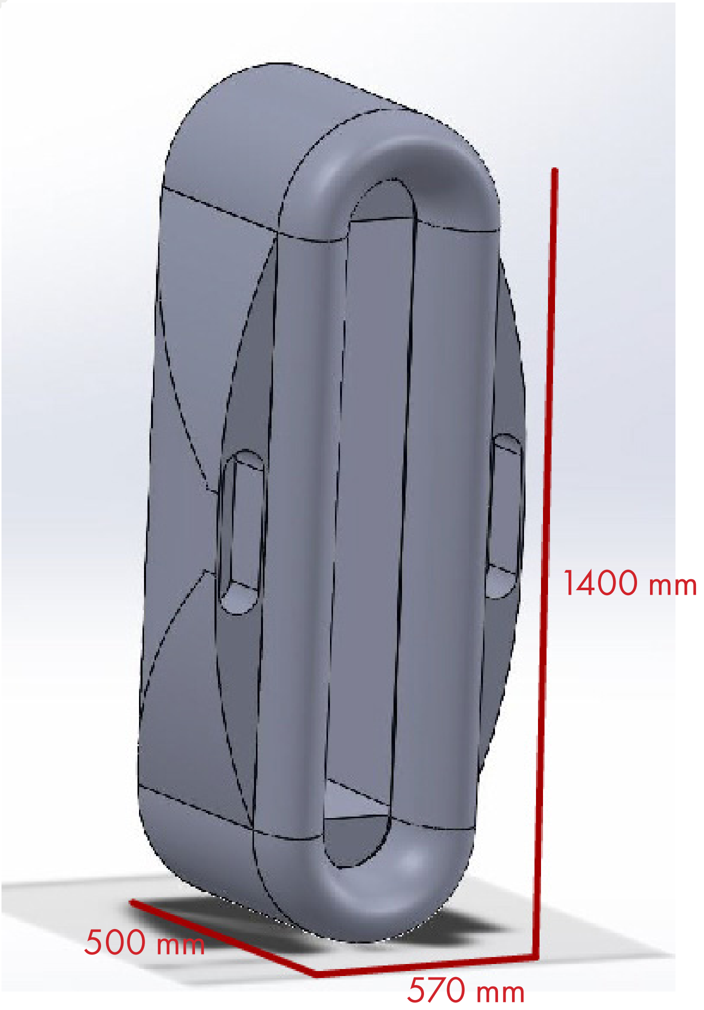
Motor speed	1000 rpm
Electric consumption	200 W

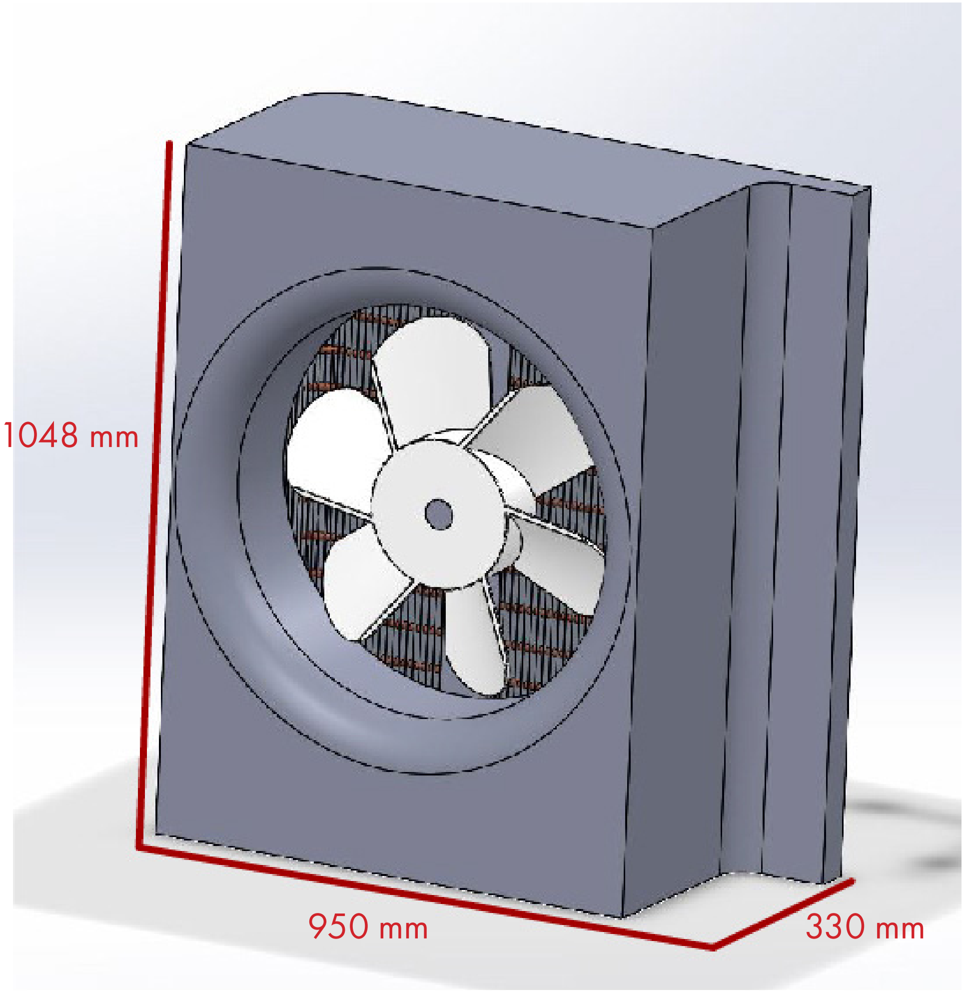
Possible design turbine motor

QBL4208-81-4 DC motor 4000 rpm

Motor speed	4000 rpm
Electric consumption	100 W

8.8 3D Model Dimensions





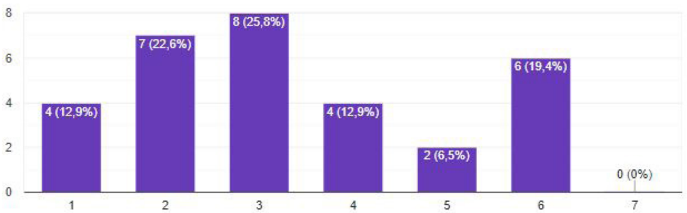
8.9 Survey Results 1 - Designs in context

1.1 Does the design stand out of fit in? *

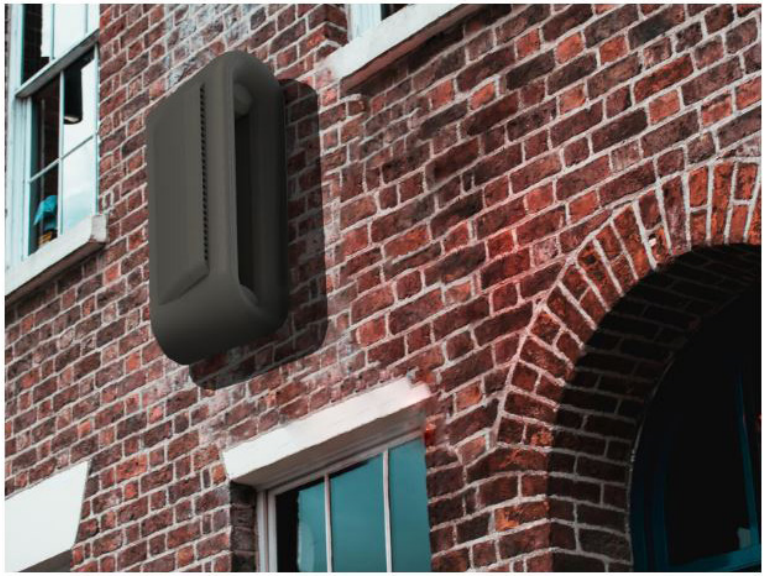
	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

1.1 Does the design stand out of fit in?

31 antwoorden



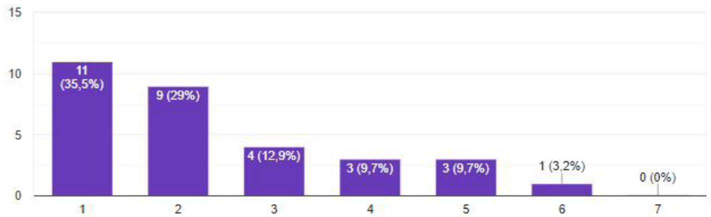
1.2 Does the design stand out or fit in? *



	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

1.2 Does the design stand out or fit in?

31 antwoorden



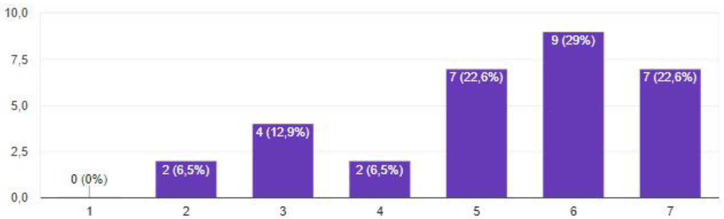
Survey Results 1 - Designs in context

2.1 Does the design stand out or fit in? *

	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

2.1 Does the design stand out or fit in?

31 antwoorden

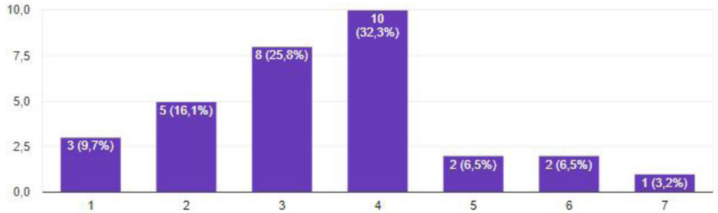


2.2 Does the design stand out or fit in? *

	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

2.2 Does the design stand out or fit in?

31 antwoorden



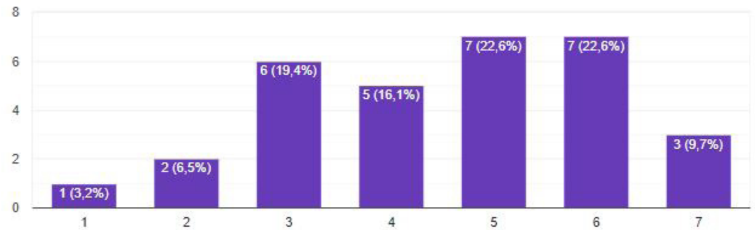
Survey Results 1 - Designs in context

3.1 Does the design stand out or fit in? *

	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

3.1 Does the design stand out or fit in?

31 antwoorden

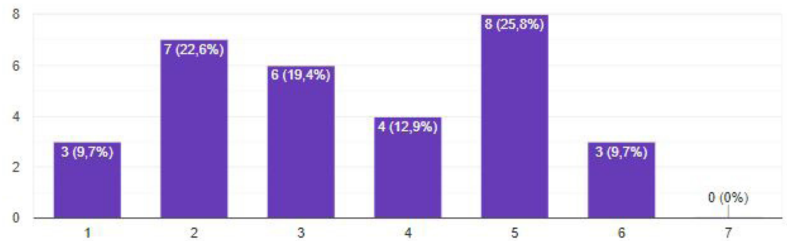


3.2 Does the design stand out or fit in? *

	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

3.2 Does the design stand out or fit in?

31 antwoorden



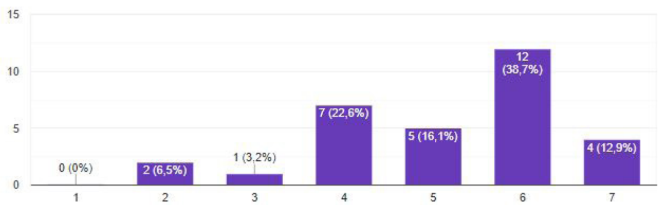
Survey Results 1 - Designs in context

4.1 Does the design stand out or fit in? *

	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

4.1 Does the design stand out or fit in?

31 antwoorden

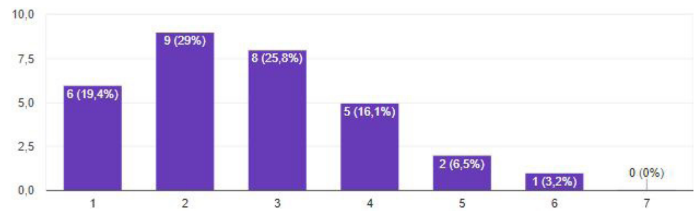


4.2 Does the design stand out or fit in? *

	1	2	3	4	5	6	7	
Stands out	○	○	○	○	○	○	○	Fits in

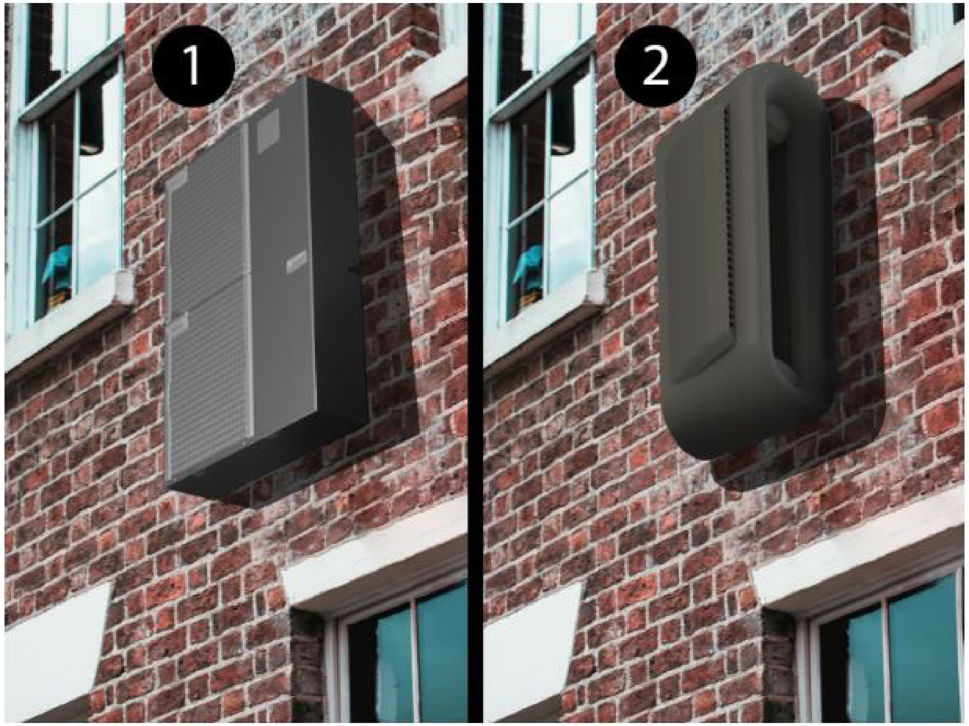
4.2 Does the design stand out or fit in?

31 antwoorden



Survey Results 1 - Designs in context

5. Which design would you choose for this building? *

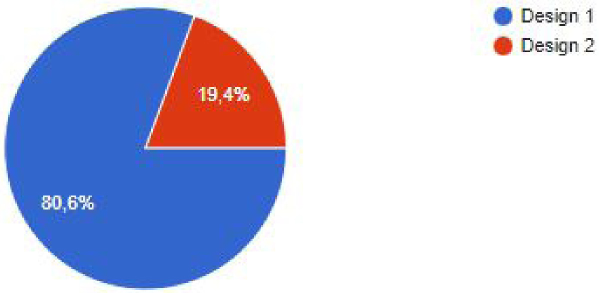


◯ Design 1

◯ Design 2

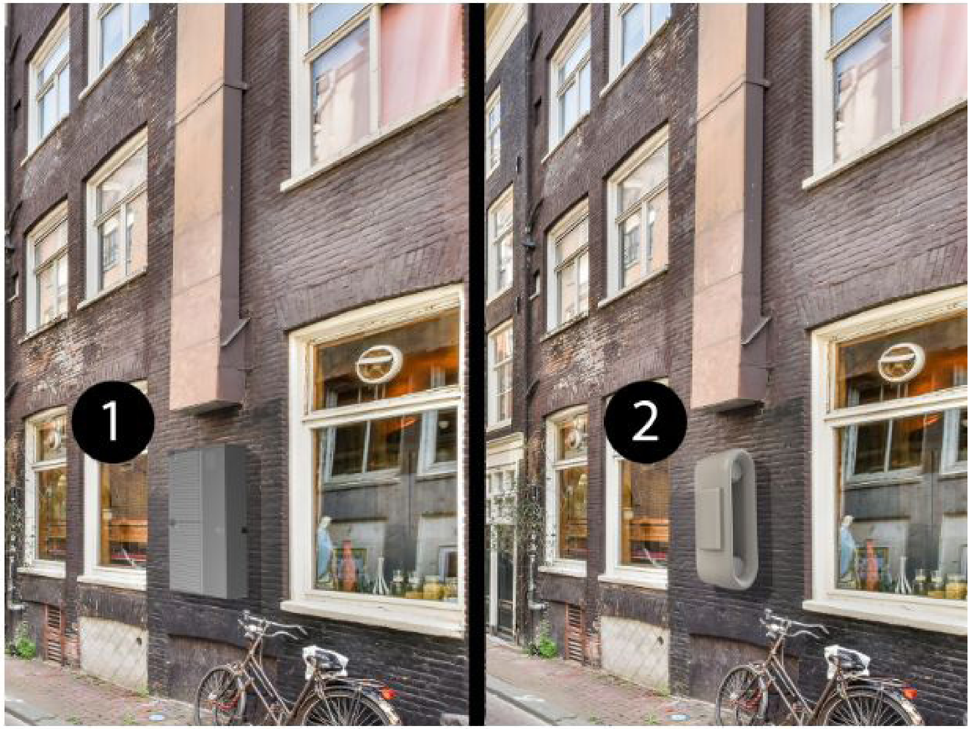
5. Which design would you choose for this building?

31 antwoorden



Survey Results 1 - Designs in context

6. Which design would you choose for this building? *

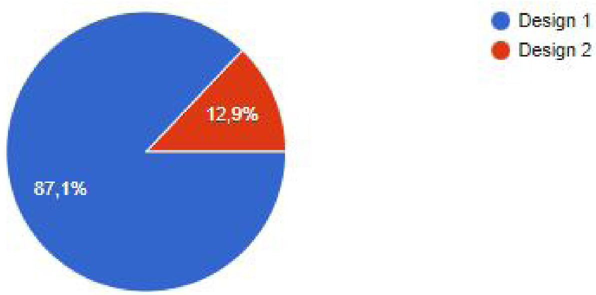


◯ Design 1

◯ Design 2

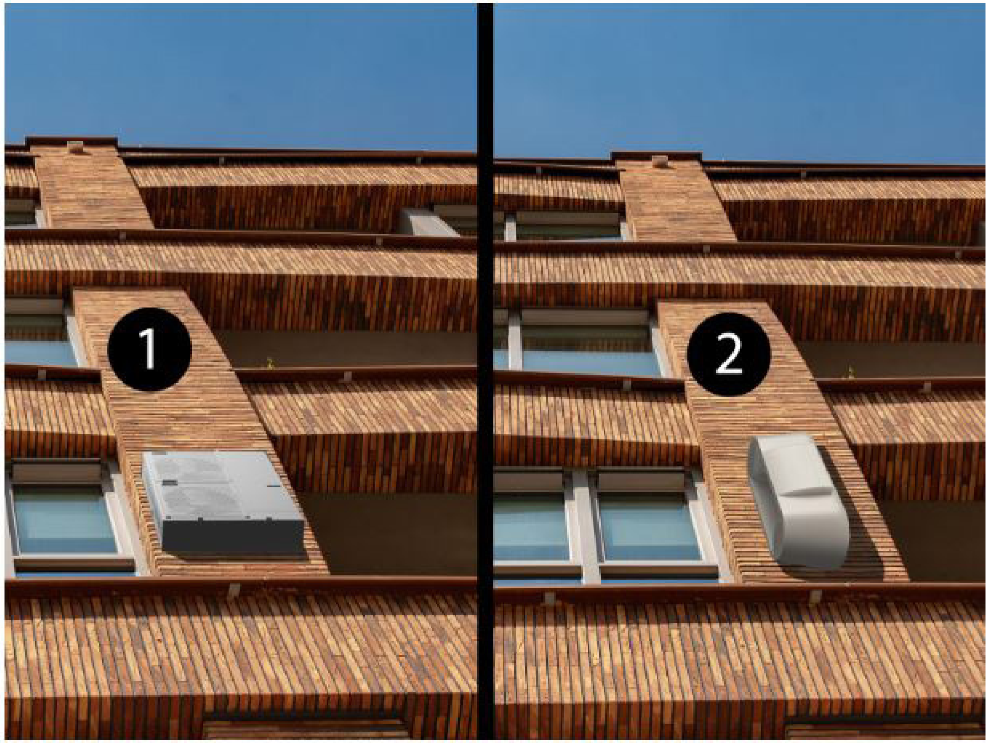
6. Which design would you choose for this building?

31 antwoorden



Survey Results 1 - Designs in context

7. Which design would you choose for this building? *

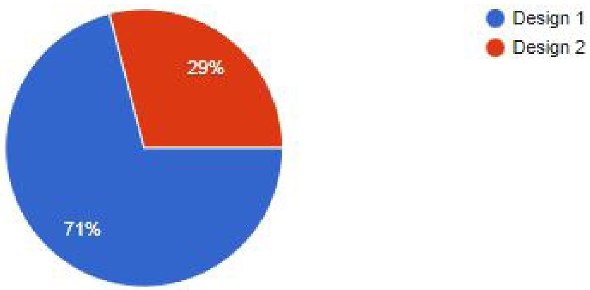


Design 1

Design 2

7. Which design would you choose for this building?

31 antwoorden

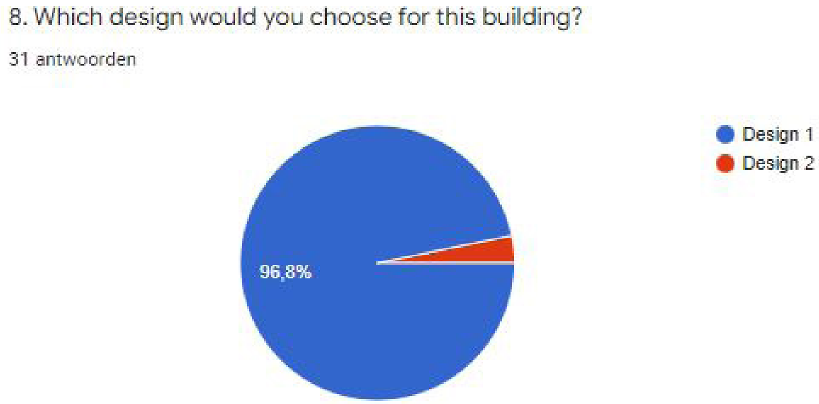


Survey Results 1 - Designs in context

8. Which design would you choose for this building? *

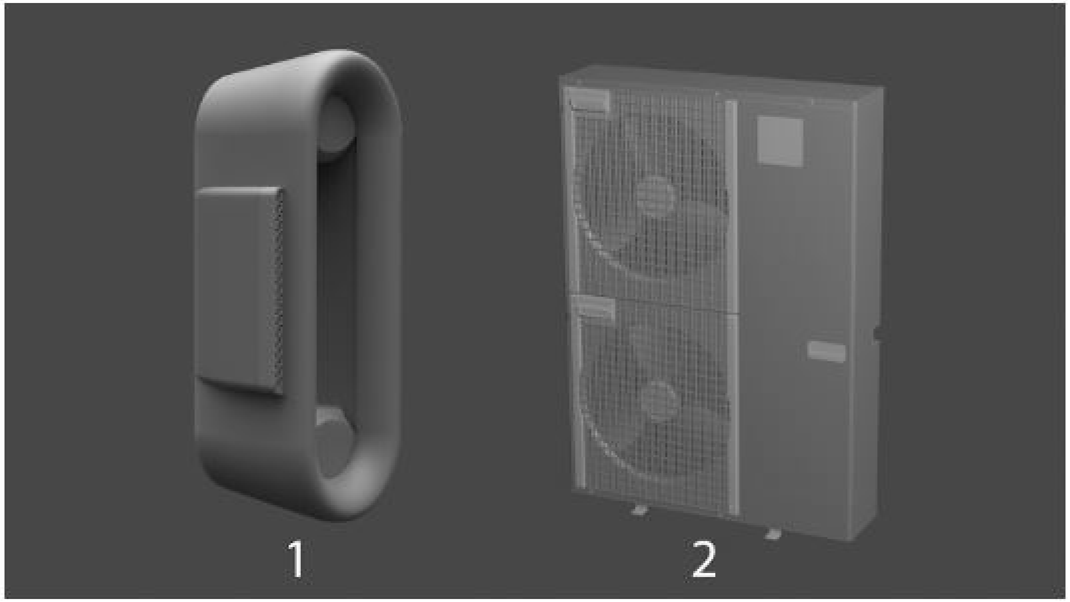
Design 1

Design 2



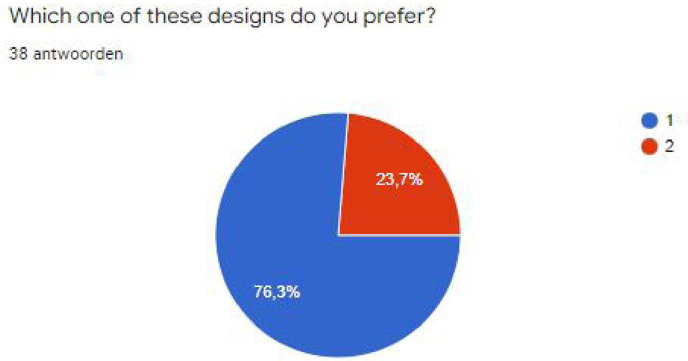
8.10 Survey Results 2 - Aesthetic Vaccuum

Which one of these designs do you prefer? *



◯ 1

◯ 2



8.11 References

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8.12 Contact Information

For the full data package use the following information:

- Name: Joost Remmerswaal
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