THE ZERO EMISSION HANGAR

REDUCING THE ENERGY CONSUMPTION OF THE AIRCRAFT HANGAR THROUGH LOCAL HEATING

a graduation study by Jens van Houwelingen

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Author
Jens van Houwelingen

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MSc. Integrated Product Design
Faculty of Industrial Design Engineering
Delft University of Technology

Company
KLM Royal Dutch Airlines

Supervisory Team
Chair Prof. Dr. Ir. Jo van Engelen
Mentor Ir. Caroline Kroon
Company mentor MSc. Jasper Rougoor

TU Delft

KLM

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Summary

The aviation industry is responsible for 2.5% of global CO_2 emissions, emitting over one billion tonnes of CO_2 in 2018 (Ritchie, 2020). The International Air Transport Association (IATA) committed to net-zero aviation by 2050 (International Air Transport Association, 2022). The first steps toward net-zero aviation can be taken in the ground operations. Air France KLM set the goal for net-zero ground operations by 2030 (KLM Royal Dutch Airlines, n.d. -b). The aircraft hangars are responsible for 67% of all ground operations emissions at KLM (Veldhuizen, van, 2022) and a large portion of those emissions can be regarded to the heating of the hangars.

The process of heating the hangar is neither efficient, nor effective, despite the large amount of energy it consumes. The opening of the hangar doors to pull aircraft in and out of the hangar cause the temperature inside the hangar to approach the outside temperature. It takes 4 to 6 hours for the hangar to be up to the desired temperature again, but oftentimes the hangar doors will have been opened before the desired temperature is reached. It was found that heat in the hangar is firstly needed for the mechanics working there and secondly for the aircraft when specific repairs with a curing element have to be performed. The fluctuations in temperature lead to thermal discomfort for the mechanics (Lampret et al., 2018) and negatively affect the drying times of sealants.

This study discovered potential energy savings of 69% when the base temperature would be lowered to 10°C and heat would be provided locally where it is needed. The 69% in energy savings can be translated to money savings of €60.000,- per winter month (December 2021 taken as reference, see Chapter 2.7), or close to €400.000,- per year and 436 tons of CO_2 (see Chapter 2.7).

Alongside the research into potential energy savings in the hangar, ideas were collected within the company. The ideas were visualized and feedback was gathered at different divisions within KLM. The ideas were divided into two main categories, namely *Heat Conservation* and *Local Heating*. In the course of the project it was chosen to focus on local heating. The heating analysis showed that conserving the heat in the hangar was not a feasible solution since the hangar doors are opened for too long for heat conservation to be effective. Furthermore, when the base temperature is lowered, and additional heating is done locally where needed, there is not a lot of heat to be preserved in the first place.

The study proposes to lower the base temperature in the hangar to 10°C and provide local heating for the mechanics through heated apparel. The aircraft is heated locally during the curing phase of composite repairs but is often not heated with other curing processes such as after paintjobs. It should be considered to heat the aircraft locally more often to ensure optimal fleet availability.

Glossary

KLM: Koninklijke Luchtvaart Maatschappij (Royal Airlines).

AFI KLM E&M: Air France Industries KLM Engineering and Maintenance.

IATA: International Air Transport Association.

OCC: Operations Control Centre.

ES: Engine Services.

CS: Component Services.

Hangar: Large halls where aircraft are maintained.

Widebody: Larger aircraft, in passenger planes with two isles, that are used for long-haul flights. In KLM's fleet: Boeing 747 (cargo), Boeing 777, Boeing 787 and Airbus A330.

Narrowbody: Smaller commercial aircraft with one isle. Narrowbody aircraft are used for flights up to approximately 4 hours. In KLM's fleet: Boeing 737, upcoming Airbus A320NEO (Cityhopper: Embraer E2, E190, E175).

A-Check/FA: Planned maintenance of 16 to 24 hours.

C-Check/FC: Planned maintenance of 2 to 3 weeks.

Corrective (maintenance): Non-scheduled maintenance due to failures, such as repairs and is primarily done in Hangar 11.

Preventive (maintenance): Scheduled maintenance such as the A-Check or C-check, this maintenance can be compared to planned servicing of a car.

H11/H12/H14: Hangar 11, 12, 14, these are the main hangars of KLM at Schiphol East.

MRO: Maintenance, Repair and Overhaul divisions of airlines maintain aircraft. Air France KLM Engineering and Maintenance is one of the world's leading MRO's. It maintains parts, engines, and aircraft of airlines from all over the world.

SAF: Sustainable Aviation Fuel.

Sunstrips: Long and narrow radiators attached to the ceiling of the hangar.

GTL: Gas-To-Liquids, a fuel made from natural gas, a more sustainable form of diesel.

Fuselage: The body of an airplane, the long hollow tube that the passengers are seated in.

CIL: Continuous Improvement Lead.

Vertical Stabilizer: The tail of an aircraft.

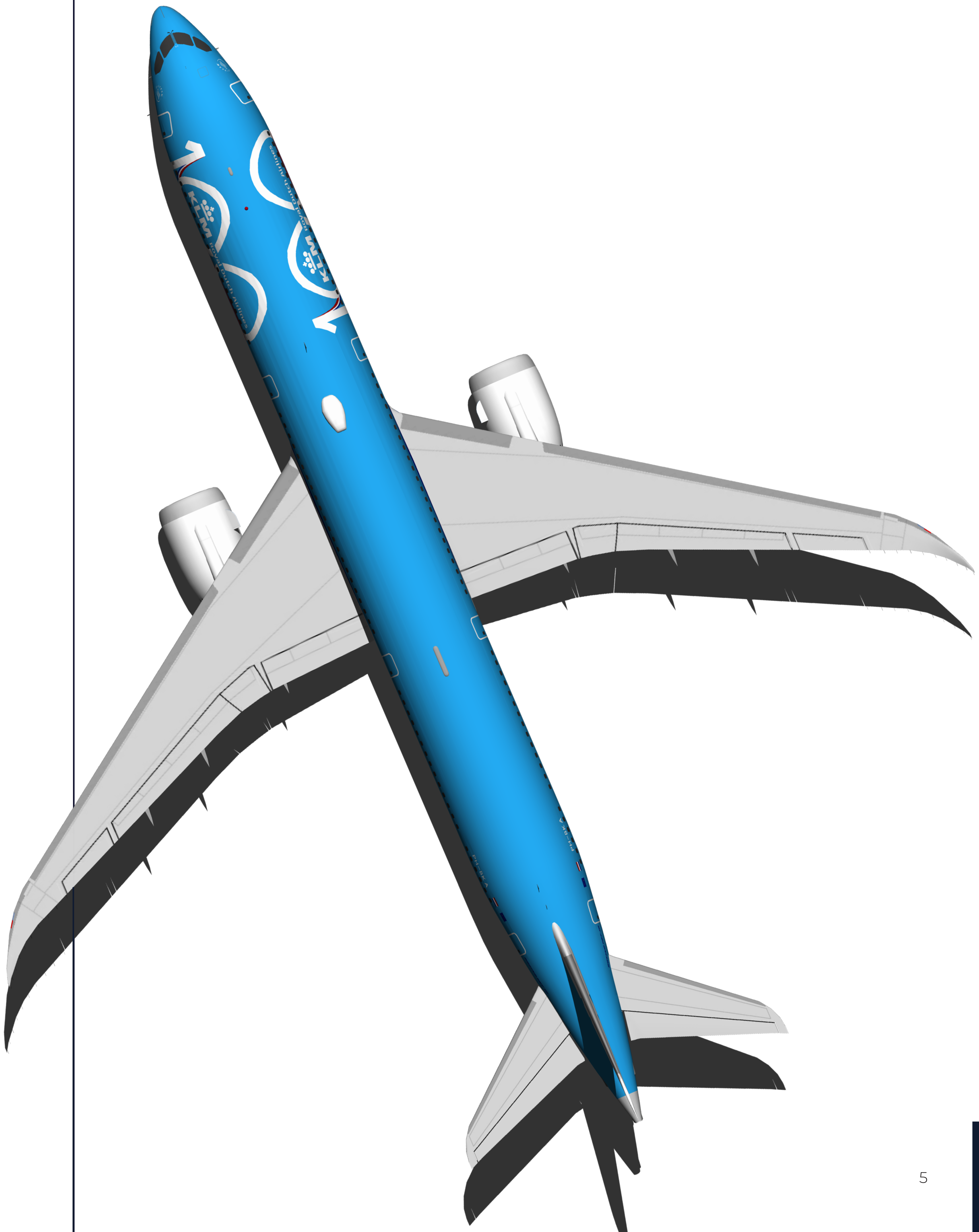
Turnaround time: The time it takes for an aircraft from arrival to departure at a certain location. This can relate to the amount of time that an aircraft is at the gate between flights, but it can also relate to the amount of time the aircraft spends in the hangar.

Bold Moves: A collection of innovation and sustainability related projects within KLM Engineering and Maintenance.

Zero Emission Hangar: The Bold Moves project that aims to reduce the CO_2 emissions of the hangars to zero. This study is part of the Zero Emission Hangar project.

Plant Leader: The top supervisor for a plant, in this case the corrective and preventive plant or Hangar 11 and Hangar 12 respectively.

Tug / aircraft tug: Special vehicle used to pushback or park aircraft.



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Chapter 1 - Context

1.1 General Introduction

From its start in the early 1900s, the aviation industry has played a vital role in connecting the world. Aviation has made the world accessible, but more recently concerns about its future have arisen. In a world where sustainability is more and more important, the inherently unsustainable industry of aviation is scrutinized and the “flygskam” (flight shame) movement, causes more and more passengers to choose alternate travel options (Hervey-Bathurst, 2019).

The aviation industry is responsible for 2.5% of global CO_2 emissions, emitting over one billion tonnes of CO_2 in 2018 (Ritchie, 2020). In order for aviation not to become “the new smoking”, drastic measures need to be taken.

The International Air Transport Association (IATA) have committed to net-zero aviation by 2050. This will have to be achieved by elimination of emissions at the source, offsetting and carbon capture technologies (International Air Transport Association, 2022). The largest contributor to this goal is the development of Sustainable Aviation Fuel (SAF) which is expected to account for 34% of the savings according to NLR (2021). The development of SAF however takes time, in the more short-term, the focus is on the renewal of fleets and the decarbonization of the ground operations.

Air France KLM has set their goal for net-zero ground operations by 2030 (KLM Royal Dutch Airlines, n.d. -b). The Bold Moves Engineering and Maintenance was set up as an initiative within KLM Engineering and Maintenance to work towards this goal. The Bold Moves E&M is an initiative of multiple projects. This study is part of the project Zero Emission Hangar. At KLM 67% of ground operation CO_2 emissions are taken up by the hangars (Veldhuizen, van, 2022). A large portion can be regarded to the heating of the hangars.

This study focuses on the concept of heating the hangar, questioning the necessity of heat and introducing the opportunity of only heating locally where the heat is actually needed. Another intern studied green heating options for the hangars that KLM could consider on the road to the Zero Emission Hangar. By innovating both the way that heating is done (heating locally) and the source of the heating (green heating initiatives), the energy consumption for heating the hangar can drastically be reduced.

1.2 The Company

KLM Royal Dutch Airlines is the oldest airline in the world still operating under its original name. In 2019 KLM celebrated its 100th birthday. Their signature “sky blue” planes are instantly recognizable and are a part of the Dutch identity.

KLM was founded in 1919 by Albert Plesman, less than 16 years after the first ever motorized flight by the Wright Flyer in 1903. KLM’s first flight was carried out on the 17th of May 1920, when pilot Jerry Shaw flew a leased De Havilland DH-16 from London to Amsterdam Schiphol Airport (KLM Royal Dutch Airlines, n.d. -c). In 1930, KLM was the first airline in the world to provide a regular service from Europe to Batavia (Jakarta) and for 10 years this was the longest scheduled flight in the world, a trip of 14.000 kilometres (Nolen, n.d.).

Over the years KLM has accomplished a lot, in 1934 KLM famously won the MacRobertson London - Melbourne air race with the Douglas DC-2 nicknamed Uiver. The most notable occurrence of the 90 hour, 20.000km trip was the emergency landing the crew had to make on a horse racing track, where the locals were instructed by a radio station to light up the track with the headlights of their cars (Steen, van der, 2013).

In 2004, Air France and KLM merged into Air France-KLM. This created the largest European airline group (KLM Royal Dutch Airlines, n.d. -a). The merger gave both airlines a more competitive position against other European airline groups. It also allowed both airlines to save costs in maintenance and operation (Hayward, 2021). Both Air France and KLM continued to operate under their own name and branding is mostly done separately.

The merger of Air France and KLM also marks the founding of AFI KLM E&M (Air France Industries KLM Engineering and Maintenance). AFI KLM E&M is a global leader in the MRO world and maintains over 3000 aircraft for more than 200 airlines worldwide (AFI KLM E&M, 2022). In 2019 AFI KLM E&M had a total revenue of 4.6 billion euros and a total profit of 260 million euros (AFI KLM E&M, 2022).

The Corona pandemic hit the world hard in 2020 and the aviation industry in particular took a hit. KLM is no exception to this. In 2019 over 35.000.000 passengers flew with KLM (KLM Royal Dutch Airlines, 2020), in 2020 this number was reduced by 68% (KLM Royal Dutch Airlines, 2021). In 2022, KLM is still recovering from the largest crisis the airline industry has ever faced. Operation is back to approximately 85% of normal and all 942 million euros in loans were paid off (VNC, 2022).

As of 2022, KLM operates a fleet of 109 aircraft (168 including its daughter company KLM Cityhopper) (Airfleets, 2022) with direct flights to 172 destinations in 69 countries (FlightConnections, 2022). KLM employs approximately 33.000 people and is in the top 10 largest employers of the Netherlands.

1.3 KLM Engineering & Maintenance - The KLM Schiphol East area

The KLM Engineering and Maintenance area at Schiphol-East houses six different aircraft hangars. In those hangars different maintenance activities are performed. Apart from hangars the area also houses the Operation Control Centre (OCC), Engine Services (ES) and Component Services (CS), as well as multiple other offices and engineering buildings. Engine Services and Component Services service engines and components for KLM but even more so for clients from all over the world. In total, approximately 5.000 employees are working at KLM Engineering and Maintenance.

The main hangars currently in use by KLM are Hangar 11, 12 and 14. Hangar 11 and 12 are used for shorter maintenance, such as A-Checks (24-hour maintenance) and corrective maintenance. Hangar 14 is used for C-checks (extensive maintenance) and modifications to aircraft. Both the C-check and modifications usually take two to three weeks. This means the hangar doors are not open frequently and the loss of heat is less of a problem compared to Hangar 11 and 12. The scope of this project mainly involves Hangar 11 and Hangar 12 because heating up these hangars is more of a challenge given their current purpose compared to Hangar 14.

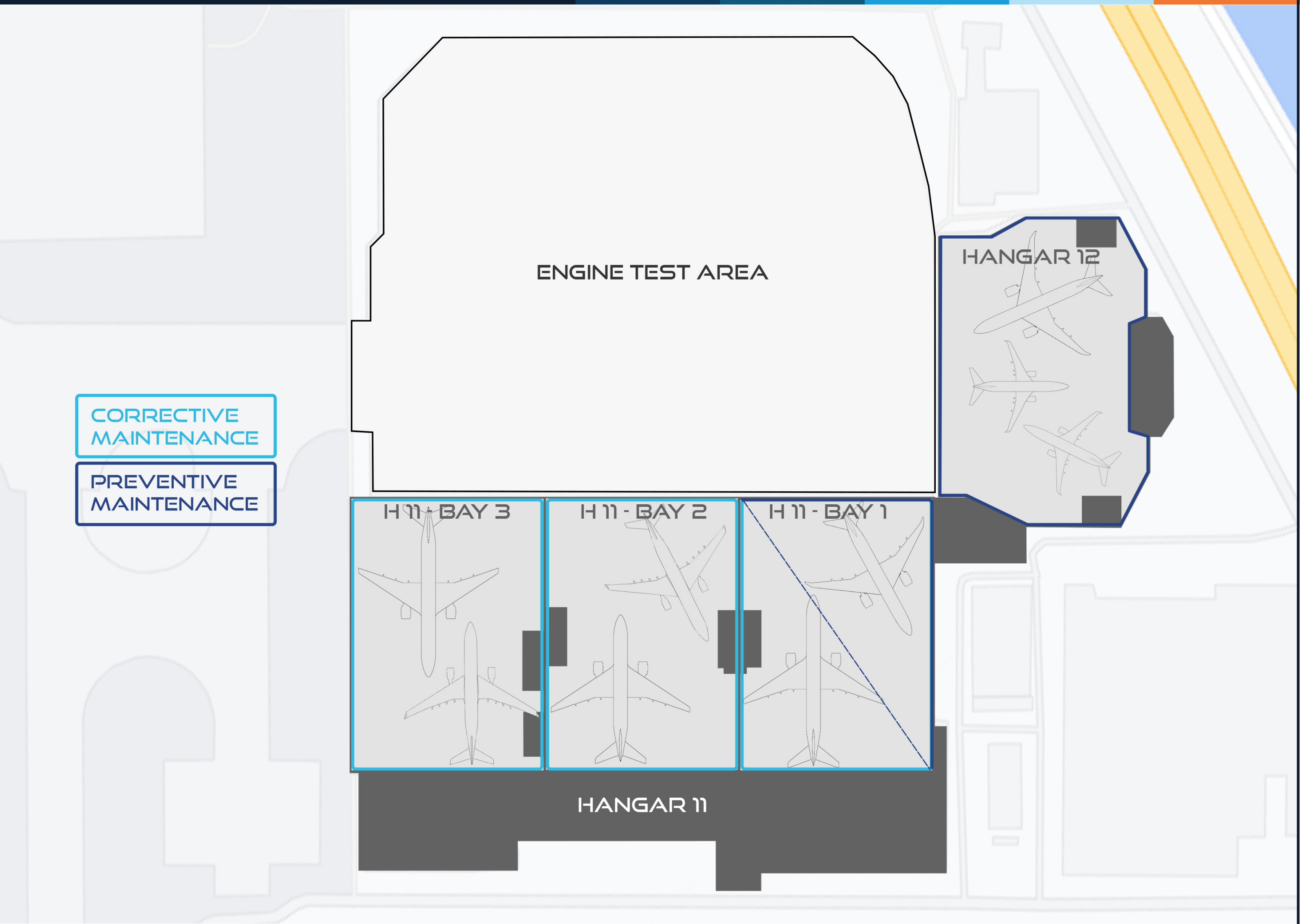


Figure 1: Map of division of preventive and corrective maintenance in H11 and H12

1.4 Preventive maintenance and corrective maintenance

The maintenance done to aircraft is divided in preventive and corrective maintenance. Preventive maintenance is scheduled, comparable to planned servicing of a car. Preventive maintenance that is done at KLM are the FA (A-check) and FC (C-Check). The FA takes 24 hours and the FC is a more thorough type of maintenance lasting approximately two to three weeks. Corrective maintenance is unplanned maintenance that needs to be done because of defects or damages. For that reason, corrective maintenance is unpredictable and highly variable in duration.

C-checks are done at Hangar 14 and A-checks are done in Hangar 12 and in Bay 1 of Hangar 11. Corrective maintenance is done in Bay 2 and Bay 3 of Hangar 11 and partly in Bay 1.

1.5 The Bold Moves Engineering & Maintenance - Zero Emission Hangar

The Bold Moves are a collection of innovation and sustainability related projects. The projects are mostly carried out by motivated employees from different divisions in addition to their normal jobs and fulltime by multiple interns. Bold Moves projects include: Sustainable Aviation Fuel (SAF), Close Your Energy Loop, Diversity & Inclusion (of gender and race), Zero-E (setting up an infrastructure for maintaining electric aircraft) and Zero Emission Hangar.

This study is part of the Zero Emission Hangar project. The project focuses on the heating of the hangars and has two main goals, namely:

1. To **reduce** energy demand of the hangars before 2025.
2. To **replace** natural gas in the hangars before 2030.

The Zero Emission Hangar project was carried out by two graduation students. This study focuses on the first goal whereas a bachelor aviation engineering student focused on the second goal.

1.6 Design problem - problem definition

Heating up the hangar is more difficult than it might seem. Hangar 12 has a volume in excess of 240.000m^3 which means it takes a long time to heat up. When the hangar doors are opened in winter to let an aircraft in or out of the hangar, the temperature in the hangar drops drastically. The current way of heating the hangar is not only expensive, unsustainable and energy consuming, it is also not effective. The long time it takes to heat up the hangar means that mechanics often have to work in the cold which is uncomfortable. Apart from that, the cold temperatures and the fluctuations in temperature increase the drying time of sealants used in repairs.

1.7 The assignment

The goal of the assignment as stated by KLM: *"To come up with and work out innovative ideas to reduce the energy consumption of the hangars in relation to heating, based on outcomes of data analyses."* (KLM, 2021, translated from Dutch).

The assignment was reformulated to the following research question:

Realize a solution that drastically reduces the energy consumption, costs and temperature fluctuations in the hangar, whilst creating a comfortable working environment for mechanics without increasing the turnaround time of the aircraft in the hangar.

1.8 Scope

This graduation study is carried out at the Engineering and Maintenance division of KLM Royal Dutch Airlines. The premise of this study is to reduce the energy consumption in relation to heating of the hangars significantly, without it requiring major infrastructural changes to the hangars. The focus is solely on the hangar space itself, that means that offices spaces in the hangar and attached to the hangar building are not taken into account. The heating of normal office spaces is done differently and of less significance in general. This study focuses mainly on Hangar 12 because of its positioning, the maintenance work that is done there and the availability of more detailed data regarding energy consumption and measured temperatures. The solution, however, should be implementable in Hangar 11 as well.

1.9 Research questions and methodology

The main research question as stated before is:

Realize a solution that drastically reduces the energy consumption, costs and temperature fluctuations in the hangar, whilst creating a comfortable working environment for mechanics without increasing the turnaround time of the aircraft in the hangar.

The goal of the project is about reducing energy and costs regarding the heating of the hangar and to do so, something needs to be changed. Therefore it is firstly important to answer the following questions:

How is the hangar currently heated?
How much energy is consumed to heat up the hangar?
How much does the heating of the hangar cost?

Part of the problem as described in the problem definition is that it takes a lot of time to heat up the large hangar space. When the hangar doors are opened in wintertime the temperature drops drastically and the process of heating the hangar needs to start all over again. To get a more precise image of the situation, the following questions need to be answered:

How long does it take to heat up the hangar?
What is the effect of opening the hangar doors on the temperature in the hangar?

The current way of heating the hangar is energy consuming and expensive and next to that takes a lot of time. To reduce the energy consumption and costs, whilst still providing the mechanics with a comfortable working environment, the concept of heating the hangar needs to be changed. To know how this can be done the following critical questions need to be researched:

Why is the hangar heated?
Where is heat needed in the hangar?

In order to realize the project goal and answer the research questions stated above within the relatively short project time of 100 days, it was deemed important to start thinking about solutions to the problem from the beginning. It was, therefore, chosen to start the idea collection and research analysis simultaneously. Ideation and research can be seen as two parallel lines throughout the project. This process could best be described as the coevolution of the problem space and solution space (Dorst & Cross, 2001), where the problem space relates to the analysis and the solution space relates to ideation. New insights into the problem influence the solution, but at the same time new insights in the solution influence the problem. It is a process of constant iteration. The problem is redefined as more information is gathered which in case requires a new solution. The process of iteration in this study ends at a predefined time based on the schedule of this project and a proposal is presented.

Chapter 2 - Heating of the hangar – a deep analysis

2.1 Introduction

This chapter is a deep dive into the heating of the hangar and focuses on analysis in order to answer the research questions. For all of the analyses Hangar 12 is taken as an example. In Hangar 12 preventive maintenance takes place. This type of maintenance is more predictable and more consistent compared to corrective maintenance as done in Hangar 11. For that reason, data from Hangar 12 is more consistent and a data analysis is more precise and reliable. Apart from that, more detailed data is available in Hangar 12 compared to Hangar 11 on for example energy consumption and hangar bay temperature. For those reasons Hangar 12 was picked as the example for this study.

Figure 2: Heating of the hangar – types of heaters

2.2 Current situation – How is the hangar heated currently?

In winter there are two main heat sources in the hangar: sunstrip radiators on the ceiling and additional temporary heaters that are situated on multiple locations in the hangar on the floor (see Figure 2). The sunstrips use hot water to heat up and can get up to a temperature of around 90 degrees Celsius. The water is heated in boilers (building 427) that run on natural gas. The temperature in the hangar is measured by temperature sensors on the walls at a height of approximately 8 meters.

Because of maintenance done to the boilers in building 427, the sunstrip radiators in Hangar 11 and 12 were out of order towards the end of 2021. For that reason, temporary heaters were put in place on the floor, near the walls of the hangar. These heaters heat up water and have fans that blow hot air in the hangar space. The water is heated by generators that run on GTL, the fans are powered by electricity from the power network of the hangar. The hangars use a lot of electricity and therefore the power network of the hangars is used close to its maximum capacity, therefore the additional power consumption of the fans of the temporary heaters is not ideal. The temporary heaters are rented and installation of them reportedly did cost a lot of money because of the complexity of the system with the generators being located outside in large containers and the fans being located at several locations inside the hangar.

In the months of January and February of 2022 the data shows that both the sunstrips and GTL heaters have been running. To see how the hangars of competitors are heated see Appendix 5.

2.3 Thermodynamics in the hangar (Hangar 12) – Warm-up time of the hangar

Introduction to calculations
In this chapter calculations will be performed to find out how long it takes to heat up the hangar in different situations. As will be described in Chapter 2.4, heat (a certain temperature) is needed for certain types of maintenance. In corrective maintenance, planes can be in the hangar for a short period of time. When in these instances a task needs to be performed where temperature plays an important role, time to heat up the hangar is of great importance. According to the Plant Leader for corrective maintenance, ideally he would want to have one or two additional positions for planes in the hangar. If a solution guarantees shorter time for heating up the necessary parts of the plane, maintenance can be performed quicker and hangar positions would be available sooner for the next plane in line, increasing both hangar space and fleet availability.

Research questions
In this chapter the following research questions will be answered:
- *How long does it take to heat up the hangar?*
- *How much energy is consumed to heat up the hangar?*

Used data
For this chapter multiple datasets retrieved from KLM are used, as well as data from third parties and data retrieved from the internet.

Steps
1. Calculating power usage (for heating) in the hangar of both the sunstrips and the GTL heaters.
2. Calculating the time to heat the empty hangar.
3. Calculating the specific heat capacity of a Boeing 787 and the time to only heat the aircraft.
4. Calculating the time to heat the hangar and the Boeing 787.
5. Calculating the time to heat the hangar and two Boeing 787s.

Assumptions
- The outside temperature is 5°C and the hangar needs to be heated to 20°C (ΔT = 15K).
- The walls of the hangar stay at 20°C after opening the hangar doors.
- After opening the hangar doors, the air inside the hangar will cool down to outside temperature.
- The temperature of the aircraft that is being moved into the hanger is equal to the outside temperature.
- Due to poor isolation, 30% of heat in the hangar is lost.
- The so-called sunstrips have an efficiency of 50%.
- The GTL heaters have an efficiency of 40% (calculated with assumptions).

2.3.1 Step 1: Calculating power usage

Example - January 2022 energy consumption for heating
In January of 2022, 39.657 litres of GTL were used for the temporary heaters in Hangar 12 (KLM Equipment Services, 2022). Additionally 13.936m^3 of gas was used for the sunstrip heaters (Sodexo, 2022). In order to compare GTL usage to gas usage, both values were translated to kWh.

GTL consumption
According to Bassiony et al. (2016), GTL has a calorific value of 35.95GJ/m^3, which translates to 35.95MJ/L:

$$1\ L\ GTL = 35{,}95MJ = 9{,}986\ kWh$$

$$GTL\ consumption = 39.657\ L * 9{,}986\ kWh = 395.997\ kWh$$

Natural gas consumption

$1m^3\ of\ gas = 10{,}55\ kWh$ according to LearnMetrics (2022).

$$Natural\ gas\ consumption = 13.936m^3 * 10{,}55kWh = 147.025\ kWh$$

$Total\ consumption = 395.997kWh + 147.025kWh = \mathbf{543.022\ kWh}$ in January 2022

The temporary heaters consist of boilers that heat water, these are running on GTL. In addition to that, there are fans that are powered by electricity from the network in the hangar. An estimation of the power consumption of the fans can be made by comparing the power consumption of the same month of the previous year (before the temporary heaters were installed). The power consumption of the fans themselves is not used for the further calculations.

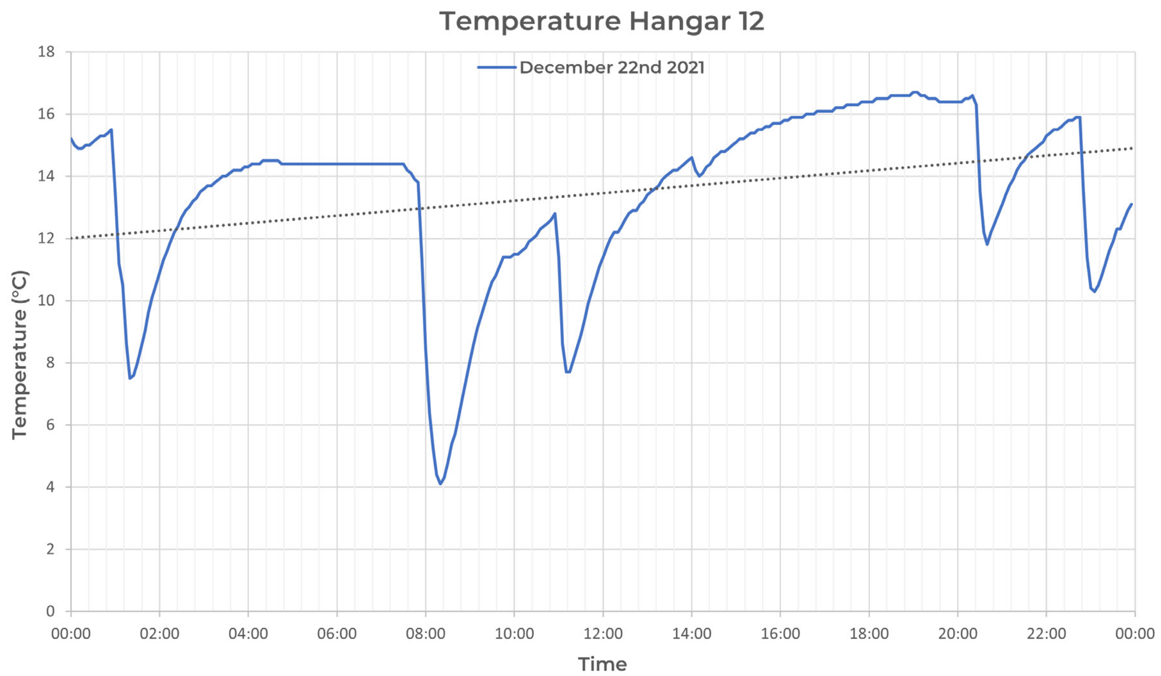
Month	Average outside temperature (°C)	Sunstrip usage (kWh)	Temporary heaters usage (kWh)	Total heating (kWh)	Temporary heater fans elec. (kWh)
January 2019	3,84	514.682	0	514.682	0
February 2019	6,35	293.009	0	293.009	0
December 2021	5,61	3.745	491.960	495.705	+- 130.000
January 2022	5,60	147.025	395.997	543.022	+- 110.000
February 2022 (28 days)	6,89	127.433	253.914	381.347	+- 90.000

Table 1: Energy consumption for different months per heating source converted to kWh

As a comparison, in January of 2019 the sunstrips were the only heaters used in the hangar and 48.785m^3 of gas was used (Sodexo, 2022). Using the same conversion rate of 1m^3 of gas = 10,55 kWh the total energy consumption for heating in 2019 was 514.682kWh. According to weather statistics, the average temperature at Schiphol in January 2019 was 3,84°C compared to 5,60°C in 2022 (Weerstatistieken, 2022). This means that even though the temperature was higher in 2022, the total energy consumption for heating was higher too. Some sources at KLM told me that there were other additional heaters in place in previous years, however, I was not able to find more information and data on those and therefore I am not taking conclusions out of the comparison between earlier years.

Calculation of maximum power output for further steps
To calculate the heating time of the hangar, the maximum power output needs to be calculated. The company 4AMS is responsible for the temperature sensors in the hangar and because of poor accuracy of the older sensors situated at 8 metres of height on the hangar walls, they have placed more accurate sensors at a lower height in Hangar 12.

I used data of the temperature in the hangar on the coldest day of December 2021 (22nd of December) in combination with data on how much GTL has been tanked on the 23rd of December. This shows the GTL consumption on the coldest day of December 2021. In December 2021, the sunstrips only delivered a fraction of the power (3.745kWh in total, compared to 491.960kWh for the temporary heaters). For that reason, data of December 2021 can be used to estimate the efficiency of the GTL heaters.



Graph 1: Measured temperature on December 22nd 2021 in Hangar 12

The temperature data showed a lowest temperature of 4.1°C on December 22nd, and in 13.200 seconds it had warmed up to 12.8°C (ΔT 8.7) (see Graph 1). The graph shows minimum values that are far below the average temperature and these minima can be related to the opening of the hangar door. I used the data of tanked GTL to calculate a day average usage by calculating the litres of GTL burned per hour. Once I filled in the ΔT of 8.7 and the average P of this day, I modified the (variable) efficiencyGTL until the calculated time came close to 13.200 seconds.

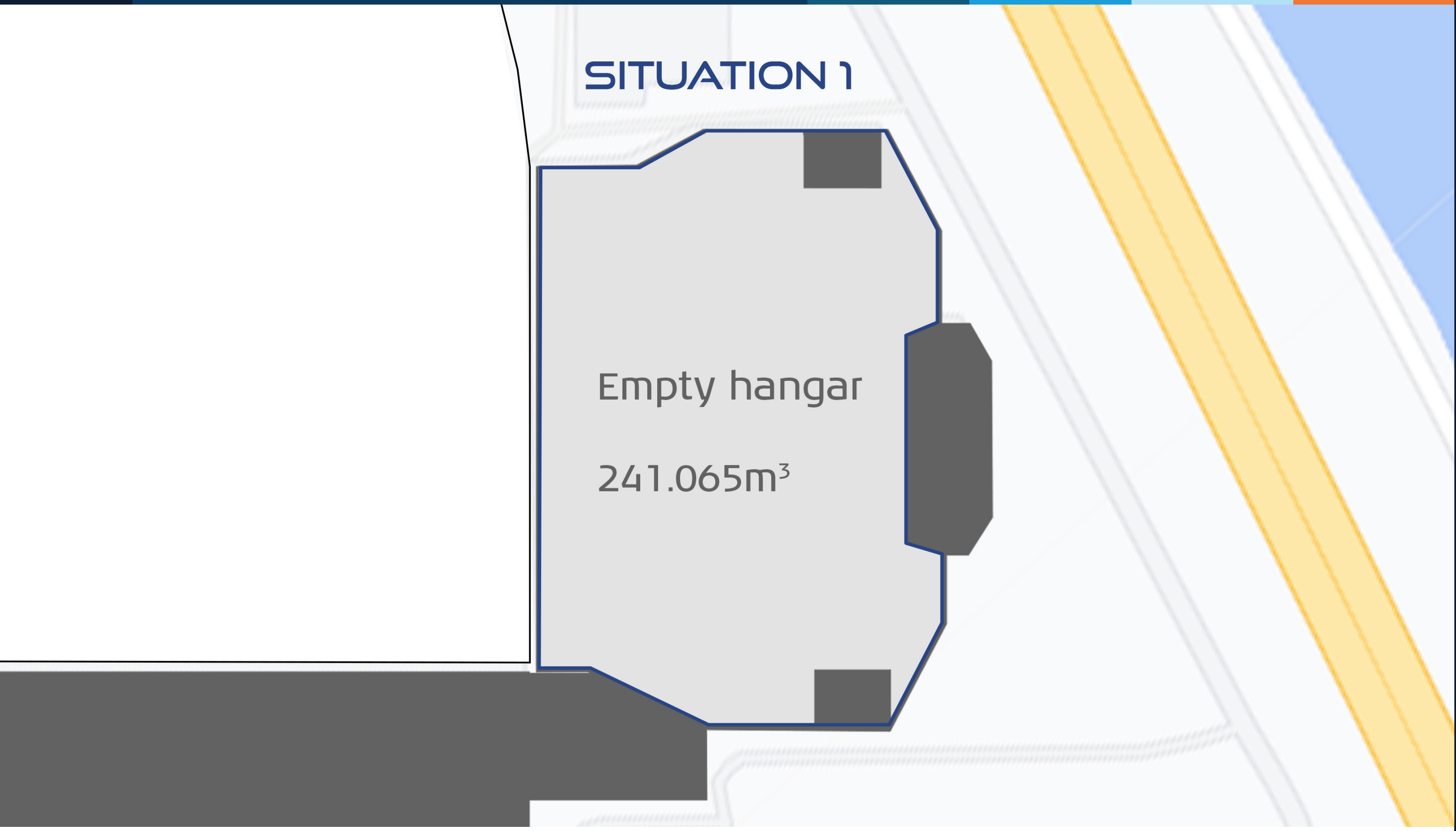


Figure 3: Visualization of empty Hangar 12

2.3.2 Step 2 - Time to heat up the empty hangar

First off, the time to heat up the empty hangar space is calculated. In this case only the air in the hangar space needs to be heated. The volume of Hangar 12 is 241.065m^3 (Meijer Energie- & Milieumanagement BV, 2004).

m = Volume Hangar 12 * specific weight air = 241.065m3 * 1,225kg/m^3
c = heat capacity air = 1.010 J/kg K
ΔT = 15K

$$Q_{hangar} = mc\,\Delta T = (241065 * 1{,}225)kg * 1.010J/kg\,K * 15K = 4{,}474 * 10^9\,J$$

efficiencysunstrip = efficiency of sunstrips = 50%
efficiencyGTL = efficiency of GTL heaters = 40%
heatlosshangar = energy loss hangar = 30% = 1,3

Taking everything into consideration, the average power output on the 22nd of December was 423028J/s (for the full calculation see Appendix 6.1). This number is maximum power output because this day was the coldest day of which data is available.

$$t_{hangar} = Q_{hangar} / P * heatlosshangar = (4{,}474*10^9\,J) / (423028J/s) * 1{,}3 = 13749\,sec. = 3h\,49mins$$

Using these numbers, it takes 3 hours and 49 minutes to heat up the hangar from 5°C to 20°C.

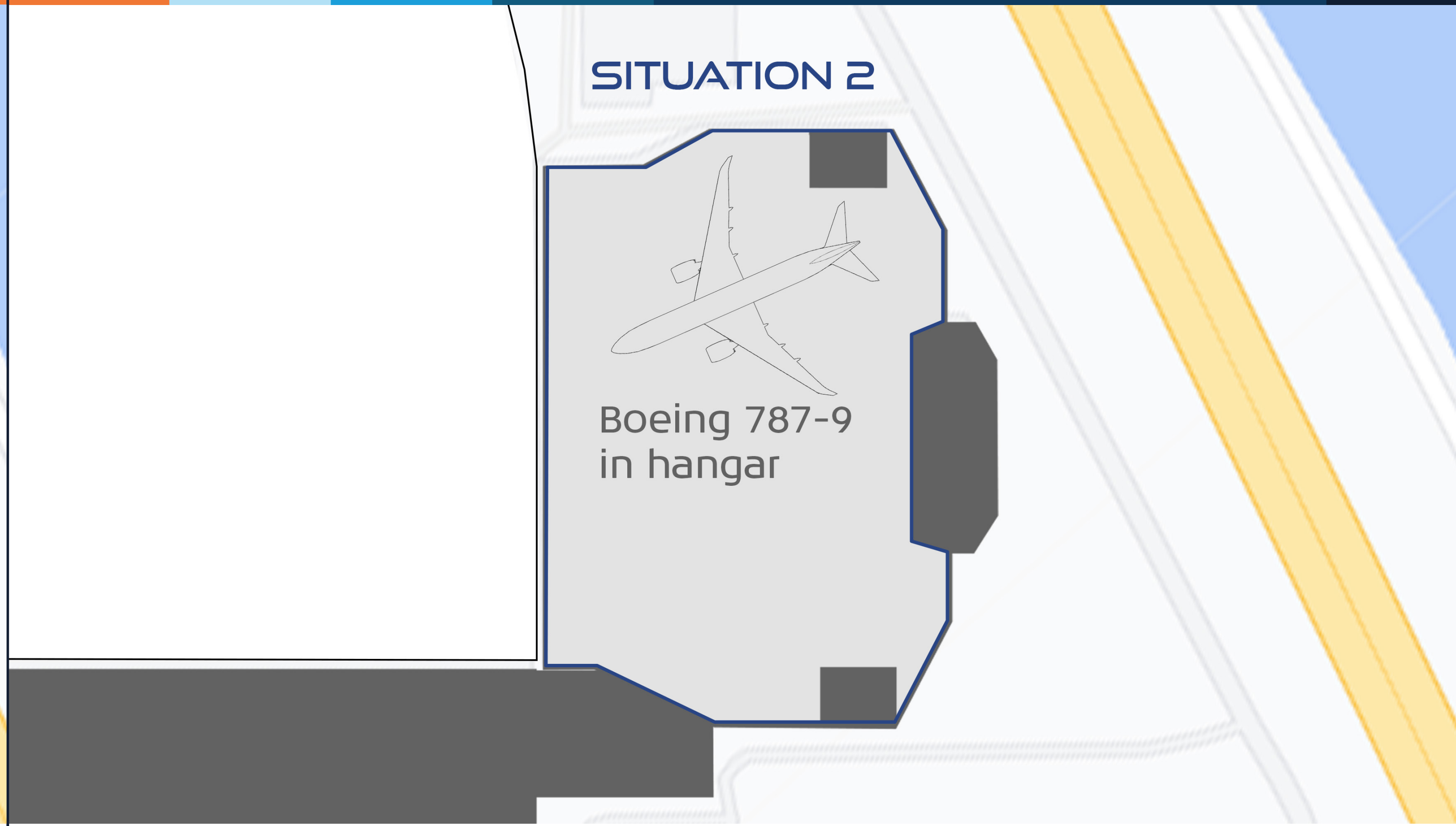


Figure 4: Visualization of Hangar 12 with one cold Boeing 787-9 inside

2.3.3 Step 3 & step 4 - Specific heat capacity of 787 and time to heat up hangar with B787 inside

In this situation, the hangar and one Boeing 787-9 need to be heated to room temperature. In order to calculate this, I first calculated the time to heat up the aircraft separately. For this, the specific heat capacity of the aircraft needed to be calculated. According to Modern Airliners (2015), the Boeing 787-9 has a total dry weight of 128.850kg and is made up out of the following materials:

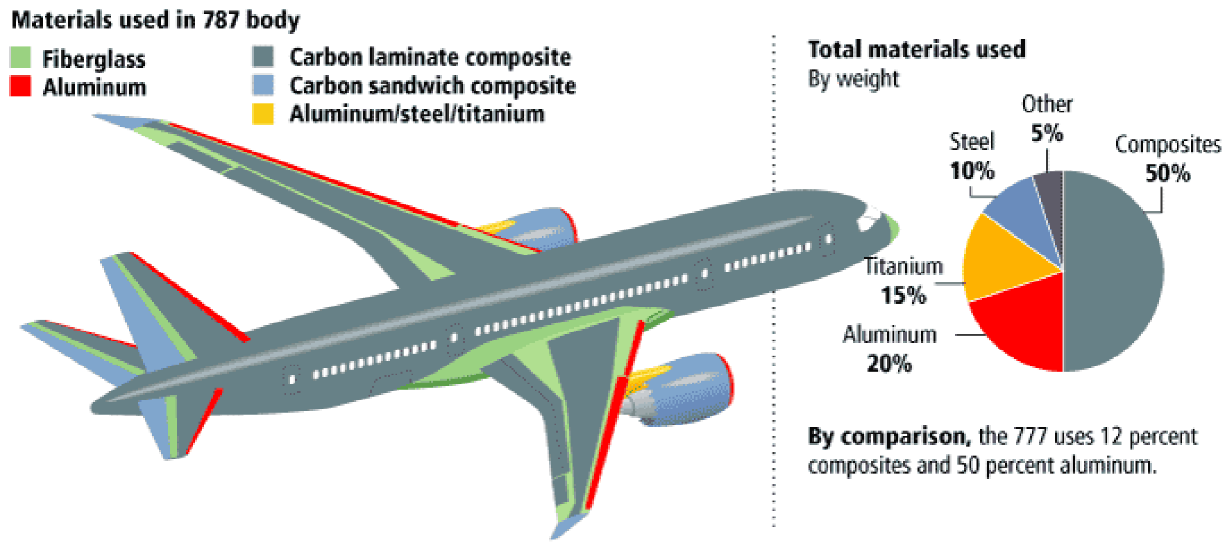


Figure 5: Modern Airlines (2015) - Materials used in B787 body

The heat capacities of each specified material were found and for "other" materials the specific heat capacity was chosen to be 600J/kg K (see Table 2).

Material	Weight percentage	Actual weight (kg)	Heat capacity (J/kg K)
Composites	50 %	64.425	800
Aluminium	20 %	25.770	900
Titanium	15 %	19.327,5	523
Steel	10 %	12.885	466
Other	5 %	6.442,5	X = 600
Combined	100 %	128.850	

Table 2: Specific heat capacity per material for Boeing

$$mc = 64.425kg * 800J/kg\,K + 25.770kg * 900J/kg\,K + 19.327{,}5kg * 523J/kg\,K + 12.885kg * 466J/kg\,K + 6.442{,}5kg * 600J/kg\,K = 94{,}71 * 10^{6}$$

$$Q_{787} = mc\,\Delta T = 94{,}71 * 10^{6} * 15K = 1{,}42 * 10^{9}\,J$$

$$t_{787} = Q_{787} / P * heatlosshangar = (1{,}42 * 10^{9}\,J) / (423028J/s) * 1{,}3 = 4366\,sec = 1h\,13\,min$$

Both the air inside the hangar and the aircraft itself need to be heated. Therefore, the time to heat up the aircraft needs to be added to the time to heat up the air in the hangar. Additionally, the volume of the plane needs to be subtracted from the volume of the air inside the hangar, since less air in the hangar needs to be heated once a part of the space is occupied by the aircraft. The volume of a Boeing 787-9 was estimated to be approximately 1780m^3 (see Appendix 6.2 for complete calculations). The time to heat up the hangar with a Boeing 787-9 inside of it:

$$t_{hangar\&787} = t_{hangar} * (1 - Volume_{787} / Volume_{hangar}) + t_{787} = 13749sec * (1 - 1780m^{3} / 241065m^{3}) + 4366sec = 18013sec. = 5\,hours$$

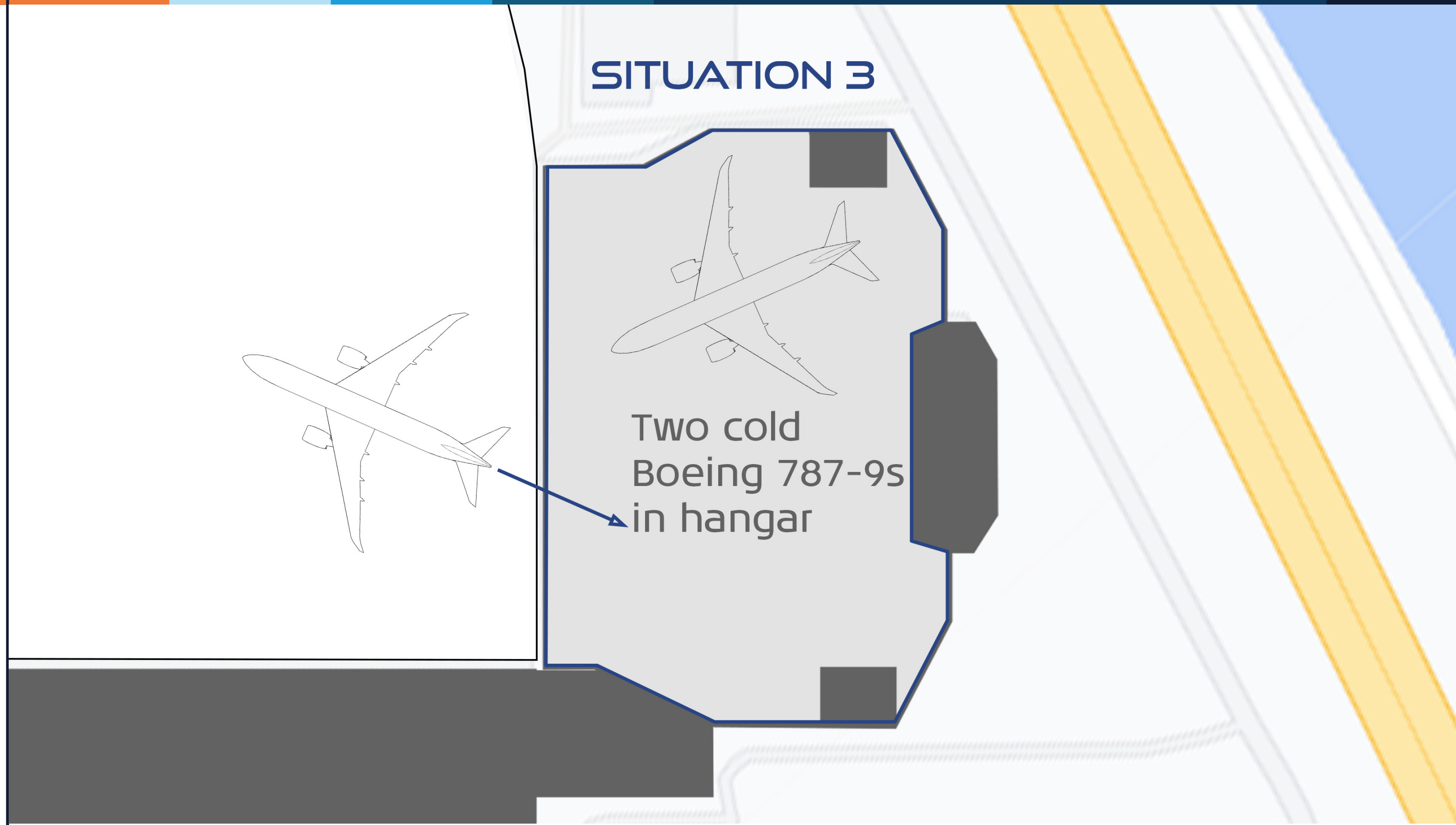


Figure 6: Visualization of Hangar 12 with two cold Boeing 787-9s inside

2.3.4 Step 5 - Time to heat up hangar with 2x B787 inside

Oftentimes there is more than one airplane in the hangar. This situation describes two Boeing 787s being pushed into the hangar from outside. This situation can be described as:

$$t_{hangar\&2x787} = t_{hangar} * (1 - (Volume_{787} * 2) / Volume_{hangar}) + t_{787} * 2 = 13749sec * (1 - (1780m^{3} * 2) / 241065m^{3}) + 4366sec * 2 = 22277sec. = 6h\,11\,mins$$

2.3.5 Conclusion of calculations

In the winter of 2021/2022 (December, January and February) in Hangar 12 each month between 400.000kWh and 550.000kWh of energy was used to heat up the hangar, when the electricity consumption of the fans of the temporary heaters is excluded.

Apart from the large energy consumption, it takes a lot of time to heat the hangar, even more so when cold aircraft also need to be heated (5 to 6 hours). The overall heating time of the hangar is roughly 4 to 6 hours and these findings coincides the findings of Kok (2016) in her Graduation study.

The long time it takes to heat up the hangar, translates to a long period in which the hangar is cold which means that the mechanics need to work in a cold environment and also the plane itself is cold.
This insight shows that the current way of heating the hangar is ineffective and leads to the question: What is the reason that the hangar is heated?

2.4 Why is the hangar heated? - A person's and aircraft perspective

Introduction

In the previous chapter it was determined that it takes a lot of time and energy to heat up the hangar. This chapter looks into the necessity of heat in the hangar and laws surrounding heating of a workspace. The chapter is divided into two main topics. Firstly, heating for the mechanics working in the hangar space, and secondly, heating for the aircraft.

Heating the hangar for the employees - laws

When it comes to a workspace, certain laws are in place. Laws that are relevant for the heating of the hangar are mostly related to the well-being of the employee (mechanic in this case). The laws that are relevant are part of the Working Conditions Law (Arbeidsomstandighedenbesluit, n.d.). Articles that particularly stand out in this instance are article 3, 6, 8 and 29.

Article 3 states the obligation of the employer to provide a safe working environment and to take into account the well-being of the employees.
Article 6.1 is specifically related to temperature and states: *"Taking into account the nature of the work performed by employees and the resulting physical strain, the temperature at the workplace does not cause harm to the health of employees."* (Arbeidsomstandighedenbesluit, n.d. - Translated from Dutch).
Article 8 covers the obligation of the employer to inform the employee about the work to be done and risks involved. This includes educating the employee about possible cold working temperatures and the measures that are in place to minimize risks.
Article 29, lastly, covers the right of the employee to stop their work if the working circumstances may lead to serious danger. When it comes to temperatures of the workplace, this law is mainly applicable to working outside in extreme winter conditions. Normally a minimum working temperature of -6°C is applicable according to the FNV standards.

Apart from laws stated by the government, there are standards by Labor Union FNV that state that employers should provide appropriate (warm) clothing when the working temperature is below 15°C when working indoors (Lenderink, 2019). The standards of the FNV are recommended guidelines but not obligations by law.

Ideal temperature for workers

According to a 2004 study at KLM regarding floor heating for hangars, the temperature can be set to 16°C by common comfort standards, given the working intensity and provided with season fitting clothing (Verweij & Kroonen, 2004). (The hangar is still heated to more than 16°C.)

Labor Union FNV provides a phone application regarding the working climate, in which an employee can fill out aspects of their current working environment such as temperature, physical intensity and clothing worn, to estimate whether it is still safe to work. Since the FNV is a Labor Union they stand up for the rights and wellbeing of employees, for that reason, the working environment app is taken as a representable source when it comes to employee comfort. The application was used to decide on a new base temperature for the hangar. To make sure that the working environment would still be safe to work in when conditions would be bad, the most extreme conditions were chosen in each screen of the app to be conservative (see Table 3). The only variable used was the temperature and the Working Climate App showed "Code Green" from 9°C (see Table 4). Figure 7 shows an example of the different screens of the FNV Working Climate App.

To have some margin and to not ignore the fact that there will still be some temperature fluctuations in the hangar once the base temperature is lowered, it is chosen to lower the base temperature to 10°C.

Clothing	Overalls
Headgear	None
Body activity	Light
Humidity	80 %
Windspeed	3 m/s
Heat radiation	Shadow

Table 3: Chosen fixed conditions FNV Working Climate app.

Temperature	8°C	9°C	10°C
App result	Code ORANGE	Code GREEN	Code GREEN
Elaboration on result	"You will likely experience discomfort due to the cold, heat up after 54 minutes of working"	"No problems are expected due to the working climate"	"No problems are expected due to the working climate"

Table 4: FNV Working Climate app results for different temperatures.

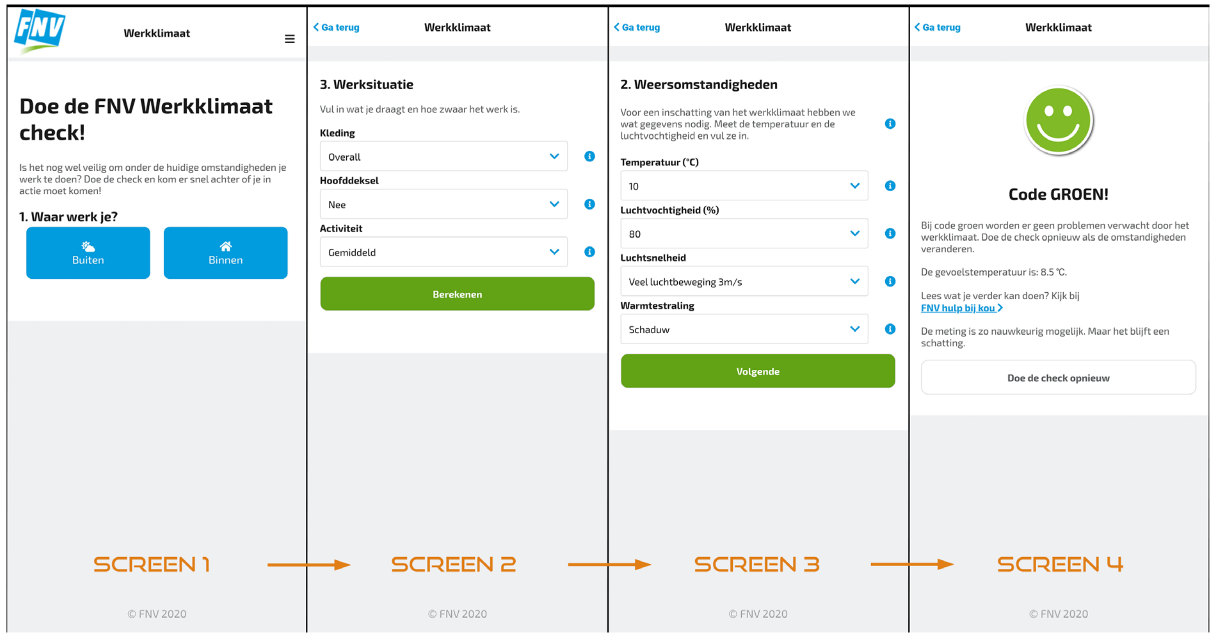


Figure 7: Screenshots from FNV Working Climate application example.

Heating the hangar for aircraft - Heat necessity for maintenance
A heated environment is not only needed for the engineers working on the plane, but for the aircraft itself too. According to a Process and Materials engineer at KLM, a warm environment is mostly needed to speed up chemical processes such as paint repairs, carbon fibre repairs and the curing of sealants. These processes are usually only local, and thus only locally heat is needed, however, the position differs greatly. A specialist company in the United States that replace and repair aircraft windows told me that they *"...are held to whatever the ambient temperature is. If it is colder you would need to increase the cure time."*

The engineering department of KLM does not specify a particular ideal temperature for processes, since, according to the engineer this is nearly impossible to accomplish given the different hangars and their temperatures. Preferably for these processes the temperature should be warm, but not too hot because of safety concerns. This temperature would be around 25 degrees Celsius in most cases. However, with certain sealants, higher temperatures are safe and can speed up drying times further.

Towards the end of 2021 Hangar 11 and Hangar 12 have been unheated for a number of months due to long-term maintenance on the boilers that provide the hot water for the sunstrip heaters. This caused the hangars to be cold at times which in turn simply meant that chemical processes were lengthened. To speed up drying times and other chemical processes, radiation heat sources were used locally on some occasions.

It is determined that the role of heating in maintenance is of influence for the aircraft when it regards curing processes, however, is it truly required? There are a number of crucial questions that need to be answered in this regard. The main question is:

Is additional heating of the aircraft necessary for curing processes?

In order to be able to answer this question, the following questions need to be answered:

- Are repairs that include curing processes always planned at the beginning of a check and in what checks are these planned? A-check, H-Check, R-Check, maybe even C-Check?
- How often do these types of repairs occur?
- What is the minimum temperature for curing processes and is this temperature actually met in the current situation? (If indeed these processes are started at the beginning of a check, then the hangar doors will just have been opened and therefore the temperature in the hangar will be low.)
- Are there currently problems with curing times in practice? Does it negatively impact the total time of a check?

2.5 Determination - are additional heaters needed for the aircraft?

The main question I wanted to answer was whether additional heating is necessary for curing processes in the hangar. The answer to this question is not a simple yes or no, because there are different situations and adhesives.

After talking with a Technical Specialist at KLM who happens to have over 30 years of experience in the hangar, as well as with a planner fleet availability, I am able to give a nuanced answer to the question.

First of all, an important insight is that there are guidelines and procedures to follow when it comes to sealants, but when it comes to drying times no precise indication can be given. The drying time and curing time, differ per adhesive or sealant and the time that is used as a reference is the curing time of the specific adhesive at room temperature (21°C). In practice, especially in winter, the ambient temperature in the hangar is most often far below room temperature. In those instances the ambient temperature is estimated (not measured) by the mechanics and a longer curing time is estimated also. The temperature in the hangar fluctuates a lot, especially due to the opening of the hangar doors, this makes it difficult to give a reliable estimation.

Secondly, repairs with a curing component are almost always planned as corrective maintenance in Hangar 11 and will be carried out as soon as the maintenance starts. The fact that the repair is started immediately when the aircraft is in the hangar, means that the temperature in the hangar will be low since the doors have just been opened (See Chapter 2.3). Most of the time the repair and especially the curing time are the leading factors in the total time the airplane is in the hangar. In other words: if the curing time could be shortened, the airplane could exit the hangar sooner.

In conclusion, are additional/local heaters needed for curing processes? No, they are not needed as such, because currently they are not used oftentimes and they seem not to be missed. Implementing local heating more, however, would reduce the time of the aircraft in the hangar, improving fleet and hangar space availability. The question in this case is whether these types of repairs occur often enough to be worth the investment, a complex question that requires the involvement of a data analyst to answer.

Conclusion on why heating the hangar is needed
In Chapter 2.4 and 2.5 the heating of the hangar was researched from two perspectives, the heating of people and the heating of aircraft. Both the mechanics and the aircraft require some heat, but that does not necessarily mean that all the air in the 240.000m^3 building needs to be heated.

For the mechanics it is important that they can do their job safely and comfortably. The FNV working climate app shows that work can still safely be done at 10°C. With proper measurements in for example clothing or local heating, the laws regarding working in cold environments will still be met.

For the aircraft heating during maintenance is only necessary for specific repairs that involve the curing of an adhesive, paint or sealant. Currently the ambient temperature is often the leading factor in the curing time.

2.6 Where is heat needed in the hangar?

In the previous chapter it was determined that the hangar is heated for the mechanics that work there and partially for particular types of repairs to the aircraft that include a curing component. The location of repairs that are done to the aircraft differs greatly and these type of repairs are mainly done at the corrective plant. Frequency is variable and patterns are therefore hard to find.

The work done during preventive maintenance is more predictable and patterns can be found. This chapter focuses on the location of mechanics during a typical Boeing 787 A-Check. The goal of this it to determine where local heating of mechanics would make sense.

Heatmap – location of maintenance on the aircraft
In order to get a clear picture of the intensity of work done in different areas of the aircraft a heatmap was made. Heat in the heatmap does not regard the temperature, but the hours of work done in a particular location.

To make the heatmaps, data was retrieved from the KLM Prognose tool. In there the tasks for mechanics are described for each individual check and for each specific plane. The average of four typical A-Checks on Boeing 787 planes was taken to make the heatmaps. It was calculated that on average approximately 56% of work is done on the outside of the plane and the remaining 44% of work is done inside the plane in cabin, cockpit or cargo bays (Prognose Tool – AF/KL Spotfire, 2022). During maintenance the inside of the aircraft (cabin, cockpit etc.) is very warm due to heat generated by the electronic systems of the airplane. The heatmaps are made to determine hotspots where mechanics work for long periods and since the temperature in the cabin is high during maintenance the heatmaps only show **work done outside of the aircraft.**

Explanation of heatmap 1
The first heatmap shows the hours of work planned per location (see Figure 8). For example 27 hours of work is planned to be done on the left engine, for that reason this area is red, whilst just shy of 2 hours of work is planned for the right engine, therefore this area is blue. Because of regulations only one engine may receive heavy maintenance at a time. More specifically this means that in this particular A-check heavy maintenance is done on the left engine and in the next A-check of this plane the right engine will be serviced. Looking at the fuselage, 12 hours of maintenance is planned giving this area a yellow glow.

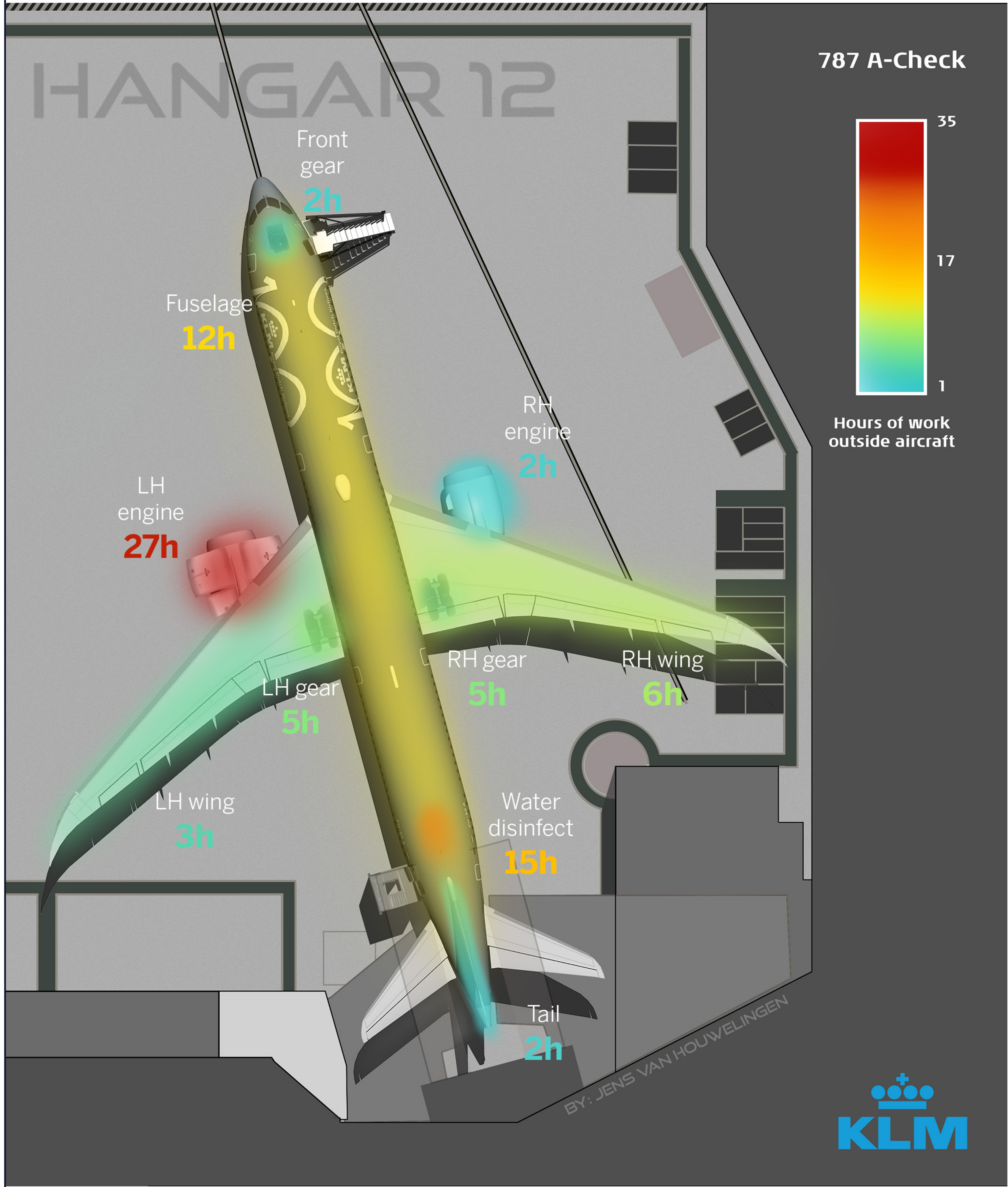


Figure 8: Heatmap 1 – hours of maintenance per location.

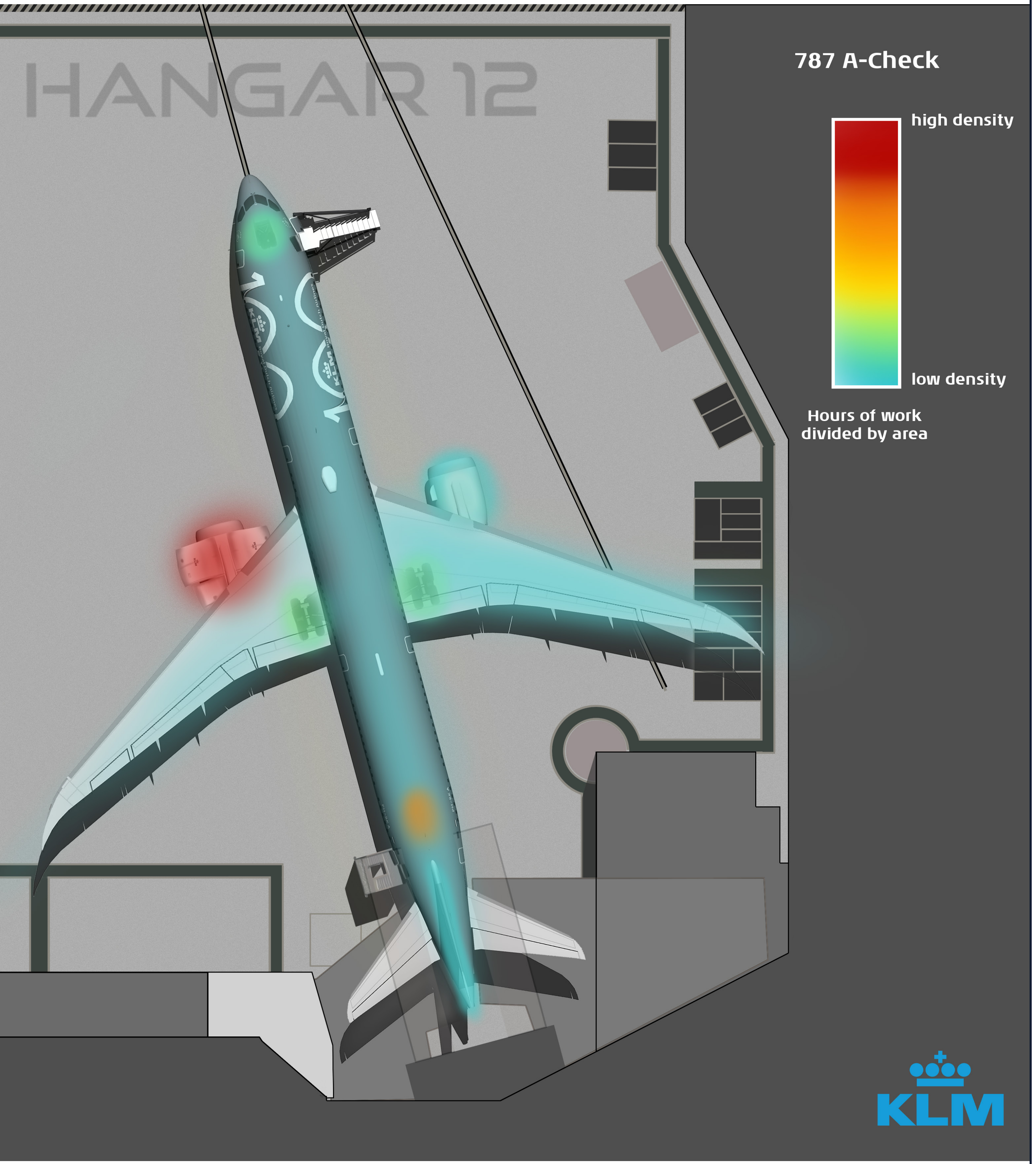


Figure 9: Heatmap 2 – hours of maintenance divided by area.

Explanation of heatmap 2 – where to heat locally for mechanics?
The second heatmap was made to paint a more realistic picture of locations to heat locally (see Figure 9). To achieve this, the hours of work per area were divided by the area in question. This shows that even though 12 hours of work was planned on the lower fuselage, due to its large area, the density of work done is very low. For that reason, it wouldn't be sensible to heat the whole lower fuselage. The areas that still show a higher density are one of the engines (the left in this instance), the landing gears and the flushing of the water system ("water disinfect") at the bottom of the fuselage towards the back (orange area).

Conclusion on where heat is mainly needed around the plane for mechanics
Roughly 56% of maintenance takes place on the outside of the aircraft. Of this maintenance it is clear that the majority of the work done on a small area is at one of the engines of the aircraft. Other relatively small areas that require some work are the landing gears and the water disinfect towards the rear of the fuselage. Whilst a lot of work is done on the lower fuselage, this area is too large to sensibly heat locally. With a working area of approximately 330m^2 (see Appendix 7) and an average of three people working in this area it would mean you would heat 110m^2 per mechanic. Instead of heating the working area, heating the mechanics themselves would be more sensible in this case.

2.7 How much energy can be saved by lowering the base temperature in the hangar?

When heating locally, the current heaters in the hangar would not have to operate at full capacity anymore. To estimate the amount of energy that can be saved by lowering the base temperature in the hangar, heating degree days will be used. Heating degree days are used to compare energy usage per time equivalent by taking into account the outside temperature. Energy consumption on its own can be higher in 2020 compared to 2019, but if in 2020 the outside temperature was lower on average, that can be part of the reason. To say anything about possible energy efficiency improvements, heating degree days can also be used.

In 2021, at Schiphol, there were 2766 weighted heating degree days (Mindergas, 2022). In weighted heating the degree days, a factor per month is used to take into account other factors that influence energy consumption in relation to heating, such as sunbeams. Heating degree days use an average inside temperature per day of 18°C as standard and this means that if the outside temperature is on average 18°C or higher, no additional heating is needed.

For the hangars it is proposed to lower the base temperature to 10°C to save energy in relation to heating. For the heating degree days calculation that means that the average inside temperature per day should be changed to 10°C and that no heating is needed when the average outside temperature is 10°C or higher. Taking these numbers, in 2021 at Schiphol, there were 859 weighted heating degree days. The 859 heating degree days are 31% of the previous 2766. This means that when the hangar is heated to 10°C, the heaters would only need to be on 31% of the time compared to the current situation. In other words, an energy reduction of 69% can be achieved.

To put that into perspective let's take the energy consumption of Hangar 12 of December 2021 as an example. In terms of costs, heating to 10°C that month would have saved over €60.000,- in Hangar 12 alone. December 2021 can be seen as an average winter month when it comes to temperature, with an average outside temperature at Schiphol of 5,61°C. The average temperature in the months of December, January and February from December 2017 through to February 2022 at Schiphol was 5,31°C (Weerstatistieken, 2022). December 2021, and the numbers that follow this calculation, are therefore deemed representative.

Month	Average outside temperature (°C)	Sunstrip usage (kWh)	Temporary heaters usage (kWh)	Total heating (kWh)	Temporary heater fans elec. (kWh)	Combined costs of energy (€)*
December 2021	5,61	3.745	491.960	495.705	+- 130.000	€88.000,-
December 2021 (projected heated to 10°C)	5,61	1.162	152.676	153.838	+- 40.345	€27.000,-

Table 5: Calculated costs of Heating Hangar 12 in December of 2021 versus projected costs with lower base temperature of 10°C.

* Cost calculations were rounded in consultation with the client.

To extrapolate these numbers to savings on a yearly basis, the standard weighted heating degree days (18°C inside and outside) of 2021 at Schiphol (2766) were divided by the weighted heating degree days of December 2021 (422). The outcome of that equation was multiplied by the combined costs of energy for December 2021 (rounded to €88.000,-) and the total heating costs for 2021 were calculated to be approximately €580.000,-. Lowering the base temperature to 10°C would result in cost savings of approximately €400.000,- (69% savings) on a yearly basis (based on 2021).

In 2021, the heating of Hangar 12 emitted 632.650kg of CO_2 (Veldhuizen, van, 2022). Lowering the base temperature in the hangar to 10°C reduces that number to 218.114kg of CO_2. A reduction of over 436 tons of CO_2 per year.

Costs of temporary heaters vs. sunstrip radiators

The temporary heaters that were used in the winter of 2021/2022, were rented and ran on GTL fuel. The sunstrip radiators run on natural gas. Looking at the cost per kWh of energy it is clear that GTL as an energy source is close to 8 times more expensive compared to natural gas. It is even more expensive when the element of the fans that run on electricity and the rental costs of the heaters themselves are also taken into account.

Type of fuel	Cost price per unit (December 2021)	Unit to kWh	Cost price per kWh
GTL diesel	€1,62 per litre	1L GTL = 9,986kWh	€0,16
Natural gas	€0,24 per m³	1m³ gas = 10,55kWh	€0,02
Electricity	-	-	€0,06

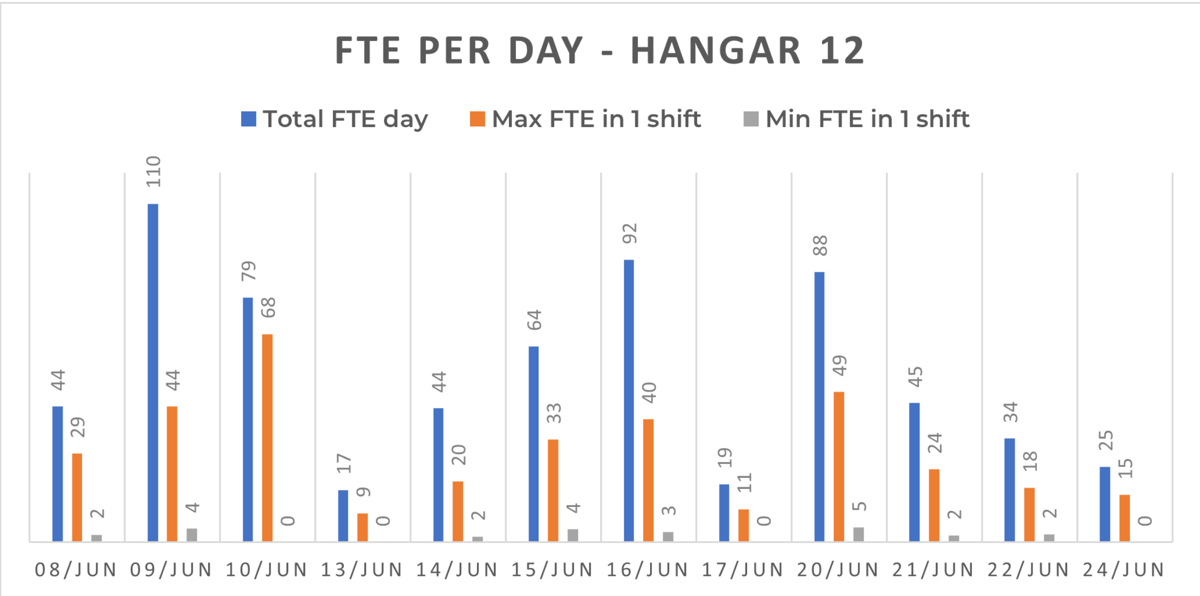
Table 6: Cost price of different energy sources per kWh

Currently the heaters in the hangar are left running when the doors are opened. The U.S. Navy prescribes that in their hangars the heating system should automatically shut off when the hangar doors are opened and the outside temperature is above 40°F (+- 4,5°C). Below 40F the systems should be kept running even with the hangar doors open (NAVFAC, 2020). The aircraft hangars of the U.S. Navy are significantly smaller in size compared to Hangar 11 and 12 and therefore most likely to heat up more rapidly. However, automatically shutting off the heating in the hangar could save additional energy and is something that should be looked into.

2.8 Current cost of heating a person

Since it is now clear that the hangar space is currently heated for the mechanics working there and only for a small part for specific maintenance for the aircraft, it is interesting to calculate the cost of heating a person.

The number of mechanics working in the hangar varies per day and per shift. To get a better insight in the number of mechanics working in Hangar 12, data from three weeks was gathered using the KLM Prognose Tool (it is important to mention that this tool is used to make an estimation based on past data, this means that the numbers are estimates.) The three weeks consisted of 21 checks and for each check I was able to find the number of FTE per shift and for the whole day. A day consists of 3 shifts. A morning, evening and night shift. Some aircraft (usually just widebodies) require work to be done in all shifts, other aircraft (narrowbodies) or specific (shorter) checks can be finished in just 1 or 2 shifts. After combining the data of all checks and dividing them by date I was able to make Graph 2.



Graph 2: Estimated FTE per day in total (blue), maximum in the same shift (orange) and minimum in the same shift (grey).

The graph shows the total FTE per day (date) in Hangar 12 in blue, the maximum number of mechanics working at the same time in the hangar for each day in orange and the minimum number of mechanics working at the same time in the hangar for each day in grey. This graph gives an idea of the variation in number of mechanics on different days. The graph shows in orange that the maximum number of mechanics (FTE) working at the same time in Hangar 12 is 68 (on June 10th) and at minimum no one is working. This can be seen on multiple days (see June 10th, 13th, 17th and 24th). Zero mechanics working implies that there is no aircraft in the hangar to work on. This representation is not fully correct. In reality the number of mechanics working in the hangar at the same time varies between 10 to 65 according to a planner at KLM. The data I could access in the Prognose Tool did not include all maintenance as some maintenance is planned short in advance. For that reason, it showed moments that zero mechanics were working in the hangar. According to the planner and another estimated graph (data: Z22 Preventive), the minimum number of people varies between approximately 10 and 15 people.

For this calculation, data from the previous chapter for December 2021 will be used for the price of heating (see Chapter 2.7) and data provided by the planner at KLM (Z22 Preventive) will be used for the number of mechanics working at the same time in each shift.

During the weekend no new A-checks are scheduled and for that reason on average only 13 people work there in each shift (Z22 Preventive). The heaters are still fully on during the weekend.

The basic calculation that can be done for different specific moments is the following:

Costs heating Hangar 12 December 2021 / 31 days / 3 shifts / number of people in one shift

Example for a weekend shift:

Costs heating Hangar 12 December 2021 / 31 days / 3 shifts / number of people in one shift = €87.736 / 31 days / 3 shifts / 13 mechanics = €73 per person per shift

Hangar 12 (data: Z22 Preventive)

	Number of mechanics weekday (average)	Cost per mechanic weekday (average)	Number of mechanics weekend (average)	Cost per mechanic weekend (average)
Morning shift	55	€17,-	13	€73,-
Evening shift	36	€26,-	13	€73,-
Night shift	20	€47,-	13	€73,-
Average	37	€30,-	13	€73,-

Table 7: Cost of heating a mechanic, calculated using Z22 Preventive dataset.

Data without 33% overstaffing

	Number of mechanics weekday (average)	Cost per mechanic weekday (average)	Number of mechanics weekend (average)	Cost per mechanic weekend (average)
Morning shift	41	€23,-	10	€94,-
Evening shift	27	€35,-	10	€94,-
Night shift	15	€63,-	10	€94,-
Average	28	€40,-	10	€94,-

Table 8: Cost of heating a mechanic, calculated using Z22 Preventive dataset without 33% overstaffing.

Conclusion

The data from the dataset allowed for 33% overstaffing. This means that 33% more mechanics are scheduled than seems to be needed for the work planned. The calculations conclude that in December of 2021 on average €30,- per mechanic was paid on weekdays and €73,- per mechanic was paid in the weekend. On average that is €42,- per mechanic each shift. When overstaffing is not in order, that number rises to €55,- per mechanic per shift. This of course assumes that the heating is only done for the mechanics and leaves heating for equipment out of the equation.

2.9 Opening of the hangar door – Hangar observations

The operation of the hangar doors has been observed on multiple occasions. It can be concluded that there is no clear pattern in the operation of the hangar doors. The time that the hangar door is open differs a lot. Sometimes the door is opened for a plane to go out of the hangar and the door is closed almost immediately after it has left. Whereas on other occasions the doors were opened for over 30 minutes and on a particular occasion the doors were opened for 40 minutes (See Appendix 8.2). In cases that the hangar doors are opened for a long time, the reason most often was that the tug driver that pulls the plane into the hangar was not ready. There is no clear policy as to when to open the hangar doors when an aircraft is expected and the opening and closing can be done by any mechanic that has followed the *Control Hangar Doors and Manoeuvre Aircraft* training (KLM E&M WPI AM5020).

Time to open and close the doors
Another factor in the time that the hangar doors are open for is the time it takes to open and close the doors. In Hangar 11 Bay 2 there are two hangar doors, one opening to the left and the other one opening to the right. The doors are controlled separately by a mechanic who walks with the door. In this process the mechanic has to push a button on the door continuously for the door to move. To close a single door takes 1 minute 30 seconds (Hangar 11 Bay 2). They are closed one after another for supposed safety reasons. In Hangar 11 Bay 1, the time to close the doors by one individual was measured to be approximately 6 minutes.

In Hangar 12 the hangar doors open in five parts. Each separate part needs to be opened with a button on that door. Therefore, either multiple people are needed to open the doors quickly or opening the doors will take a lot of time (approximately 13min 30sec. when done alone, according to measurements done by a mechanic (see appendix 9.1)).

Hangar bay	Time to close all hangar doors by one individual
H11 Bay 1	360 seconds
H11 Bay 2	210 seconds
H12	810 seconds

Table 9: Time to close hangar doors per bay when done by one individual.

Conclusion
Given the long time it takes to open and close the hangar doors, it makes sense that the mechanics start this process well before an aircraft arrives. This, however, leads to the hangar doors being opened for a long period, which in winter causes most of the heated air to escape out of the hangar.

2.10 New hangar Heating – road to 2030

Another Graduation Thesis
Another intern at KLM has also been working on the Zero Emission Hangar Bold Move initiative. She studied green heating options for the hangars that KLM could consider on the road to the Zero Emission Hangar.

The study found three promising solutions for hangar heating and concludes: *"... it is recommended to either include PV electricity heating, thermal energy storage including a heat pump and PV panels, or district heating"* (Veldhuizen van, 2022).

The final recommendation is to select district heating as a new heating solution. District heating uses *''... local fuel or heat resources, that would otherwise be wasted, to satisfy local customer demands for heating by using a heat distribution network of pipes as a local marketplace''* (Frederiksen & Werner, 2013). According to van Veldhuizen (2022): *"Polderwarmte makes district heating a possibility for KLM. It also makes it possible for KLM to supply their waste heat resulting from, for example, the engine tests or the flight simulators to the heat net. Polderwarmte expects to construct this heat net in 2025 when there are enough customers."* As stated by van Veldhuizen, the company Polderwarmte is planning to construct their heat grid but for them to do so, there need to be enough interested parties. Van Veldhuizen (2022) states that according to Polderwarmte, KLM's current CO_2 emissions would be reduced by 75% once connected to their heat net.

A combination of both solutions
It is expected that the district heating net will be operational by 2028 (Veldhuizen van, 2022). Before then a lot of energy can already be saved by lowering the base temperature in the hangar and heating locally. An energy reduction of 69% can be achieved by lowering the base temperature in the hangar to 10°C (see Chapter 2.7). Once district heating is added to this in 2028 a further reduction of 75% in emissions can be achieved, reducing the total CO_2 emissions for heating of the hangars to 7,75% of the total emissions in 2021, a total reduction of 92%.

Chapter 3 - IDEATION & CONCEPTUALIZATION

Summary of Ideation & Conceptualization

The analysis of heating of the hangar revealed that current hangar heating is not effective. A heated working environment is firstly important for the mechanics and in specific instances, mainly with repairs that have a curing component, for the aircraft as well. Heating of the hangar should be focused more on those two subjects, instead of heating the entire hangar space.

As stated previously, this study consists of two parallel processes: analysis and ideation. Both processes were started in the first week of this study. The first ideas were gathered by talking to a large number of people within KLM. Part of the ideas were thought of within KLM and a few additions of my own were added. An overview of those ideas was made including a first visualization of each idea to form an image of what the idea could look like and to show to employees to spark their imagination (see Appendix 1.1).

The ideas were divided into the categories of Heat Conservation and Local Heating. Ideas in the category of Heat Conservation focus on increasing efficiency (see Appendix 1.1.1 and 1.1.2). The heat that is already in the hangar could be preserved better by focusing on isolation and minimizing the effect of opening the hangar doors. The category of Local Heating consists of ideas that only provide heat where the heat is needed, thereby saving a lot of energy and changing the concept of heating the hangar (see Appendix 1.1.3 through 1.1.6).

The ideas were shown to a number of stakeholders within KLM. These stakeholders included, mechanics (who will be the end user of the solution), the Continuous Improvement Leads of both Hangar 11 and Hangar 12 and three Vice Presidents who could each provide a different perspective.

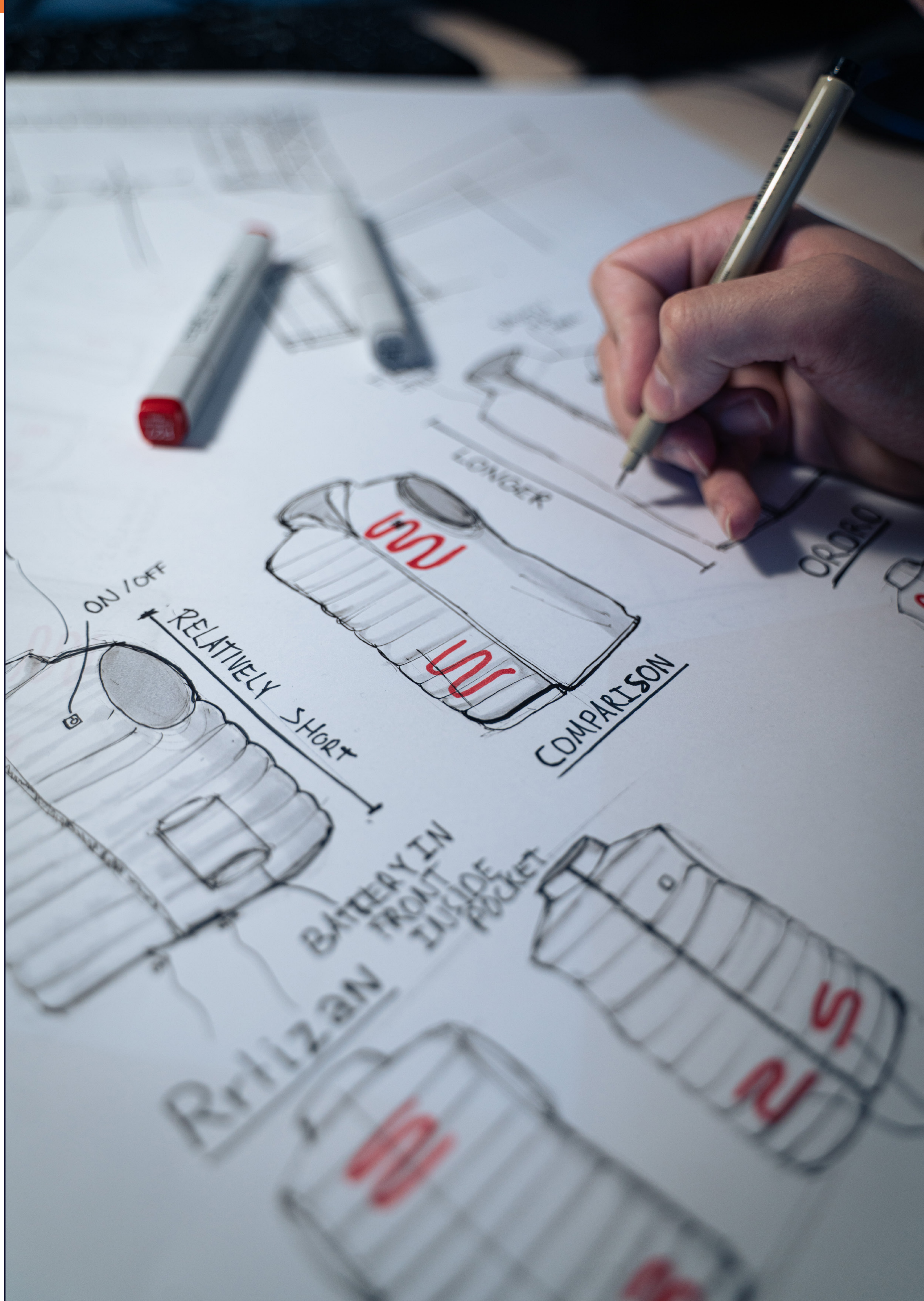
The combined feedback of the stakeholders (see Appendix 1.2), outcomes of the parallel analysis and the ever developing list of requirements (see Appendix 4), were at the basis of a converging process that consisted of further development of certain ideas (see Appendix 1.3), testing ideas and finally discarding ideas until a choice was made (see Appendix 1.4).

The most notable idea that was further developed initially, but not chosen eventually, was that of the Aircraft Curtain (see Appendix 1.1.2). This idea was received very well and sparked a lot of enthusiasm (see Appendix 1.2). Different concepts of the Aircraft Curtain were introduced and scrutinized (see Appendix 1.3). Eventually, the Aircraft Curtain was not considered effective enough considering the long periods the hangar doors are opened for. Next to that, the lowered base temperature in the hangar in combination with heating locally, makes the conservation of heat in the hangar of less importance in general (see Appendix 1.4).

The idea choice concluded to continue with IR panels for heating of the aircraft and Active Body Heating for heating of the mechanics (see Appendix 1.4).

In the Conceptualization phase, a low-fi prototype of flexibly deployable IR panels was made (see Appendix 2.1.1). After this, a deeper look was taken into heating of the aircraft with IR panels for repairs with a curing component (see Appendix 2.1.2). Composite repairs require specific heat cycles to cure and are therefore always heated using specialist equipment. Easier repairs do not always need additional heating, but can be heated locally when the process needs to be accelerated, this is already done sometimes. When large areas need to be cured, local heating is not always an option and the ambient temperature becomes the leading factor. All of these repairs do not often occur in the hangar and for the majority of them a local heating solution is already in place. For those reasons, it was not deemed relevant and significant enough to design a specific heating system for local repairs in this study (see Appendix 2.1.3).

It was decided to put all focus on Active Body Heating for mechanics. New advancements in the field were explored (see Appendix 2.2.1), different existing heated vests were purchased to experience and test (see Appendix 2.2.4), safety concerns were addressed (see Appendix 2.2.3) and battery placement was further explored (see Appendix 2.2.5). After this an extensive interview was held with the designer of the best perceived heated sweater that was purchased (see Appendix 2.2.6). His expert opinion and insights helped in the development of the proposed design for heated apparel to be used in the hangar for KLM.



Chapter 4 - DESIGN PROPOSAL

4.1 KLM heated apparel design choices

The insights of the interview with Rasmus Fannemel, product designer at the heated apparel brand Heat Experience (see Appendix 2.2.6 and Appendix 9.5), were taken as a base for designing KLM heated clothing. One of the big insights was that the choice for a bodywarmer style heated vest, or a more sweater style heated vest, has mostly to do with personal preference. The main features for a heated vest or sweater and the requirements were adjusted.

The vest specially designed for KLM should be used as a top layer and should have a zipper. The vest being a top layer makes it easier to take off the vest and the zipper gives flexibility in terms of temperature control. The vest can in this case also be worn with the zipper open, for quicker release of the heat and to reduce the tightness of the fit of the vest.

The heated vest should regulate the heat automatically. The mechanics can focus on their tasks whilst the vest keeps them at their desired temperature. This means that the vest will automatically heat less whilst inside the cabin of the aircraft. This is made possible by the addition of an NTC thermistor that measures the temperature of the heating elements. The users can set their desired temperature through an app (see Appendix 2.2.6). This being said, the user should still be able to turn on and off the vest by using a physical power button on the left side of the chest.

The heated vest should also be able to be comfortably worn as a normal vest or sweater without using the active heating. When it is able to be worn like this, it can replace the current fleece vest or bodywarmer whilst adding additional functionality.

Heating elements should be placed on the chest area and at the lower back. This is based on research done by Heat Experience, as well as personal experience with multiple heating element positions in different vests.

Place in the KLM clothing line-up
At KLM Engineering & Maintenance the mechanics are provided with their working clothes. There are clothing packages available for each specific function. In most categories there is a choice between different items of clothing. There is for example the choice between either a fleece coat or a bodywarmer. According to a long time mechanic at KLM the fleece coat does not have the best fit and a more slim fitting option would be preferable. As stated before the newly designed product should be able to be worn comfortably as a normal vest or sweater when you are not using the active heating. For this reason, it is chosen to introduce both a sweater (long sleeved) version as well as a vest (bodywarmer) type heated product to replace KLM's current offerings (see Figure 10).

Figure 10: Picture of current clothing choice for mechanics between a fleece coat and a bodywarmer

Material choice for top layer usage
At KLM the heated apparel would make most sense as a top layer. The sweaters currently offered by Heat Experience are meant to be mid layers and are minimally insulated. Interestingly the materials used in the Heat Experience heated sweater are similar to a softshell jacket (95% polyester, 5% Spandex (elastane)) even though the sweater is breathable and not water or wind resistance. According to Rasmus, they way the material is knitted/weaved, the density of the weave and surface treatments determine the characteristics of the final product. For use in the hangar, a more wind, weather and dirt resistant top layer would be preferable. A soft shell type jacket is easier to clean/wipe off and better insulated. For that reason it would be a better fit to use as a top layer. A bodywarmer type heated vest is already fitting to use as a top layer.

Battery
The battery pack for KLM heated apparel should last at least one shift (8 hours). Rasmus expects that the current battery should last the whole shift when the mechanics start to get used to how to control the settings and that it is not needed to have the heating at the maximum setting all the time. This has to be tested in a real life situation to be determined. The battery should have a USB-C port for charging. Many of the latest battery packs make use of a USB-C port. USB-C is the current standard in smartphones, which means that most people already have a charger that could charge the battery. USB-C also enables fast charging of the battery. The battery will most likely be charged at home given the fact that each heated jacket belongs to a specific mechanic (like it is currently the case with clothing items) and given the fact that the battery life should last the entire shift.

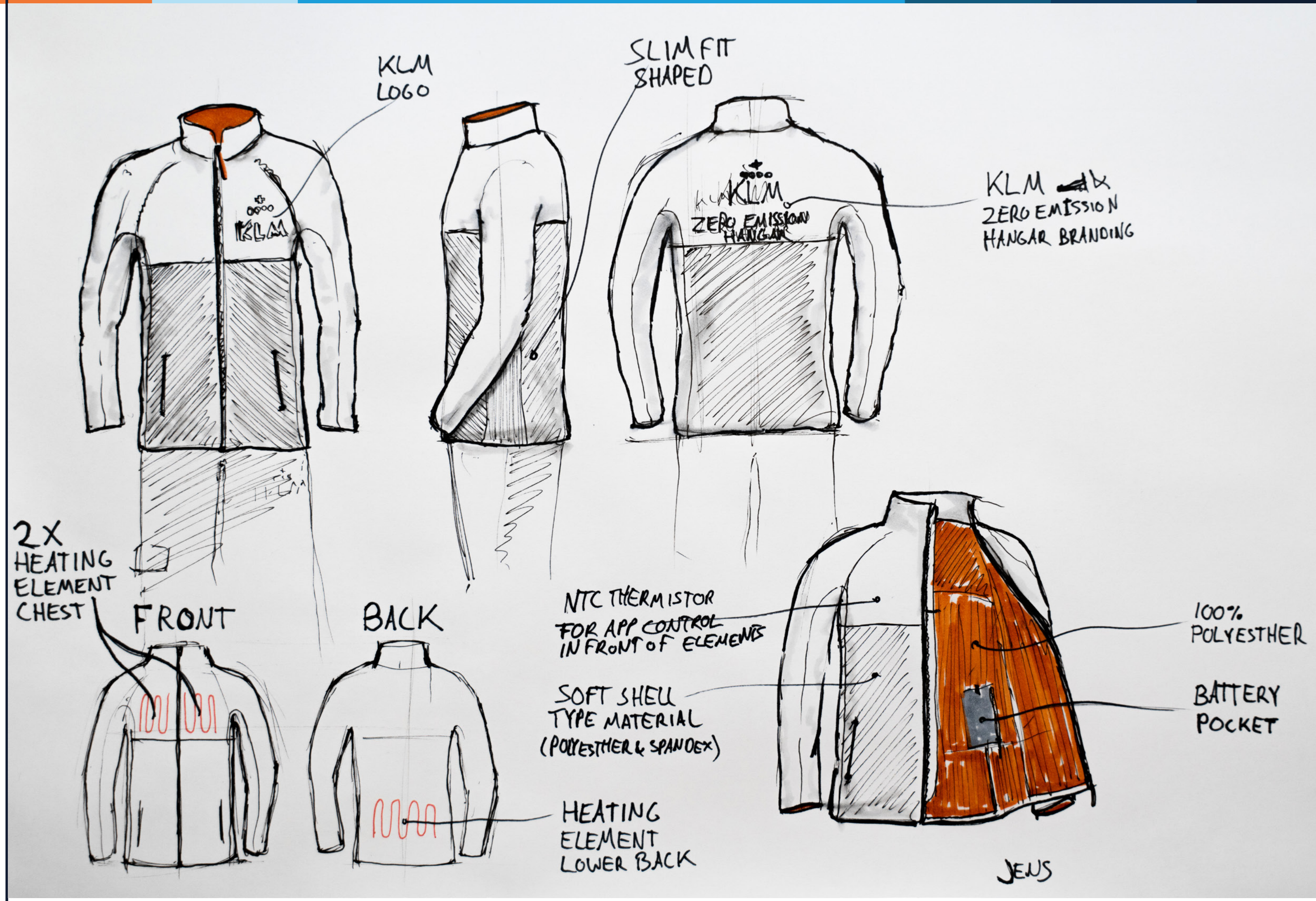


Figure 11: First hand drawings of KLM heated softshell jacket

4.2 A design for KLM

Taking the insights and requirements into account, the first hand drawings of the envisioned heated soft shell jacket were made (see Figure 11). The jacket should have a professional look and fit the current clothing line of KLM. Yet the product does not have to be as plain as the current products and should stand out slightly. The jacket can in that way serve as a bit of advertising and can help in raising awareness regarding the Zero Emission Hangar.

The jacket should be a high quality product and it may have a special feel to it. High quality comes at a cost but will ensure durability. Furthermore, it is important to show the mechanics that KLM does not cut costs when it regards the working conditions and health of their employees. When the heating of the hangar is significantly reduced, a well designed, warm and high quality heated jacket is a sign to the mechanics to show that they are deemed important.

Only a male version of the jacket and bodywarmer were designed. Unfortunately it was not deemed viable to develop a women's version for KLM, since approximately 1% of mechanics is female. It is therefore recommended to let the female mechanics try on the male's version for fit and otherwise purchase a women's version of a heated bodywarmer or jacket that already exists and print the KLM logos on those.

Figure 12: KLM Heated Bodywarmer (left) and Heated Soft Shell Jacket proposal (right)

Figure 13: KLM Heated Soft Shell Jacket proposal on KLM light blue work pants

Current KLM upper garments are either KLM light blue but more often a blue so dark it can easily be mistaken for black. KLM logos are printed on the products in white. For the new jackets it was determined to choose a dark colour that can be combined with the clothing that is currently present (see Figure 13), but is slightly more saturated and unique. Orange, although rarely displayed on their aircraft, is used as an accent colour at KLM and refers back to the Dutch origins of the brand. To make the new jackets stand out a bit more, orange touches can be found on the zipper tag, in the logo on the back and in the lining of the jacket (see Figure 15).

The jacket uses three heating elements, two on the chest and one on the lower back (see Figure 14). The battery is located on the inner left side of the jacket (see Figure 15) and the battery fits snugly in the battery pocket to prevent the battery pack from moving around in the pocket. An NTC thermistor is placed in between the fabric and the front of the heating element to measure the temperature of the element. These measurements are used to keep the temperature of the element constant (reduce temperature fluctuations). The wearer of the jacket can use an app to change the temperature of the elements as they desire, this application was not developed but the application of Heat Experience could be used when they would become partner in development of KLM heated apparel (see Appendix 2.2.6).

There is still a physical power button present on the heated vests. When the button is pressed for 3 seconds the vest will turn on and the KLM logo on the front will light up (see Figure 16). When turned on with the power button on the vest, the vest will heat up to its latest temperature setting as set in the mobile application. Short pressing the power button will make the vest cycle through three pre-set power settings of low, medium and high. This feature is currently present on most heated vests (see Appendix 2.2.4), and will allow the mechanics to use the heated vest without the app if they so desire.

Figure 14: KLM Heated Soft Shell Jacket with descriptions

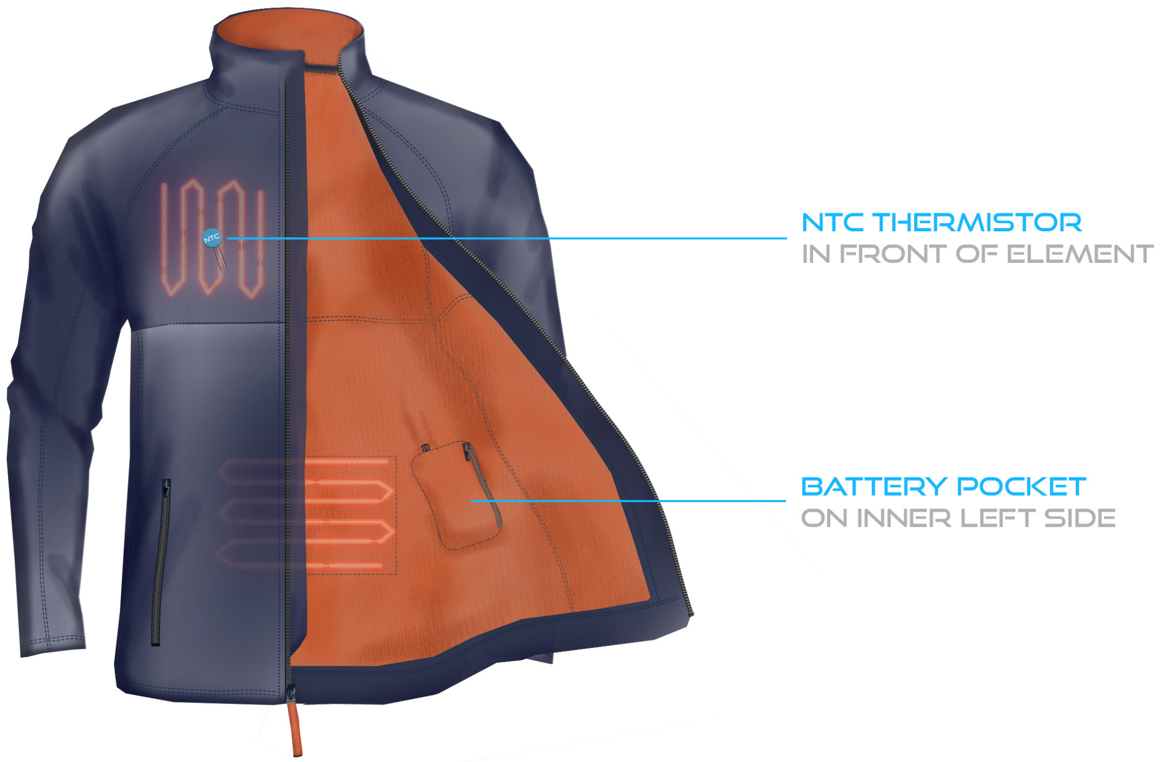


Figure 15: KLM heated Soft Shell Jacket inside with explanations

Figure 16: On/off button placement of heated jacket and explanations

Cost estimation and energy consumption

For this cost estimation Hangar 12 will be taken as an example. In Hangar 12 there are 11 teams in total and each team consists of 18 mechanics on average, that means that approximately 200 mechanics work in Hangar 12. Heated apparel of high quality is not cheap and prices for heated vests and sweaters from Heat Experience range from €190,- to €235,- at non-discounted prices. Considering the fact that the products for KLM need to be developed first, include a softshell jacket (which will most likely be more expensive than a sweater) and that the products will include the technology for app control. The mechanics will get the choice for either the heated soft shell jacket or the heated bodywarmer. The average price per item (bodywarmer and soft shell jacket) is conservatively estimated at €350,-.

*Initial investment heated apparel: 200 units * €350 = €70.000*

The battery pack that comes with the products of Heat Experience is a 6.000mAh and 44,4Wh unit. Each day on average 100 people work in the Hangar 12 spread out over three shifts (see Chapter 2.7, average number of mechanics per shift +-33 * 3 shifts). Heated apparel would only be necessary outside of the aircraft and approximately 56% of work is done outside of the aircraft (see Chapter 2.7). If everyone that wears heated apparel would use up a full battery in a shift, on a monthly basis that would mean:

*44,4Wh * 100 mechanics * 0,56 working outside * 31 days = 77.078Wh = 77,1kWh*

Using the electricity price as found in Chapter 2.7, which was retrieved from bills of KLM of €0,06 per kWh, that equates to monthly energy costs of:

$$\textit{Cost price per kWh} * \textit{number of kWh used} = €0{,}06 * 77{,}1kWh = €4{,}62$$

Which means the energy consumption and costs are completely negligible for a company like KLM.

The initial investment for purchasing the heated apparel of €70.000,- is a large sum of money, but this is the price for a high quality and durable product. Given the cost reduction that comes with lowering the base temperature in the hangar to 10°C, around €400.000,- per year (see Chapter 2.7), the payback time for this investment would be less than two winter months.

Figure 17: KLM Heated Bodywarmer proposal

Chapter 5 Final Conclusion & Proposal

Heating of the Hangar
Heating of the hangar is not effective, takes a lot of time, energy and money. A lot of the time mechanics are still working in the cold.

In Chapter 2 the heating of Hangar 12 was analysed. The time to heat up the hangar is between 4 to 6 hours in winter time. The average power consumption was between 400.000kWh and 550.000kWh per month in the winter of 2021/2022 and the cost for heating in December was approximately €88.000,-.

The hangar is heated for the mechanics and for the aircraft. The mechanics need a safe working environment and when the temperature indoors is below 15°C, KLM should provide appropriate clothing (according to FNV). The aircraft needs heat locally at repairs that include curing processes. These processes mainly take place in Hangar 11 (corrective plant) and only occur sporadically.

No reasons have been found to heat up the whole hangar space to room temperature (21°C). Therefore a lower base temperature in the hangar is proposed and decided to be 10°C, using advise of the FNV Work Climate app (see Chapter 2.4). I propose to use the sunstrips to heat the hangar to 10°C and to provide additional heat locally for the mechanics and the parts of the plane that need the heat. I propose to not use the temporary GTL heaters anymore because their running costs are six times higher compared to the sunstrips. The energy consumption of the GTL heaters is also higher compared to the sunstrips, especially when the additional power consumption that can be dedicated to the fans of the temporary heaters is taken into consideration.
By lowering the base temperature in the hangar to 10°C, 69% of energy and costs can be saved. In December 2021 these savings would translate to more than €60.000,- and on a yearly basis to approximately €400.000,- (see Chapter 2.7) and 436 tons of CO_2. CO_2 emissions can be reduced by an additional 75% in 2028 when KLM decides to go with district heating to provide their energy. This would result in a total reduction of emissions of over 92% compared to 2021.

Heating of mechanics and aircraft
It was determined that heat is necessary for mechanics working in the hangar and for the aircraft, in case of specific repairs. There are already local heating solutions in place for specific repairs, especially when it comes to composite repairs that need a fairly particular heat cycle in order to cure. When it comes to other repairs that have a curing component such as a paint repair, the repair area is often not heated locally, in which case the ambient temperature becomes the leading factor. It is recommended to heat locally more often in these instances, when the base temperature in the hangar is lowered, to ensure fast enough curing times. It was not deemed relevant enough to develop a local heating solution for repairs with a curing element, because of the fact that a local heating solution for most of these repairs is already available at KLM. In addition to that, these repairs only occurre sporadically.

Figure 18: Proposal for heating of the hangar, lower the base temperature, turn off and remove GTL heaters and introduce heated apparel

The focus was therefore shifted towards the heating of the mechanics. Heated clothing was determined to be the most effective way to heat the mechanics, as well as the most cost effective solution. Different types of heated vests were purchased and trialled to experience and learn about their working and which considerations to make when it comes to designing these types of products. Together with an expert on heated clothing it was decided to design two versions, a long-sleeved heated jacket and a bodywarmer, as the preference for either is highly personal. The heated jacket and bodywarmer would replace KLM's current fleece coat and bodywarmer offerings for mechanics. The long-sleeved heated jacket was designed as a slim fit soft shell jacket since it should be worn as a top layer. A soft shell type jacket is more wind and weather resistant, better insulated and easier to clean compared to a sweater type jacket.

The purchase of the new heated soft shell jacket and bodywarmer for all mechanics in Hangar 12 is expected to be €70.000,-. This is a large sum of money, but it does guarantee a high quality and durable product. Given the cost reduction that comes with lowering the heaters in the hangar to provide a base temperature of 10°C, the payback time for this investment would be less than two winter months.

To summarize, the energy, emissions and cost of heating of the hangar can be reduced with 69% before 2025. This can be achieved by lowering the base temperature in the hangar to 10°C and providing the mechanics in the hangar with heated jackets and vests. The one time investment of €70.000,- for the development and purchase of heated apparel is compensated by a yearly saving of €400.000,- in heating costs, making the payback time for this investment less than two winter months. In this study, Hangar 12 was taken as an example, but when Hangar 11 would be included, total yearly cost savings would be significantly larger. The reduction in emissions can be brought back further to 92% in 2028 when KLM opts to go with district heating as their energy provider.

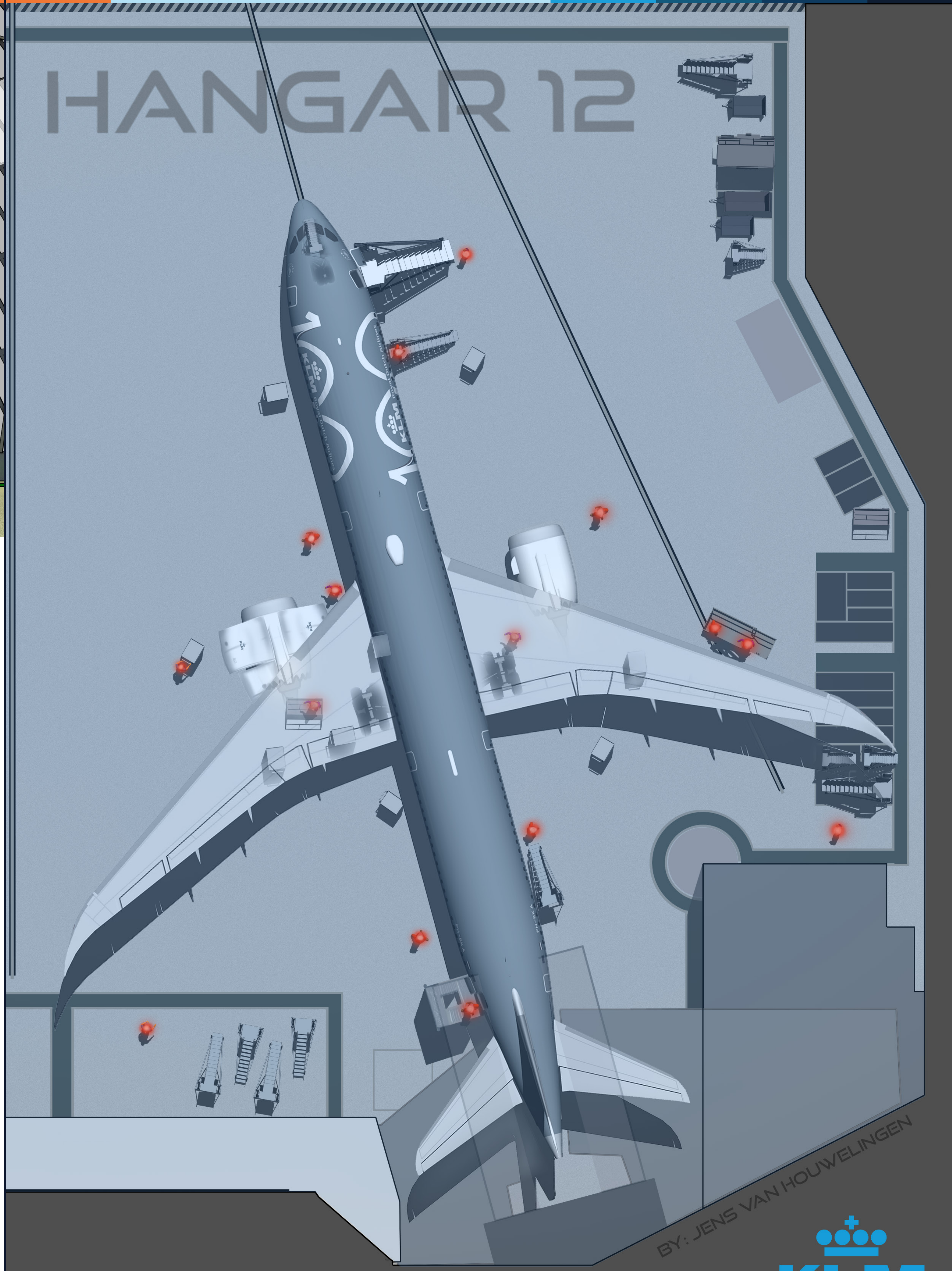


Figure 19: Map showing locally heating the mechanics in the hangar.

KLM

Chapter 6 NEXT STEPS & RECOMMENDATIONS

A concept for a heated soft shell jacket and heated bodywarmer were presented in this study, but these would need to be developed further. It is recommended to get a third party on board to make this a reality. Heat Experience is a brand whose mission is to be THE expert in heated clothing. They have a lot of experience in this field and the widest product range when it comes to heated clothing. A significant difference in quality and effectiveness were found in the heated apparel of different brands that were tested in this study. Heat Experience makes the most polished and thought through products in this space that I have been able to find throughout this study and they have shown interest in a collaboration with KLM for the development of the heated soft shell jacket and bodywarmer.

Heated apparel has been proven effective in use cases comparable to the hangar in terms of working conditions, but it should be tested in the hangar environment by mechanics to fully proof its effectiveness in combination with the lower base temperature of 10°C. Lowering the base temperature to 10°C should also be tested to discover any unforeseen effects that could negatively impact the operation.

Heating locally at repairs with a curing component should be done more often. Decreasing curing times could increase both hangar space availability as well as fleet availability. The potential time savings should be analysed by the Planning (fleet availability) department together with data analysts. The analysis should involve the frequency of occurrence of different types of repairs, the type of repairs themselves and their curing time at different temperatures. Depending on the findings of this analysis, clear procedural changes should instruct to also utilize an additional local heater for repairs that do not necessarily need an additional heating source to cure, but that will benefit shorter curing times when using this heater. The introduction of a more flexibly deployable IR heating panel (see Appendix 2.1.1) could benefit this cause by being able to apply heat on harder to reach surfaces as well. The benefit of such a product and its viability need to be further explored.

Even though focusing on heat conservation was not considered to be the most effective way to solve the heating problem in the hangar, it is recommended to take actions to improve the heat conservation of the hangar to further reduce energy consumption. Multiple observational walks through the hangar revealed that relatively easy gains can be achieved. Higher priority should be given to the right use of doors. The large doors in both Hangar 11 and 12, that connect the both hangars with a corridor are permanently opened. These doors act as an airlock when used correctly but the doors are supposedly non-functional currently. The same issue was found in a 2004 study (Meijer Energie- & Milieumanagement BV, 2004).

Furthermore, I recommend reconsidering the procedure of opening the hangar doors. Currently, the procedure is not polished enough which leads to the doors being open for long periods unnecessarily. Procedural and process-related optimization in relation to the tug drivers and opening of the doors could significantly reduce costs and energy consumption. The procedure for opening the doors instructs: *"When moving the hangar door, pedestrians or vehicles may not pass through the passage and the operator will have to stop the door."* (KLM E&M WPI AM5020). It does not state anywhere in the document however that the doors may not be closed partially whilst the aircraft is parked but the tug is still decoupling. This by itself could already save approximately 5 minutes. The process of closing the hangar doors can further be shortened by changing the procedures to always operate the hangar doors with multiple mechanics. It still happens that doors are opened or closed by one individual, which makes the whole process take significantly longer (see Chapter 2.9).

In practice, there is oftentimes only one tug driver available for the KLM Schiphol-East operations. When there are a lot of aircraft movements this means that the wait for the availability of the tug can be lengthy. The communication between the tug driver and mechanics is not optimal which can lead to mechanics opening the door for a plane to be moved in or out but the tug driver being on a break or moving another aircraft first. Furthermore, the opening or closing of the hangar doors is left too much by the initiative of the mechanic that is operating the doors, rather than it being a precisely thought out procedure, this leads to inconsistency in the time that the doors are opened for. Better communication with and availability of the tug driver by procedure, and providing the mechanics in the hangar with a more precise estimation of the availability of the tug, in addition to improving the procedure of opening the doors itself, would enable the mechanics to open the doors with improved timing, thereby improving heat conservation in the hangar further and minimizing temperature fluctuations.

Making the procedural changes suggested in this study will bring KLM even closer to a true Zero Emission Hangar.

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Appendix 1 – IDEATION

1.1 First Idea Collection

In the first few weeks of my graduation project I have gathered information by talking to a large number of people within KLM. Part of this information consists of ideas that have been tested before or were planned to be tested. This part aims to give an overview of the ideas that have been thought of within KLM to reduce energy consumption of the hangars in regards to heating, with a few additions of my own. A first visualization of each idea was made to form an image of what the idea could like and to show to employees to spark their imagination.

The design problem can be looked at from two main perspectives, namely the conservation of heat and the adding of heat. On the one hand, to increase efficiency, the heat that is already in the hangar could be preserved better by focusing on isolation and minimizing the effect of opening the hangar doors. Whilst on the other hand the concept of heating the hangar could be changed. Instead of heating the whole hangar, only heating where the heat is needed (local heating), could save a lot of energy.

The ideas were divided into the categories of *Heat Conservation* and *Local Heating*. On the basis of the outcomes of the research of Chapter 2, a list of requirements was set up (see Appendix 4).

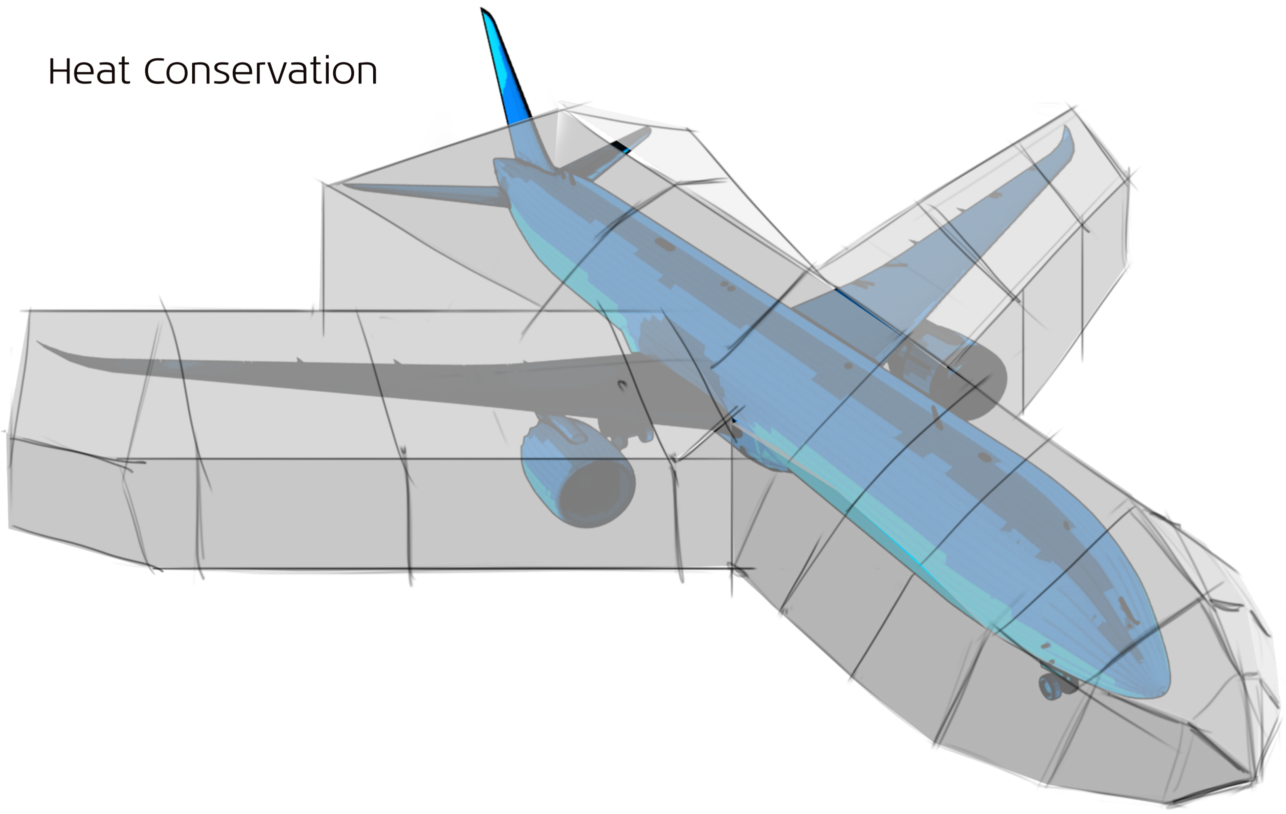


Figure 20: First visualization of Aircraft tent

1.1.1 Aircraft tent

The aircraft tent is an idea to put a tent over the aircraft in order to reduce the space that needs to be heated. The origin of the idea is in tents that are already used in specific circumstances in airplane maintenance. These “motor tents” are put at the inlet of the engine to create an enclosed space to prevent fine particles to spread through the hangar.

Figure 21: Motor tent currently used for specific engine maintenance

Figure 22: First visualization of Aircraft curtain

1.1.2 Aircraft curtain

The opening of the hangar doors is one of the main issues regarding heat loss in the hangar. Opening the doors in Hangar 12 creates an opening of close to 100 metres in width and 25 metres in height. The idea of the Aircraft curtain, is to minimize the size of the opening by creating a curtain with a cut-out in the shape of the plane. This way less heat will get lost when the hangar doors open.

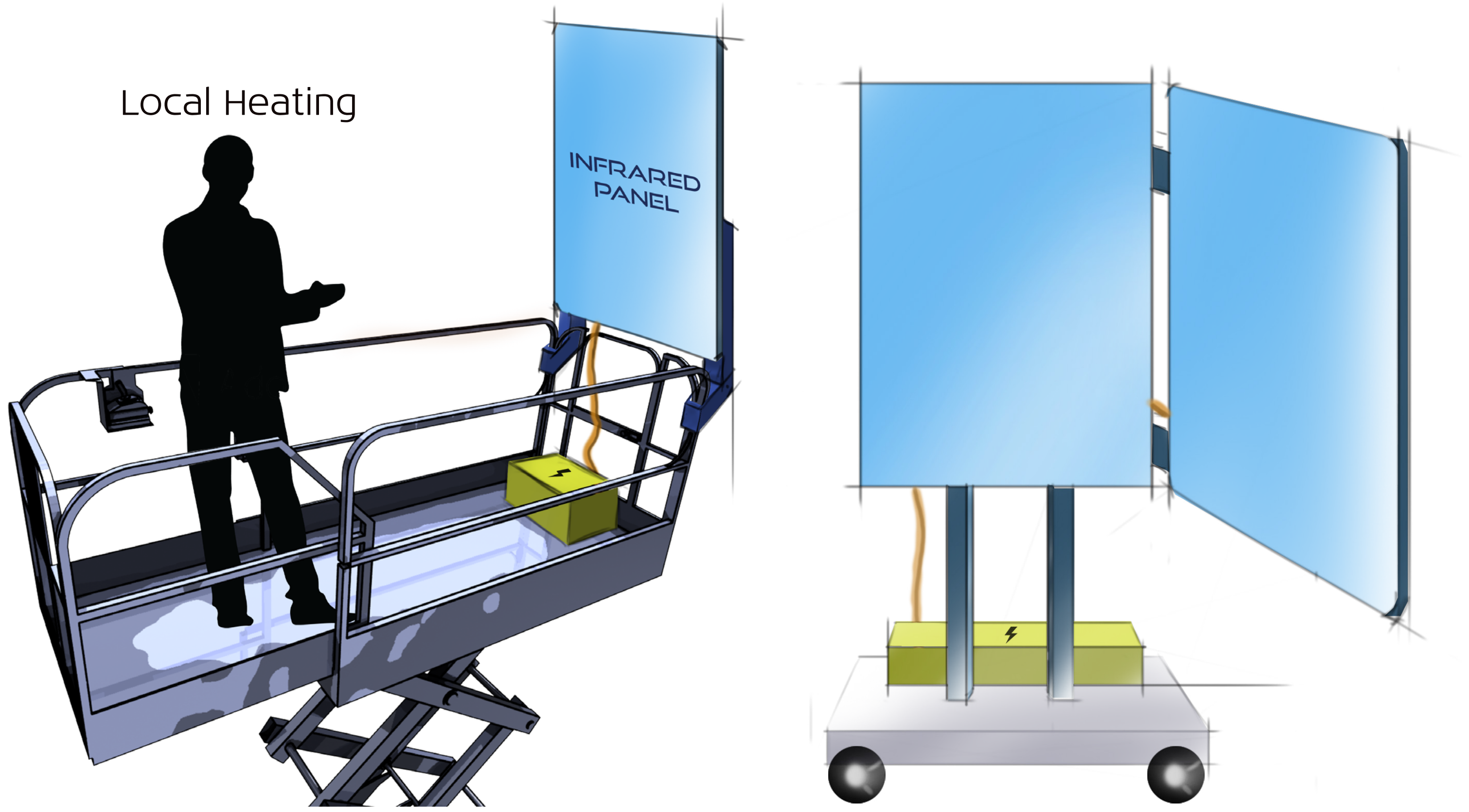


Figure 23: First visualization of IR panels on a scissor lift and on a rolling structure

1.1.3 Infrared panels for heating

Similarly to active body heating solutions, the idea to implement infrared panels at workstations outside of the cabin is focused on providing a comfortable working environment (temperature) for the people instead of heating up the whole hangar space. Infrared heating panels are relatively energy efficient and could be mounted to scissor lifts and a frame on wheels to heat up the colder workspaces locally. Alternatively, infrared panels could be attached to tool carts. Most mechanics take a tool cart at the start of their shift. A tool cart contains most standard tools needed to do most maintenance like screwdrivers, hammers, wrenches, a ratchet, etcetera. By attaching an infrared panel to a tool cart, this panel could be assigned to a mechanic during a shift.

Currently, infrared panels are powered by wall power. One shift takes approximately 8 hours. To heat an infrared panel of 400W for 8 hours, 1,8kWh is used.

$$400W * 8h = 1800Wh = 1{,}8kWh$$

More concretely, this for example means a battery of at least 12V 150Ah is needed.

$$12V * 150Ah = 1800Wh$$

A battery of that capacity is significant in weight, price and size. Their prices vary between €300,- and €700,-, weigh approximately 40kg and are approximately 50x15x25cm in size.

This realization begs the question whether powering a panel for 8 hours is needed. Are mechanics working in cold conditions for longer periods uninterrupted during a shift? Perhaps a 4 hour period for the infrared panel would already be sufficient.

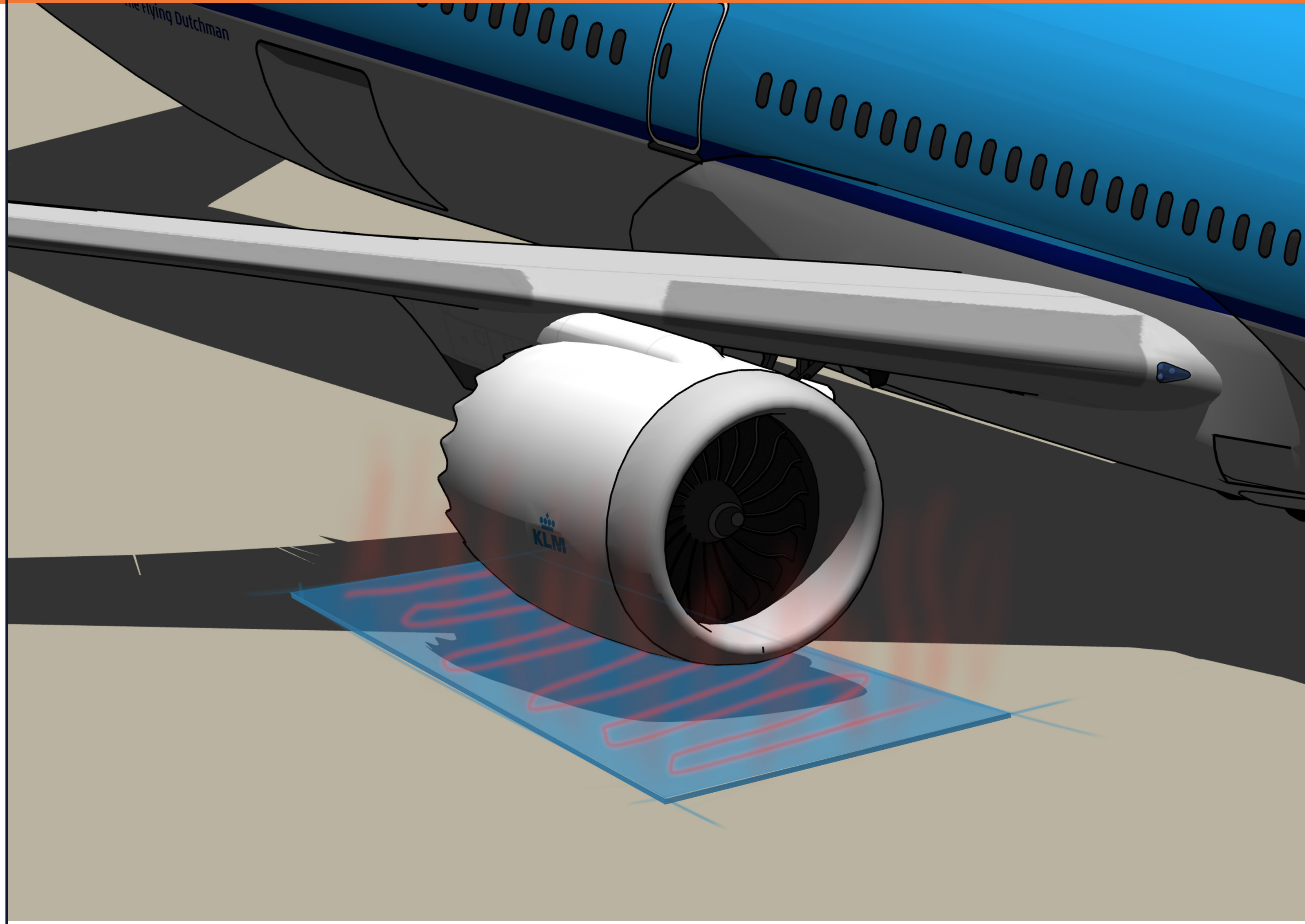


Figure 24: First Visualization of Local floor heating below an engine

1.1.4 Local floor heating - heating mats

Instead of installing floor heating in the hangar which would require major infrastructural modifications to the hangar, it might be possible to have a type of mat or panel that would act as local floor heating at places where a lot of maintenance is done, for example at the engines.

Figure 25: First visualization of active body heating

1.1.5 Active body heating

The hangar is a huge space and the question can be raised whether that whole space needs to be heated. Cold temperatures in the hangar affect the people (mechanics) the most and therefore it could be interesting to look into finding a solution to heat them instead of the whole hangar space. This could for example be done with heated vests or heated gloves.

According to Hutton (2022), electronically heated clothing was already used by pilots a century ago, among whom Charles Lindbergh in the 1930s. Later on, these types of clothes were used by the U.S. military in the second world war. Currently, heated clothing can mainly be found in skiing equipment stores.

Deng et al. (2020), did a study in local heating of the human body. They simulated people standing in the grandstands at the 2022 Olympic Games using a cryogenic chamber. The study shows that heated insoles significantly improved thermal comfort and sensations. The study showed that *"Compared with the hands and back, the thermal satisfaction rate of the feet increased the most…"*, in addition to that: *"…heating the feet from the inside of the shoes can eliminate cold and discomfort of the feet and effectively improve overall thermal comfort in a cold environment"*.

A thermal study done in 2013 with a far infrared (FIR) heating vest showed that: *"The FIR heating vest used in cold conditions turned the heat loss from skin to heat gain of the skin and increased temperatures between clothing layers and micro climate close to the skin. Nevertheless, the effects were local and were not sufficient to increase temperatures at the fingers and toes during very low physical activity in the cold."* - Jussila et al. (2013).

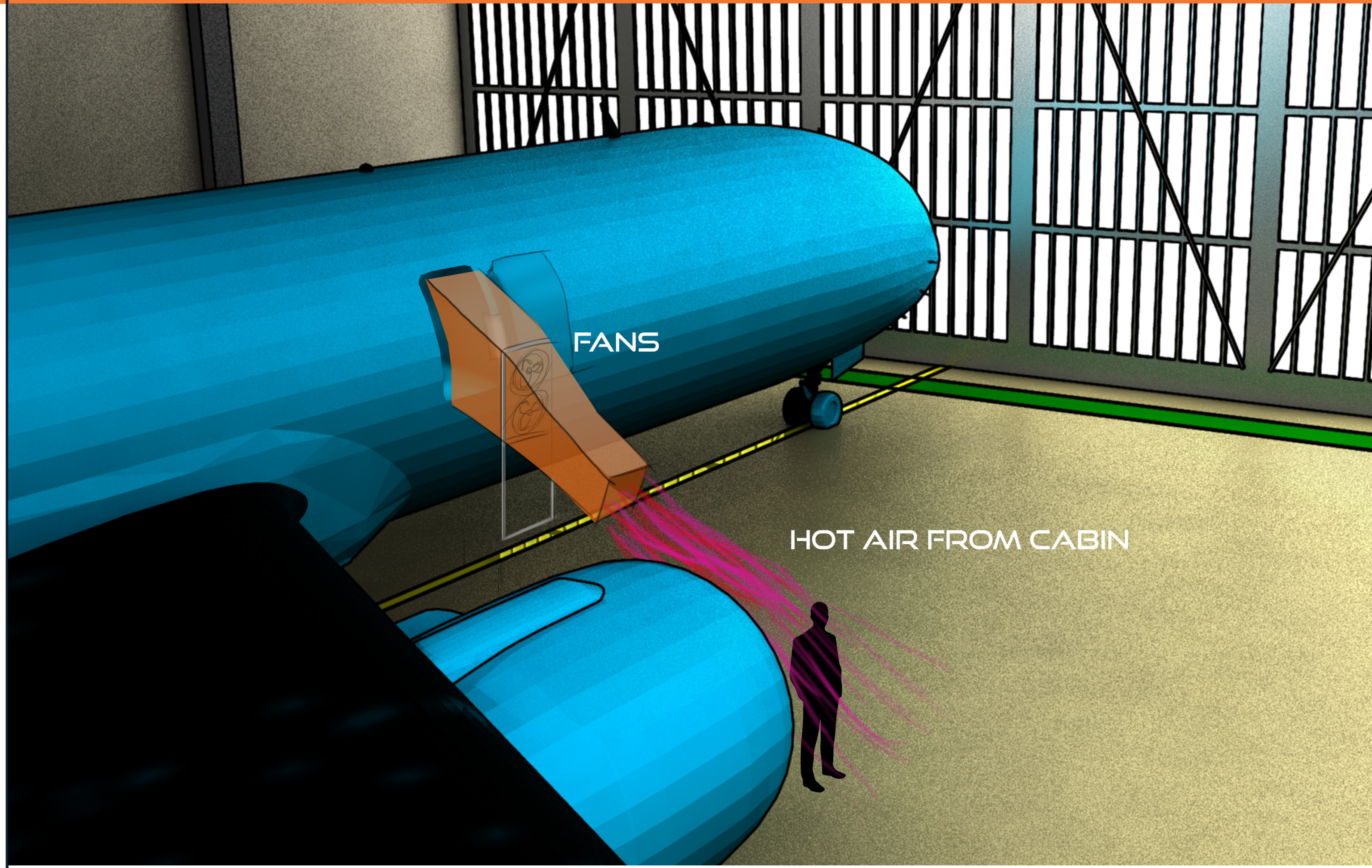


Figure 26: First visualization of Heat Funnel

1.1.6 Heat funnel

During maintenance, the electronic systems in the cabin are turned on in order to be able to check and operate parts of the aircraft. The APU (Auxiliary Power Unit) is turned off and for that reason there is no air-conditioning inside. These two factors combined with the fact that the cabin can be crowded during maintenance causes the temperature inside to be between 25 and 35 degrees Celsius. In order to cool down the cabin, the doors oftentimes are opened with nets placed in the door openings.

The idea of the heat funnel is to use the hot cabin air and direct it to cold workplaces outside of the cabin. The funnels could at the same time actively cool the air in the cabin when implemented in a smart manner.

1.2 Feedback on first ideas

The ideas were shown to a number of stakeholders within KLM. Firstly, the ideas were shown to mechanics, since they actually work in the hangar and therefore would be the end user. Secondly the ideas were discussed with the Continuous Improvement Leads (CILs) of both Hangar 11 and Hangar 12. The CILs are highly involved with new developments and innovation projects within the hangar and have are in close contact with the mechanics. Lastly the ideas were presented to the Vice President of Planning, Scheduling and Fleet Control, VP ICT Data and Digital and VP Strategy, Marketing and Communication. The first has a large involvement in processes in the hangars, the second was involved with the Bold Moves projects, and had a lot of experience at KLM, and the last was a help when it comes to marketing and actually implementing a new idea. Feedback of all stakeholders was combined per idea.

Aircraft tent
The aircraft tent was thought of in a council of mechanics. In that council it was mainly critiqued for fire safety. Feedback that I got was: *"The airplane tent seems a huge challenge"* (Barry Ruitenbeek, CIL). This mainly because of the deployment time (an engine tent takes approximately 1 hour to set up and a full aircraft tent would take longer to deploy), the logistical challenges of entering and exiting aircraft and their positions in the hangar and the movement of equipment and people surrounding the aircraft during maintenance. Every party that was spoken with seemed sceptical about aircraft tent.

Aircraft Curtain
The Aircraft Curtain was well received within KLM and its main ambassador was my KLM supervisor Jasper Rougoor. The premise of the aircraft curtain was clear but the effectiveness would need to be proven. The aircraft curtain was the idea that was received with the most enthusiasm and me presenting this idea led to loads of suggestions, it seemed to spark creativity and provoke their imagination. An interesting suggestion was to only cover the top half of the hangar door opening with a permanent (non-movable) curtain, with vertical stabilizer cut-outs, since most of the heat is in the top half of the hangar anyways.

IR Panels for heating of mechanics
Using IR Panels for the heating of mechanics received mixed responses. There have been some pilots within KLM with IR panels before and issues that were found were that: there was no use for the panels if something was in between the panel and the mechanic, they were power consuming and the hangar is already at top capacity and even when the people were heated, the material was still cold. Even with these insights there was still willingness to give IR panels another chance and the idea to mount IR panels to a toolcart or scissor lift was well received by the CILs, VPs and supervisory team. The mechanics, however, were less enthusiastic. They were mainly concerned about the panels blocking their view or getting in the way of their work tasks: *"Everything (talking about tools, tool carts and scissor lifts) already has its own function, if you add new things to it the function will die"* (Mechanic Hangar 12).

Local Floor Heating
Local floor heating was an idea that was introduced by the CILs. The mechanics could see it work, for example under the engines, if the heating panels could withstand the chemicals that are used during maintenance and could support the weight of things (such as scissor lifts) driving over them. Similarly to IR panels however, once you would have to collect a part or tools in the workshop, you would be cold again.

Active Body Heating
Active body heating is an easy to understand solution. It does seem to be an effective way to approach the problem, however, the overall perception of heated vests was that they are clumsy and large. Heated vests were thought of as a life jacket and there were concerns about movability and comfort. Another concern that was mentioned regarded static electricity. When presenting the idea to mechanics they seemed to like it. Certain mechanics always where a T-shirt, no matter the weather but even they could see the benefit for the mechanics that are currently often cold. The idea of being able to control your own temperature and to have your personal heater always on you, wherever you go seemed like a pleasant proposition.

Heat Funnel
The heat funnel was well regarded overall: *"It is a nice idea that creates a win-win situation"*. Namely cooling down the aircraft cabin whilst heating up the hangar space. Most parties could appreciate the ingenuity and creativeness of the idea, although there were some doubts about the effectiveness, both expressed by the supervisory team, some VP's and the CIL's. Other than that the comfort was questioned: *"You have to keep in mind that airstreams don't feel pleasant/comfortable oftentimes."* (Marco Steinmetz, CIL)

Conclusion
The idea of the Aircraft Tent was received the worst and implementation would not only be extremely challenging, it was also deemed a safety hazard. This idea is not further looked into for those reasons. The Heat Funnel was seen as a creative solution, but its effectiveness needs to be determined. Local Floor heating will need to be compared to using IR Panels for the heating of mechanics as they serve the same purpose, but both ideas were received well by enough people to look further into them. Active Body Heating did not need a long introduction and was received as a potentially good solution by everyone spoken to and will therefore be further explored. Lastly, the Aircraft Curtain sparked the most enthusiasm, as it is a creative yet understandable solution. Since nothing like this exists yet, a further development needs to be made to be able to determine its effectiveness.

1.3 Further development of ideas

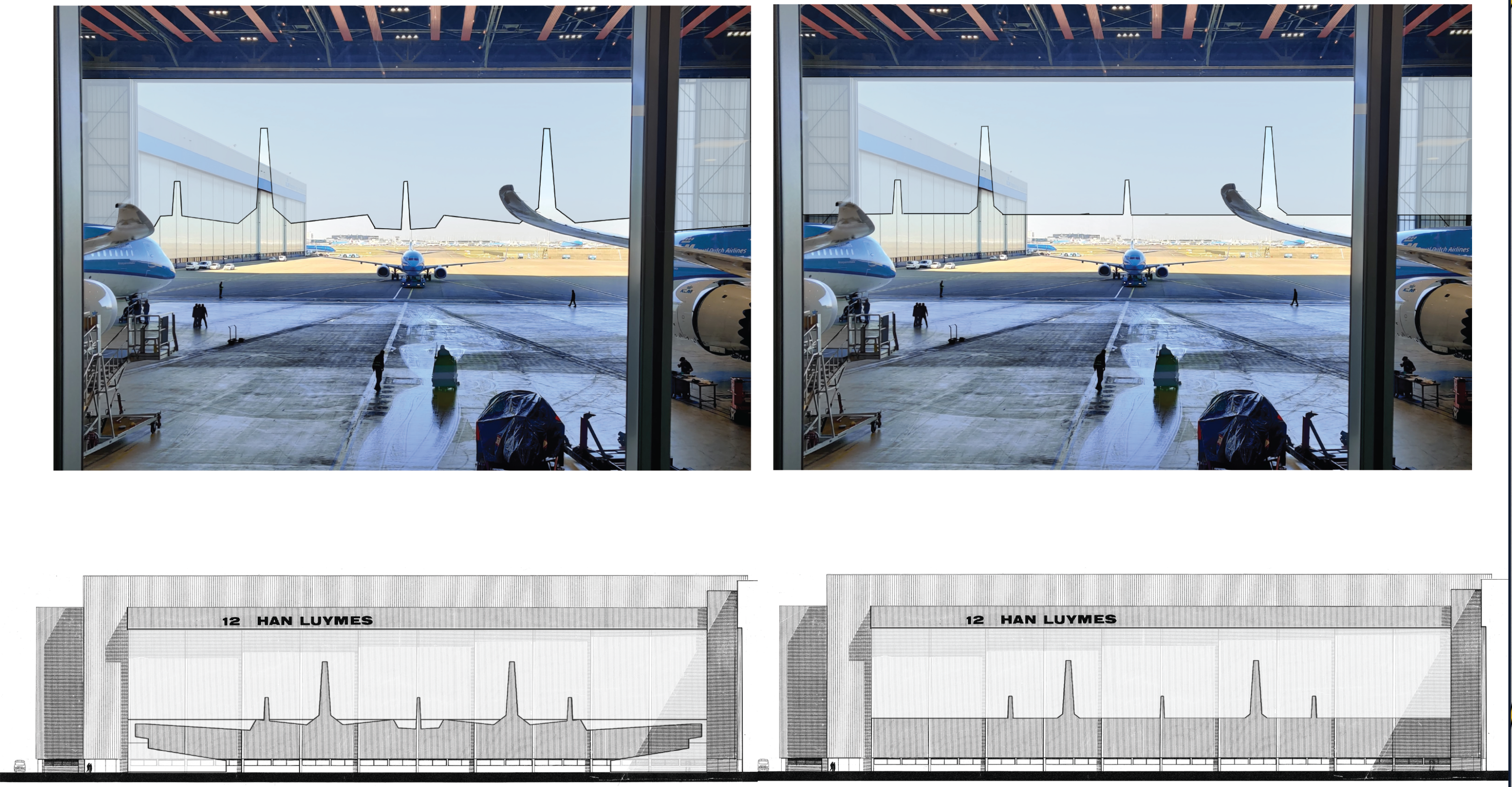


Figure 27: Aircraft curtains taking all aircraft into account.

1.3.1 Aircraft curtain further development and feasibility determination

Because of positivity towards the idea of the aircraft curtain within KLM and to get a better understanding of the feasibility of the idea, it was developed further. The aircraft curtain is a completely new idea and therefore there are a lot of questions related to its effectiveness, costs, materials to use and integration in the hangar that need to be answered.

The first aircraft curtain visualization showed the curtain with an opening for the Boeing 737 and just for the middle position in the hangar (see Appendix 1.1.2). After showing that visualization to multiple people and having received a lot of promising feedback I made a more realistic design. For this version all five positions for aircraft were taken into account (see Figure 27 and Figure 28). With that, for each position all possible airplane models were considered. This means that the curtain could technically be in place at all times and would not have to be moved up and down. On positions 1, 3 and 5 only a Boeing 737 can be serviced (see Figure 28). On positions 2 and 4 all aircraft of KLM's fleet could be serviced (B737, B777, B787, A330).

In order to define the openings of the aircraft curtain, a scaled overlay of all aircraft was made for positions 2 and 4 (see Figure 29). For positions 1, 3 and 5 the front view of a B737 was used in the same scale.

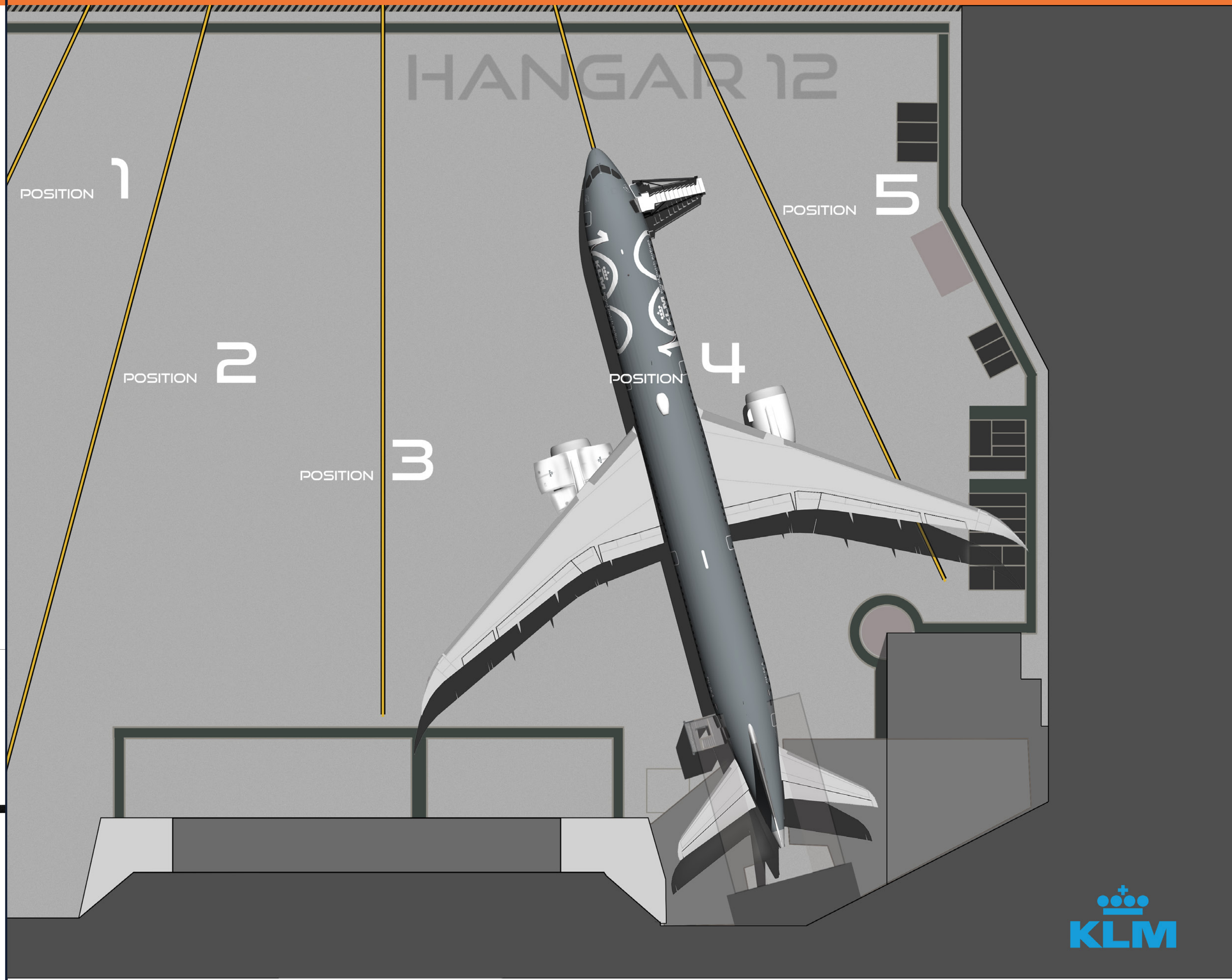


Figure 28: Aircraft positions in Hangar 12

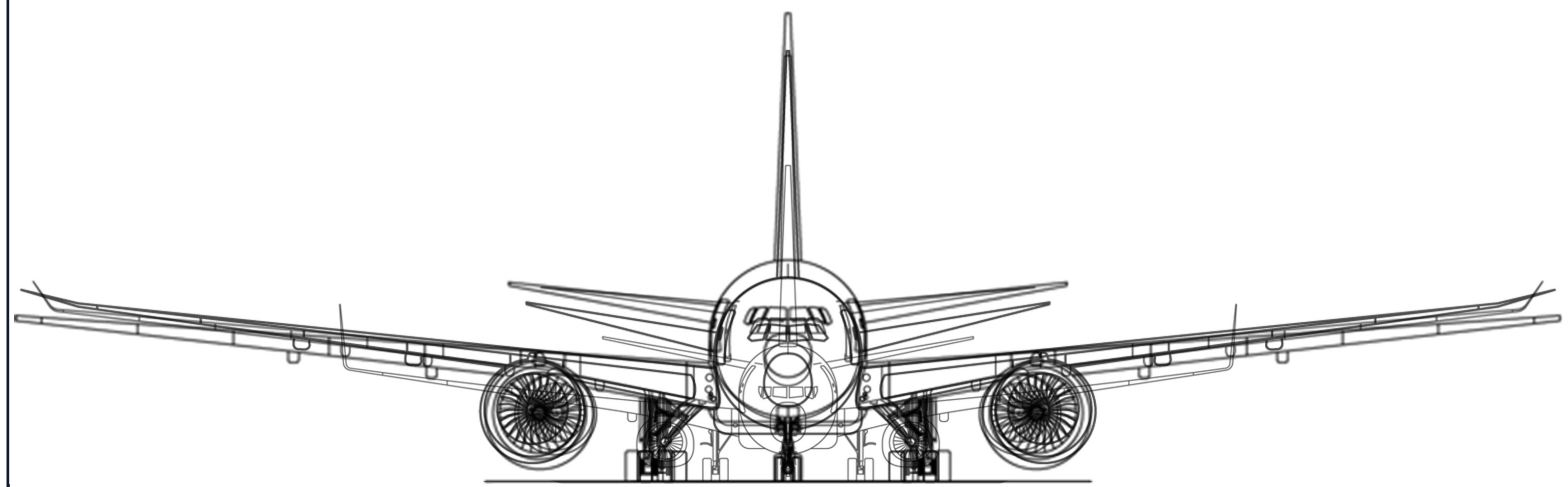


Figure 29: Scaled overlay of all current KLM aircraft

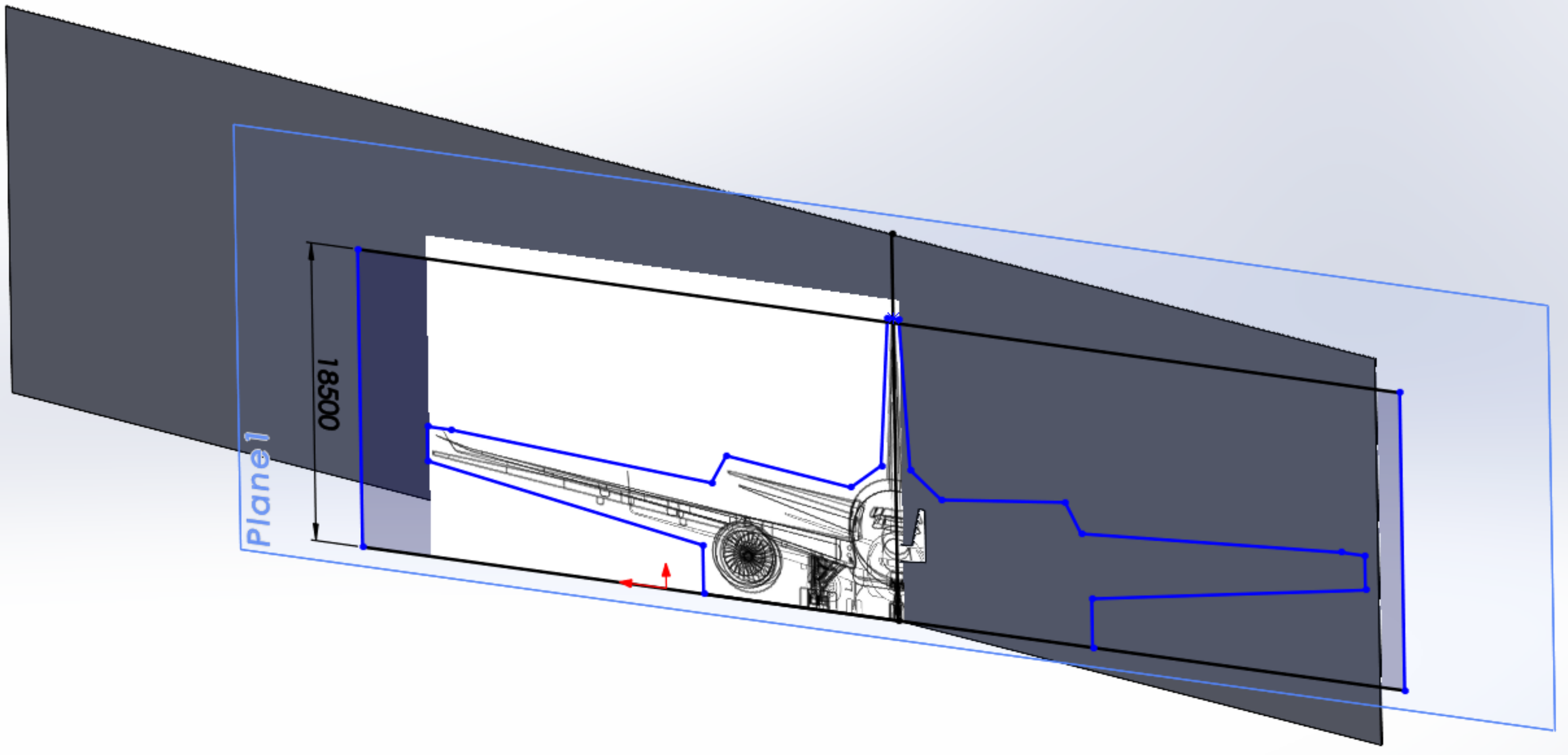


Figure 30: Screenshot of SolidWorks process

SolidWorks was used to create the cut-outs for the curtain. The results can be seen in Figure 30. The surface area of the two new proposed curtains was calculated using SolidWorks. Curtain version 2 was determined to have a surface area of approximately 1700m² and the curtain version 3 was determined to have a surface area of approximately 1482m² (see Figure 31).

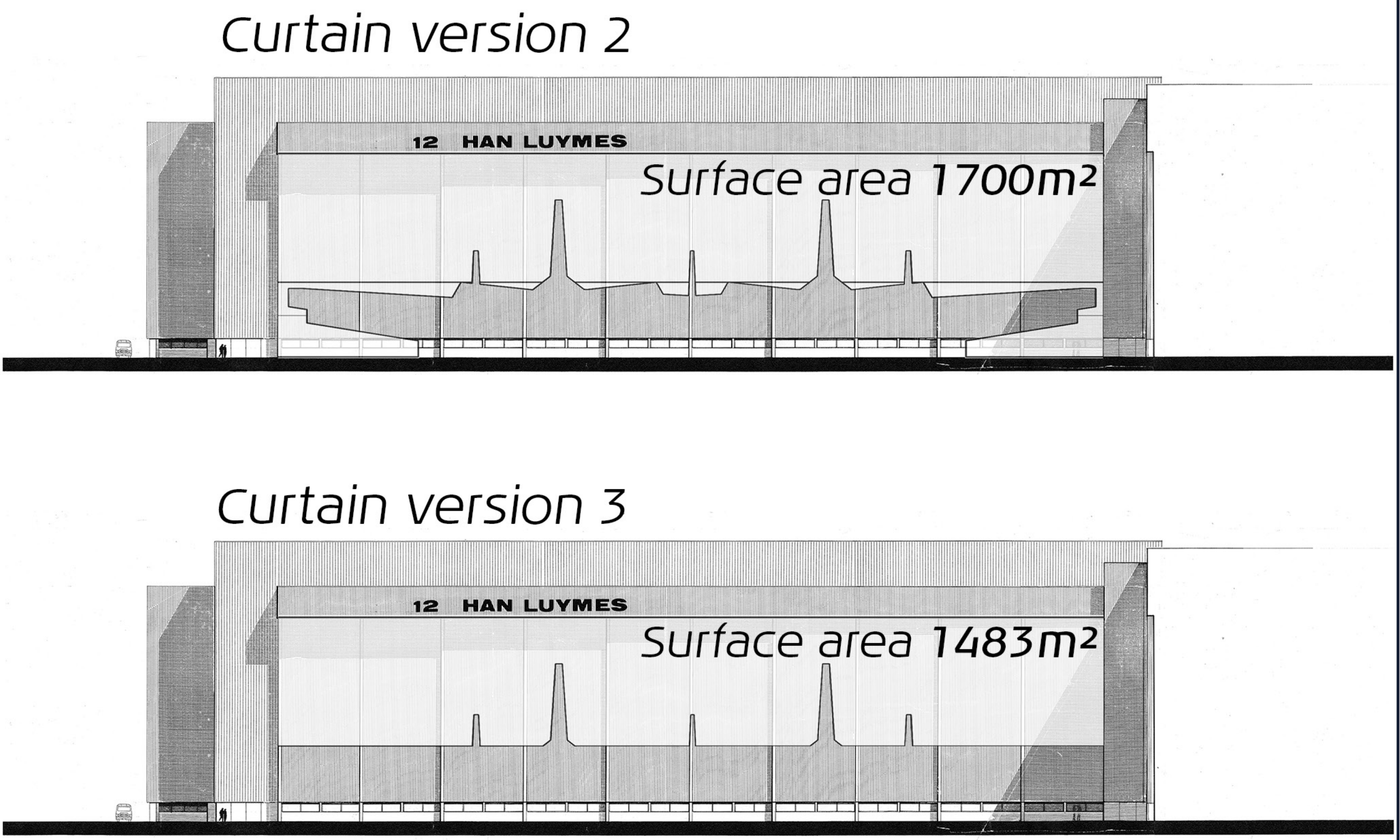


Figure 31: Aircraft curtain version 2 and version 3

Curtain version	Material	Thickness	Weight (kg)
2	Vinyl	10mm	24.650
3	Vinyl	10mm	21.500
2	PVC canvas	550gram/m² = 0.38mm	935
3	PVC canvas	550gram/m² = 0.38mm	815
2	VALMEX POLYMAR	2mm (900-1500 gr/m²)	1530-2550
3	VALMEX POLYMAR	2mm (900-1500 gr/m²)	1334-2224

Table 10: Possible materials for aircraft curtain

A possible material option would be Vinyl. This is the same material that strip curtains are often made of. Because of the large surface area of the curtain a material thickness of 10mm was taken as an example. The weight of this would be close to 25.000kg and would need to be distributed somehow along the 100 meter width of the hangar door opening. This would mean that even if 50 it would be attached to 50 suspension points, each of those points would have to support close to 500 kilos.

Valmex Polymar is a material that is currently used in the manufacturing of large roll up hangar doors according to Shipyarddoor (n.d.). The material is highly inflammable and wind and crease-resistant.

Looking at the hangar right now the most logical point of attachment for a curtain seems to be the beam shown in yellow in Figure 32. Whether this beam is capable of supporting a lot of additional weight is uncertain. A reference is the large yellow beam to which a crane is attached. This beam largely shows that it can support up to 10.000kg. This beam does look different and not completely comparable since the whole beam is moveable and the crane itself too. This means that the crane is capable to carry 10.000kg in any position which would suggest that with a constant evenly distributed weight along the full length of the beam, the maximum load would be higher.

Figure 32: Left: possible mounting beam in yellow, right: crane on the ceiling of the hangar.

Figure 33: Inspiration for Aircraft curtain. Upper left: Strip curtains at baggage belt, upper right & lower left: Aircraft curtains in miniature at Miniatur Wunderland Hamburg, lower right: carwash dryer that follows the shape of the car.

1.3.2 Inspiration and analogies aircraft curtain

In an ideal situation, the plane should be able to move into the hangar without having a door opening. It should be like vacuum forming. The plane would drive into the hangar without taking the outside air into the hangar.

Going through a door without there ever being an opening where air can pass through directly from the outside in almost sounds like a utopian idea, yet that is exactly what a revolving door does. The revolving door was invented by H. Bockhacker who called it “Tür ohne Luftzug” which means door without draft of air (Bailes, 2016). A study done at MIT showed that using the revolving door instead of a normal swing door, saved 36Wh each time the door was used. In the particular building on a yearly basis everyone using the revolving door instead would save 80.000kWh (Cullum et al, 2006).

The concepts of vacuum forming and the revolving door were taken as inspiration during ideation and led to new concept approaches for the aircraft curtain where the shape of the opening in the curtain almost seamlessly wraps around the plane.

Inspiration was taken from strip curtains as can be found in walk-in fridges at supermarkets or at baggage belts at airports (see Figure 33). A version of a strip curtain as an aircraft curtain so to speak is already used in Miniatur Wunderland in Hamburg (see Figure 33). This gives an idea of the way the strips would move over the aircraft. Lastly, inspiration was found in the moveable dryers that can be found in drive through carwashes. The dryer follows the shape of the car whilst the car moves through the carwash (see Figure 33).

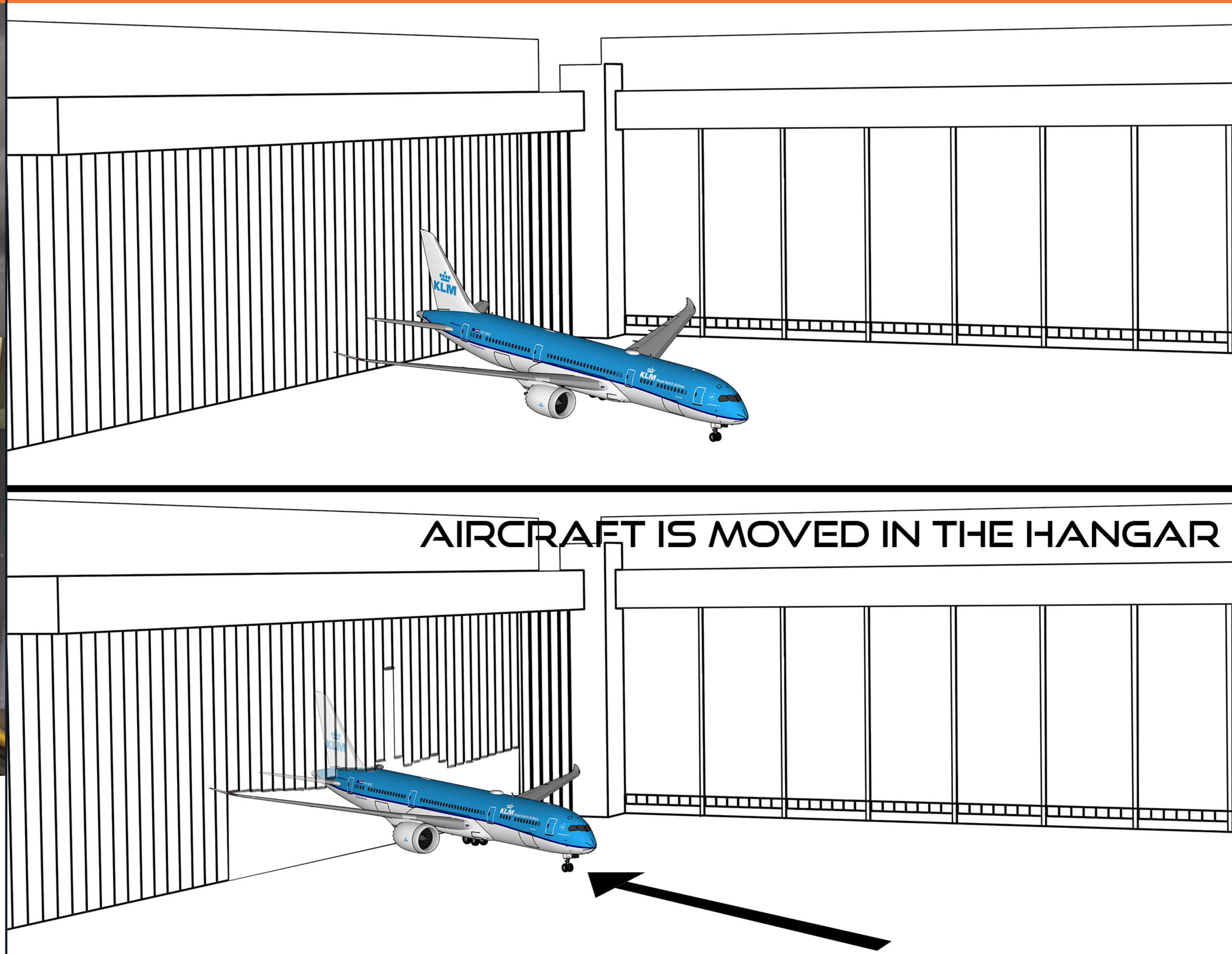


Figure 34: Idea Aircraft curtain based on inspiration (Figure 33) and analogies.

New idea from inspiration
The inspiration was taken into a new idea for what the aircraft curtain could look like. The curtain could be made up out of strips, just like a strip curtain, and the strips could move up and down individually, using the principle of a carwash dryer. The strips would follow the shape of the aircraft and will only create the necessary cut-out at any given moment (see Figure 34). The shape of the cut-out would be formed around the shape of the plane at any moment in time and it would be like vacuum forming.

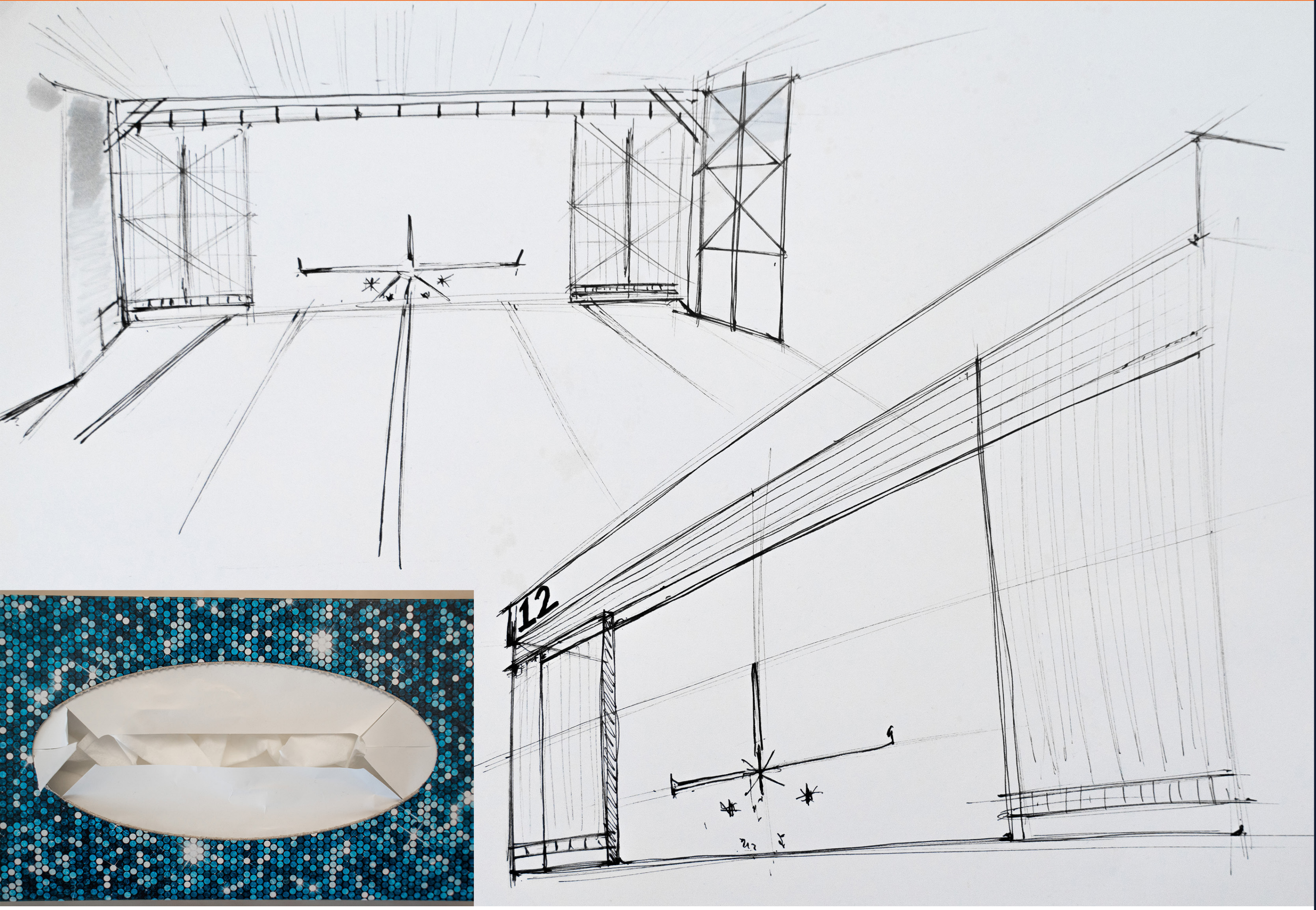


Figure 35: Drawing of the hangar with curtain with solely a cut-out inspired by a tissue box

1.3.3 Lo-Fi prototyping Aircraft Curtain

Inspiration was found in a tissue box that was at hand. The cut-out in the tissue box is made out of a flexible material that changes shape when a tissue is pulled out of the box. The tissue box cut-out made me wonder what a cut-out with the same principles would look like for an aircraft. Since I was not sponsored by KLM for this part of prototyping, I had to use a model plane of a different airline since no KLM model plane was at hand.

The particular model of plane was looked up for sizing and some parts of the model plane were measured. Simple (part) cut-outs were first tried (see Figure 36) and it was determined that the Asterix pattern cut-outs for the fuselage and engines needed to be slightly larger than the diameter of the fuselage and engines respectively. Baking paper was used as material for the “curtain”.

A complete “tissue box cut-out” was made and a cardboard border was made to keep the baking paper stretched out (see Figure 37). The plane was able to fit through the cut-out and pictures were made to see how the material would deform. It was clear that the baking paper curled up in this configuration. In reality the material would need to be heavy enough to not curl up, but still flexible and soft enough to not damage the aircraft.

A second more simple “big hole cut-out” was made in which the aircraft would not touch the material (see Figure 38). With this cut-out the material curled up noticeably less compared to Figure 37.

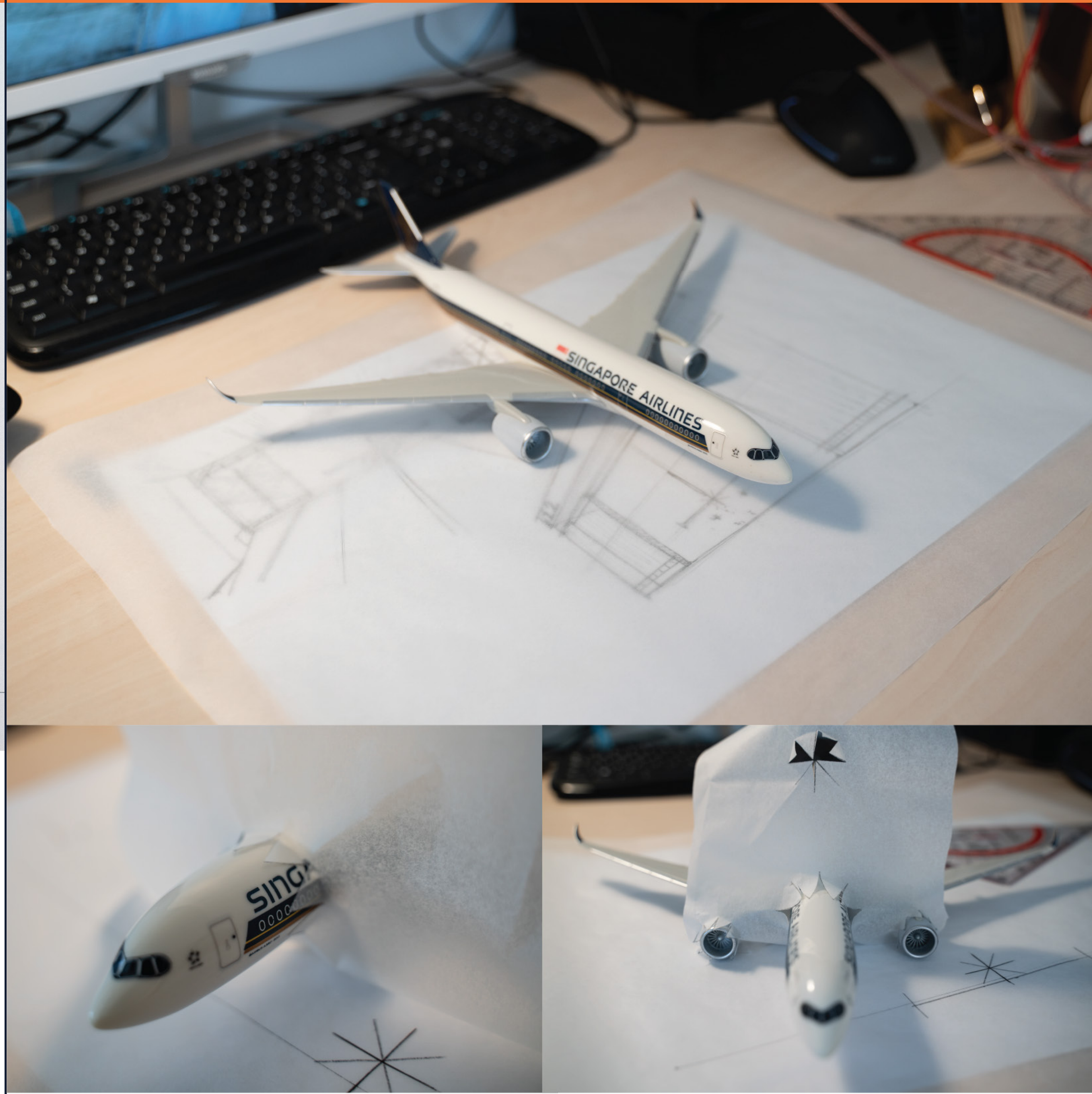


Figure 36: Model airplane in 1/200th scale and first cut-out tries

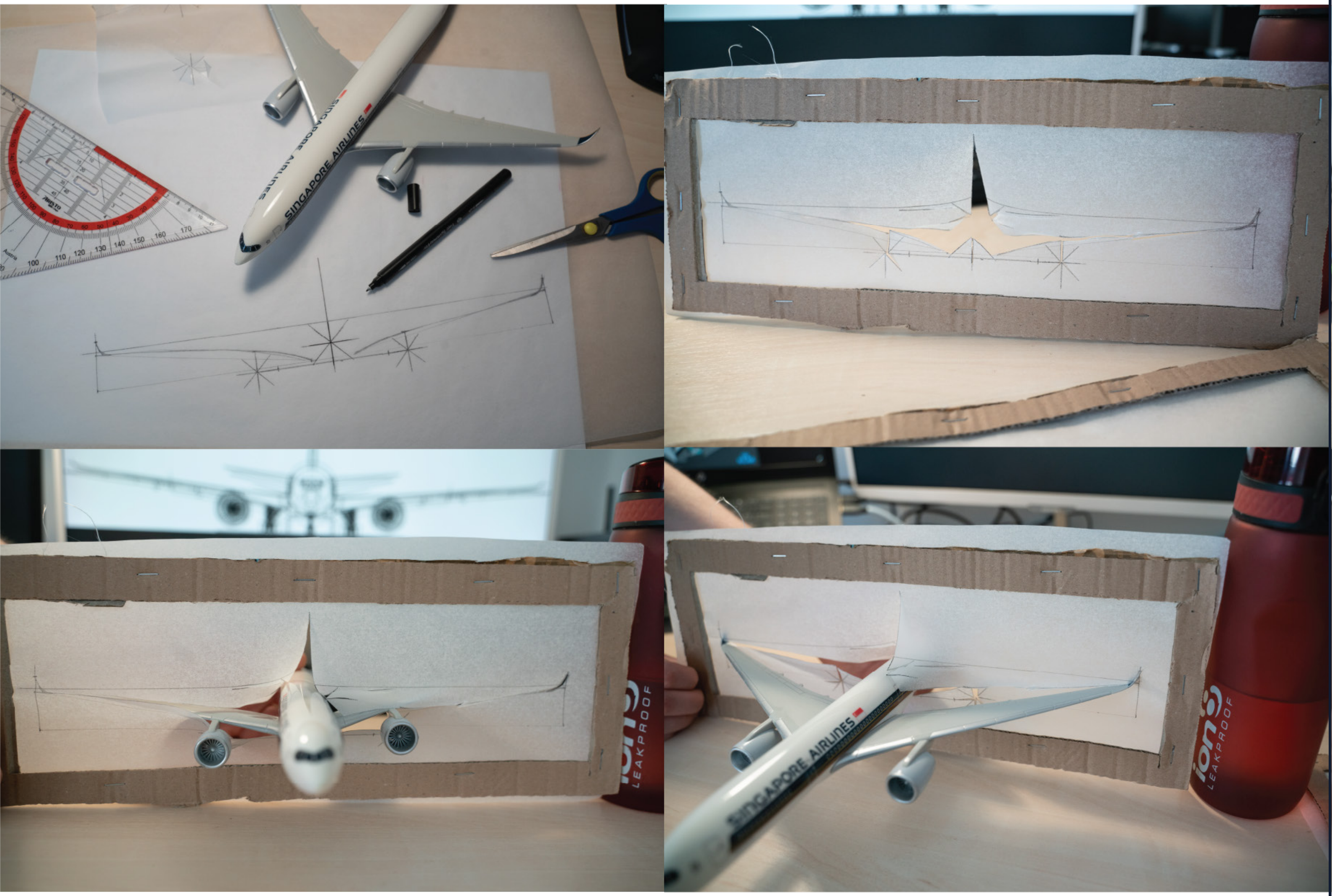


Figure 37: "Tissue box cut-out" drawing, cut and the plane was pushed through to see how the material would deform.

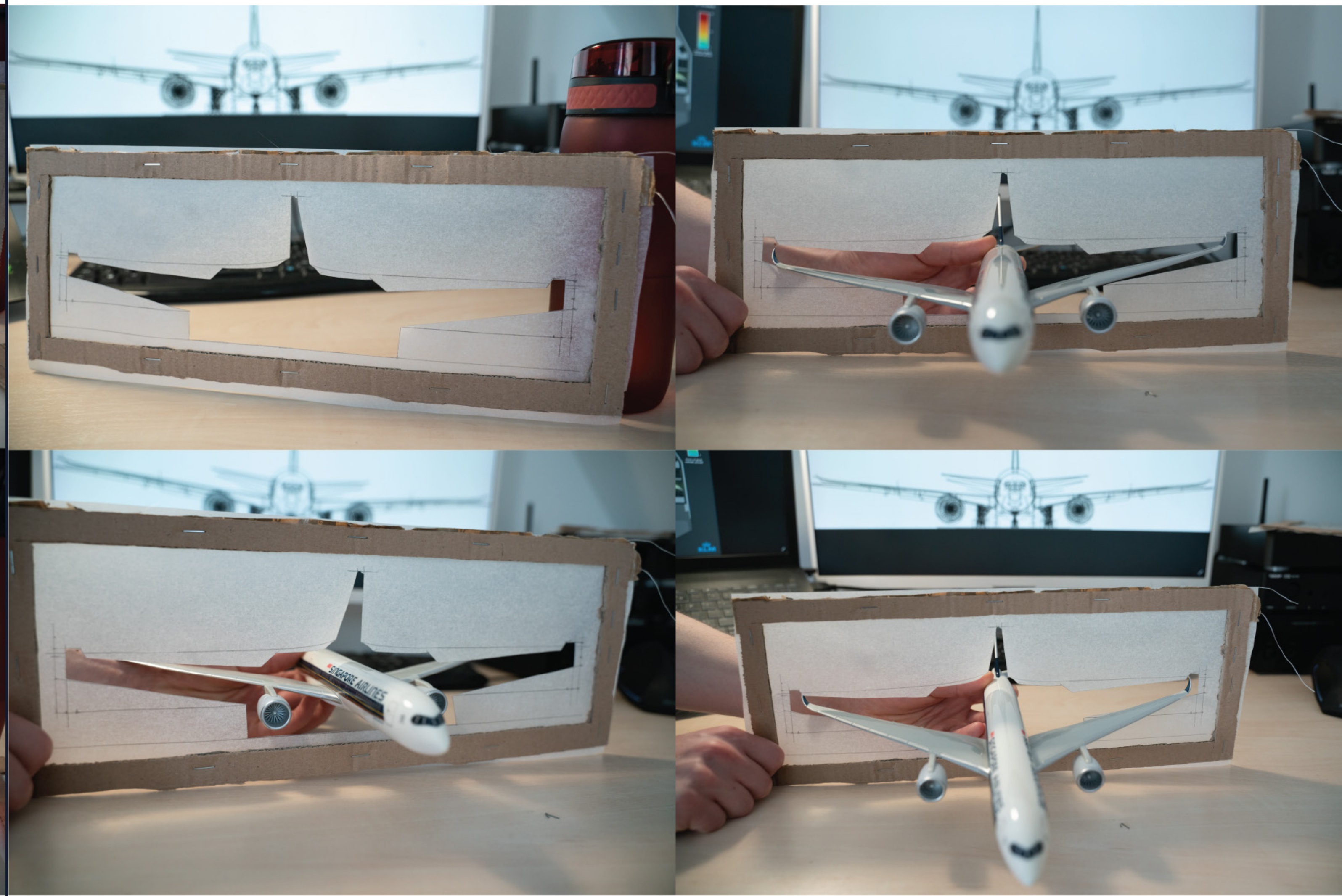


Figure 38: Second more simple "big hole cut-out".

1.4 Idea choice/selection thought process

The process of selecting an idea to continue with is not a straight forward one. Feedback from stakeholders and outcomes of the parallel analysis into hangar heating influenced the list of requirements, which in case influenced the ideas. The idea selection process is a converging process that was influenced by many factors. This chapter aims to summarize this process. The starting point of the idea selection process is the six ideas divided into the two categories *Heat Conservation* and *Local Heating*.

1. Heat Conservation
1.1. Aircraft Tent
1.2. Aircraft Curtain

2. Local Heating
2.1. IR Heating Panels
2.2. Local Floor Heating
2.3. Active Body Heating
2.4. Heat Funnel

The first round of elimination
In the category of Heat Conservation, The Aircraft tent (1.1) can be eliminated on the basis of severe concerns such as an expected additional time consumption of at least 2 hours per A-check and reduced manoeuvrability around the aircraft, thus, the idea does not meet all requirements. Furthermore, the idea was not well received within KLM (low desirability), and are there fire safety concerns. For those reasons, the idea of the aircraft tent is discarded.

Looking at the local heating options, ideas 2.1, 2.2, and 2.3 transfer heat through radiation, whereas 2.4 makes use of convection. Convection can be a logical way of heating (for example a room) in a more general situation but is illogical for local and directed heating. Apart from that, airflows are generally not considered to be good for comfort and are suggested to be kept below 0,2m/s for comfort at a stationary workplace (Griefahn et al. (2001)). The Heat Funnel (2.4) would need to be positioned very close to the subject to be heated for this reason. The heat will dissipate quickly in the large hangar space. Furthermore, the distance that the funnel would need to overcome is at least 8 meters (see Appendix 3 idea 2.4 for full explanation), which would make it quite an obtrusive structure to only potentially heat one small workspace. For those reasons, 2.4 Heat Funnel is eliminated.

1. Heat Conservation
~~1.1. Aircraft Tent~~
1.2. Aircraft Curtain

2. Local Heating
2.1. IR Heating Panels
2.2. Local Floor Heating
2.3. Active Body Heating
~~2.4. Heat Funnel~~

The second round of elimination
The IR Heating Panels (2.1) and Local Floor Heating (2.2) both focus on the local heating of stationary workspaces and can therefore be compared. Local Floor Heating was only deemed a valid option below the engines because only at the engines stationary work of significant duration is done consistently every A-check. Calculations reveal that using IR Panels for heating that space instead, would be approximately 22% more efficient (19,2 GWh per year instead of 23,4 GWh per year) (see Table 11 and Appendix 3 2.1. and 2.2.). Apart from that, IR panels have a wider range of employability and better movability. For example, IR panels used at the engines in the first shift could also be used elsewhere in the second shift. To install local floor heating for just one area or task of the A-check is not a feasible solution. For those reasons, idea 2.2 Local Floor Heating is eliminated.

Product name	Power consumption per year (kWh)	Costs of product	Costs of power (yearly)
2.1 IR Heating Panels	19.200	€7.600,-	€2.688,-
2.2 Local Floor Heating	23.400	€26.371,-	€3.276,-
2.3 Active Body Heating	768	€3.200,-	€108,-

Table 11 – Comparison 2.1, 2.2 and 2.3 for use only at the engine

1. Heat Conservation
~~1.1. Aircraft Tent~~
1.2. Aircraft Curtain

2. Local Heating
2.1. IR Heating Panels
~~2.2. Local Floor Heating~~
2.3. Active Body Heating
~~2.4. Heat Funnel~~

The third round of elimination
Active Body Heating (2.3) and IR Heating Panels (2.1) were initially compared for the heating of people. In that comparison, Active Body Heating has the advantage because it is more effective and efficient (heating closest to the subject as well as always heating the subject no matter their location)(see table 11 and Appendix 3 2.1 and 2.3). lower in costs (both initial costs and yearly costs, see table 11), slightly better received within KLM (desirability) and it leaves each individual the freedom to choose whether they want to be heated or not.

The heating of the aircraft is a different issue, however. Actively heating the aircraft is relevant in the processes of curing sealants and paints. Currently, the aircraft are not actively heated which means the duration of tasks that include a curing process of sorts are variable and dependent on the ambient air temperature in the hangar (see Chapter 2.4 – Heat necessity for maintenance). I recommend a new way of heating the hangar which includes a lower base temperature in the hangar and for that reason, the curing times will already be longer from the outset. Therefore, an additional heating solution for those tasks should be implemented. IR Heating Panels (2.1) are a solid option for that application. They use long waves that can travel through the air with minimal heat losses, only heating when they reach a surface. This means there is flexibility in the placement of the panels as long as they are directed to the surface that needs to be heated, and there is nothing blocking their path.

Both Active Body Heating (2.3) and IR Heating Panels (2.1) remain valid ideas for different purposes and are therefore not eliminated.

The idea that still remains to be validated is the Aircraft Curtain (1.2). The premise of the curtain is to conserve part of the heat that is in the hangar when the doors are opened, thereby minimizing the effect that opening the hangar doors have with regards to heat loss. However, the question that remains is how effective the curtain would be.

In recent observations, the hangar doors were opened 27 minutes before the aircraft was moved into the hangar. To move the aircraft into the hangar position, decouple the tug and drive the tug outside only took 5 minutes. The process of closing the doors started when the tug had left the hangar and the closing of the doors took 6 minutes (see Appendix 8.2).

Opening the hangar doors with a lot of time to spare, or closing the hangar doors late, is common practice. When the hangar doors are opened for such long periods of time, a lot of heat will be lost, even with the Aircraft Curtain in place and the wind has a large influence on this. The initial investment for the Aircraft Curtain is expected to be high, due to its large size (width of 100+ meters) and development costs. The Aircraft Curtain would be a large investment and would be trying to solve a problem that would better be solved by improving on the timing of opening and closing of the hangar doors. Lastly, when local heating becomes the norm, there is not a lot of (general) heat in the hangar to be preserved (temperature of 10°C) and the Aircraft Curtain becomes obsolete in that sense too. For those reasons, it is not deemed wise to continue with the Aircraft Curtain, and therefore it is eliminated.

~~**1. Heat Conservation**~~
~~1.1. Aircraft Tent~~
~~1.2. Aircraft Curtain~~

2. Local Heating
2.1. IR Heating Panels
~~2.2. Local Floor Heating~~
2.3. Active Body Heating
~~2.4. Heat Funnel~~

Idea Choice & Recommendation
I recommend that both Active Body Heating (for heating the mechanics) and IR Heating Panels (for heating parts of the aircraft will be implemented. According to Jo van Engelen, *Technically speaking, controlling heat flow (like with the Aircraft Curtain (1.2)) cannot be made sufficiently efficient while heat radiation (IR Heating Panels (2.1)) and conduction (with clothes (2.3)) can.* I will continue with both IR Heating Panels (2.1) and Active Body Heating (2.3).

I recommend reconsidering the procedure of opening the hangar doors. Currently, the procedure is not polished enough which leads to the doors being open for long periods unnecessarily. Procedural and process-related optimization in relation to the tug drivers and opening of the doors could significantly reduce costs and energy consumption.

In practice, there is oftentimes only one tug driver available. When there are a lot of aircraft movements this means that the wait for their availability can be lengthy. Furthermore, communication is not optimal which can lead to mechanics opening the door for a plane to be moved in or out but the tug driver being on a break or moving another aircraft first. Better communication with and availability of the tug driver by procedure, and providing the mechanics in the hangar with a more precise estimation of the availability of the tug, would enable the mechanics to open the doors with improved timing. This could save, energy, time and money.

Appendix 2 – CONCEPTUALIZATION & PROTOTYPING

2.1 IR Panels - Local heating of the aircraft

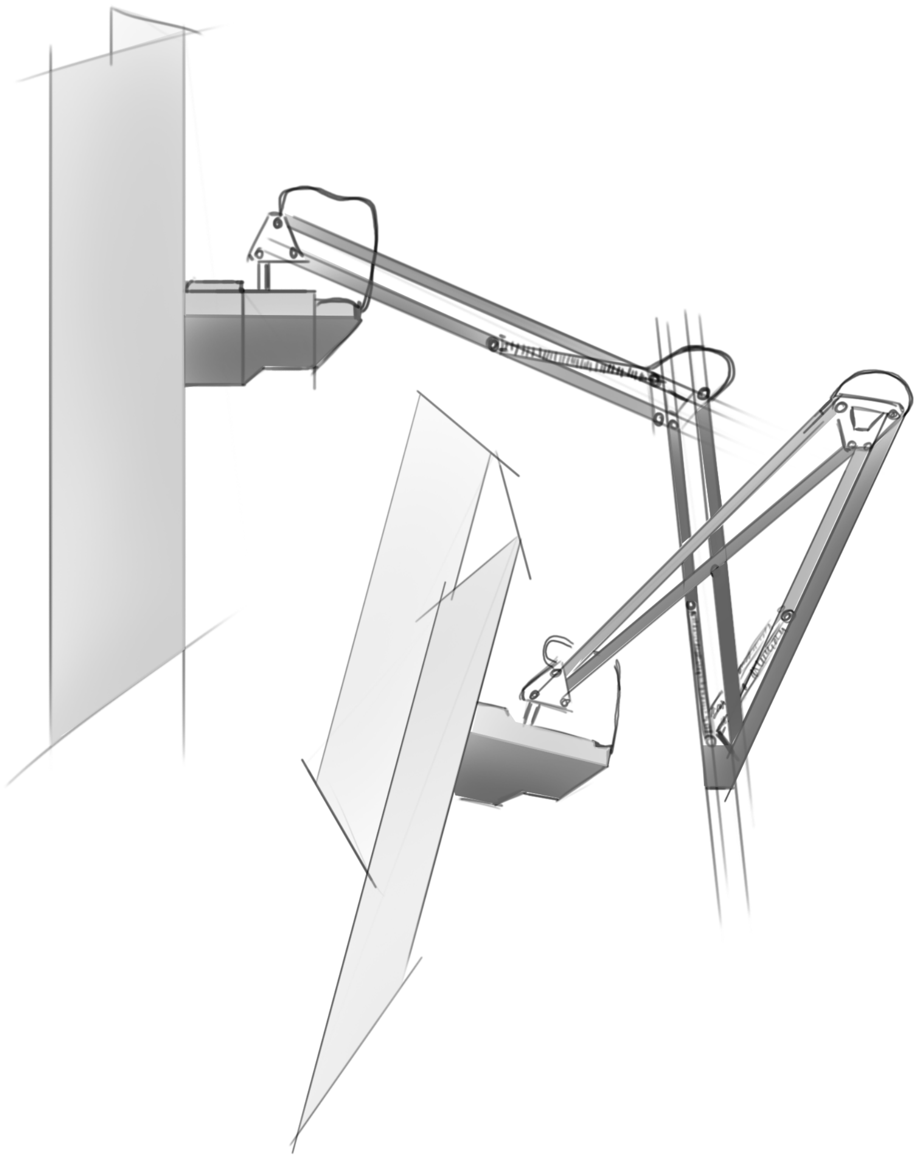


Figure 39: Prototype with cardboard as IR Panels

2.1.1 Lo-Fi prototype - IR panels for repairs with curing processes

Repairs with curing processes can occur on multiple places around the aircraft. Examples are replacing of cockpit windows, sealing of pitot tubes (on the bottom and side of the fuselage) but also some panels on the top of the fuselage might need to be replaced. For that reason a heating solution needs to be flexibly employable. In other words, the proposed infrared heating panels will need to be adjustable to be able to reach different places and orientations around the aircraft.

Therefore a first prototype was made to show what sort of adjustable arm could be an option for an infrared panel.

Top: Figure 40: Prototype of IR panel structure displaying 360° rotation capabilities.
Bottom: Figure 41: Prototype of IR panel structure facing downward

Figure 42: Prototype of IR panel structure facing upward

Figure 43: Prototype of IR panel structure facing to the side

Figure 44: Curing process of composite repair with heat cycle regulating blanket

2.1.2 Composite repair on B777 flap – local heating currently at KLM

I was able to observe during a composite repair on a flap of a Boeing 777-200ER. In this case, damage was found during an inspection in the A-check. A composite specialist from Hangar 14 came in a van to carry out the repair. Composite repairs are time consuming and specialist work. In this specific case the material was a glass fibre and the flap is build up out of four layers of glass fibre on the outside, with a honeycomb structure in the middle. In this case the honeycomb was damaged as well and a part had to be replaced. The composite specialist told me that a colleague had carried out most of the repair the previous night, and all that was left to do for him was to cure the pre-impregnated glass fibre and finish the repair.

Curing of a composite repair
The curing of a complex composite repair such this is a complicated process. For each sealant that is used a different curing process is in place. In this case a specific heat cycle was needed and therefore a special "heated blanket" was used (see Figure 44). The blanket was controlled by a large control unit which measured the temperature of the surface and was programmed to do the exact heat cycle that was needed. The highest temperature for this cure was 127°C (with some other sealants/resins/adhesives an even higher temperature in proximity of 180°C is needed).

Figure 45: Final sanding after curing completion and before paint

The control unit did allow for a variation of +- 6°C. When the ambient temperature fluctuates a lot, the temperature of the blanket can be more than 6°C lower than desired, in which case the control unit will give an error and will take longer to cure the repair. When the cure is complete, a tap test is done to check for audible differences. The control unit prints out a receipt of the curing process, showing a curve of the cure and measured temperatures. This receipt is given to quality assurance who will check it over and in some cases when it concerns structurally critical parts, will test the cure with more advanced equipment before the aircraft is released.

Sanding and painting
After the blanket is removed and the cure is tested, the repair position is sanded in preparation for paint (see Figure 45). According to the composite specialist, the paint is mainly for aesthetic purposes and partly to prevent erosion.

Painting is done by a separate person and in the case of this repair was as simple as a quick inspection of the repair and the application of a layer of white paint with a paint roller (see Figure 46). The painting process took less than 5 minutes disregarding the drying time of the paint. No heat source was used to cure the paint quicker.

Figure 46: Painting over the repair

The influence of the ambient temperature - other instances
According to the composite specialist, the desired ambient temperature for most repairs/sealants is room temperature, which in this case is defined as 25°C. In the hangar it is almost never the desired temperature and ambient temperature fluctuates (even in summer time) with the opening of the hangar doors. This affects the curing times.

In some particular cases when a repair is lengthy and a stable temperature is of great importance, a tent can be build around the area of repair. In this tent separate heaters are still used to heat up the repair area. The process of building a tent is time consuming.

With erosion, in some cases a simple "sealant sweep" can be enough to repair it. These sealants cure at room temperature (25°C) and are heated by a directed heat source if needed. Sometimes the area of a sealant sweep can be large and difficult to heat. In these

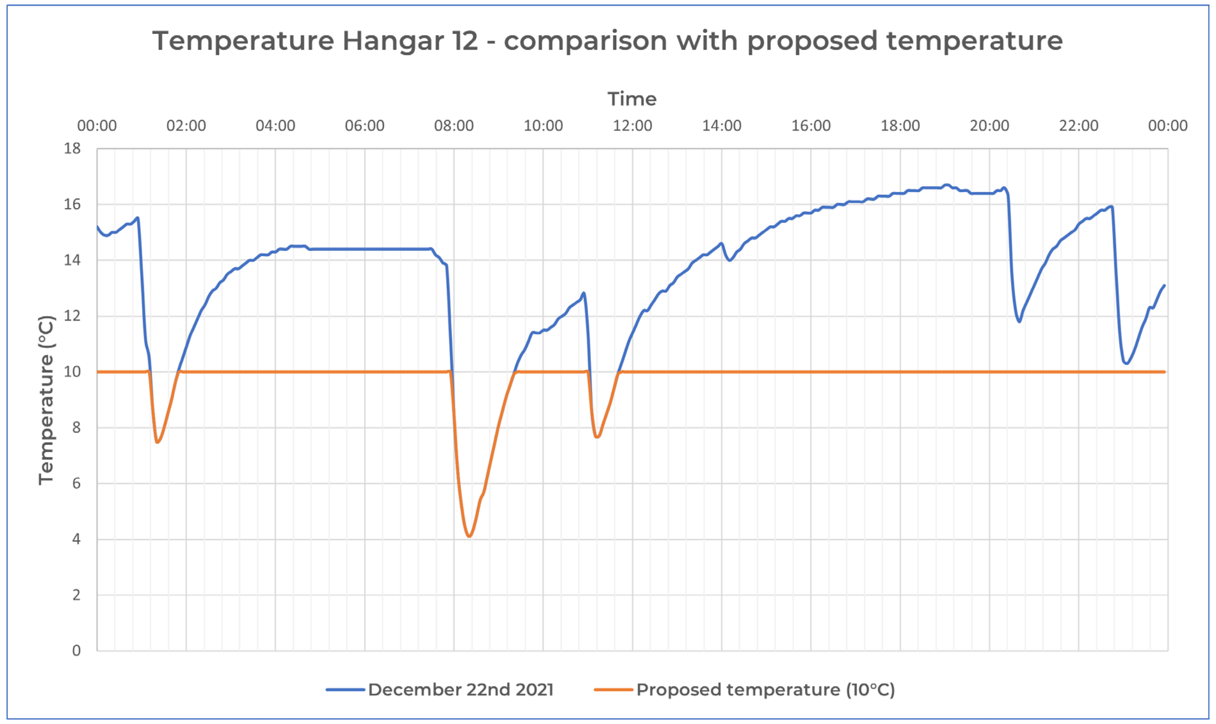
As a general rule, repairs in winter take longer compared to repairs in summer time due to the lower ambient temperature. The lower ambient temperature causes the control unit of heated blankets to have more error codes and therefore the curing to take longer.

Frequency of composite repairs in the hangar
The composite specialists have their own workshop attached to Hangar 14. In their workshop they have full control over the environment and they can carry out complex repairs on parts. In certain instances a repair needs to be carried out in the hangar, for example when it regards a repair on a large surface, such as the fuselage or when the aircraft needs to leave the hangar quickly. These composite repairs in the hangar, do not occur on a weekly basis. The composite specialist was not able to give me an exact number, but he did tell me that just occasionally he had to carry out a repair in the hangar.

Conclusion
Carrying out repairs in the hangar is not ideal in any circumstances since it is not a well controlled environment. Composite specialists would prefer to always have a constant ambient temperature of 25°C, but in the environment of the hangar that is not realistic.

Lowering the temperature in the hangar would not be ideal for a composite repair, since it would mean that heat sources would need to be used more often for sealant sweeps. Having said that, the current situation is already not ideal and given the infrequency of certain repairs that are carried out in the hangar, it is a concern that is of lower priority compared to lowering the energy usage for hangar heating.

Furthermore, lowering the temperature to which the hangar is heated would make the ambient temperature more stable (see Graph 3) which may lead to less error codes for the control unit for heated blankets used for curing composites.



Graph 3: Temperature in Hangar 12 and new proposed temperature

2.1.3 Conclusion and recommendations – Local Heating for curing processes

Composite repairs are done by specialists and require a specific curing process for each repair that is done. Heating is of great importance in these instances and specialist equipment is used, such as a heated blanket as discussed in Appendix 2.1.2. When these repairs have to be done in the hangar, temperature fluctuations in winter time due to the opening of the hangar doors increase curing times, since the control unit is unable to keep the cure in the right temperature window. This is already the case in the current heating situation in the hangar. The control unit would arguably have less trouble to keep the cure in the right temperature window when the temperature in the hangar would be set to 10°C since the difference in temperature would be less.

Easier repairs done by composite specialists include simple sealant sweeps. These sweeps of sealant sometimes are left to cure in the ambient temperature, but are heated locally in winter to accelerate the curing process when it is deemed necessary. In the cases where a large area needs to be sealed, heating locally is not always an option and the ambient temperature in the hangar becomes the leading factor. Lowering the temperature in the hangar would increase the curing times of these specific repairs. Having said that, these types of repairs do not often occur and therefore it is not deemed an important enough issue compared to potential cost and environmental savings of lowering the temperature in the hangar.

In the specific case of a cockpit window replacement there is the option to seal the window, put two layers of special tapes over the seal and let the curing of the sealant commence with the aircraft operational (see Appendix 9.4). Lowering the ambient temperature is therefore not expected to affect this repair significantly.

To sum up, composite repairs require specific heating equipment due to heat cycles that need to be precise. Easier repairs do not always need additional heating, but can be heated locally when the process needs to be accelerated, this is already done. When large areas need to be cured, local heating is not always an option and the ambient temperature becomes the leading factor. All of these repairs do not often occur in the hangar and for the majority of them a local heating solution is already in place. For those reasons, it is not deemed relevant and significant enough to design a specific heating system for local repairs in this study.

It is expected that lowering the base temperature to 10°C will slow down general curing processes and it is therefore recommended to provide heat locally, as is already done when needed, more often. It is also recommended to more often heat locally when it comes to paint repairs.

2.2 Active Body Heating – Heating of the mechanics

2.2.1 Clothing solutions that both heat and cool the body

One of the concerns with heated clothing is the fact that oftentimes with tasks that happen outside of the aircraft, things need to be checked in the cockpit. This means going from a cold (the hangar) to a rather hot environment (the cabin of the plane). In this situation it would be possible to just take off the garment, however, it would be more efficient if the garment could be kept on by its wearer. Clothing that can be used in cold as well as hot conditions would for that reason be ideal. Apart from that, working conditions can be cold in winter, but they can be hot in summer too.

There are multiple technological advancements in this field. State of the art solutions include: temperature regulating fabric (Aouf, 2019), clothes that can change their thermal properties (Hodson, 2016), and a t-shirt that can heat when worn normally and cool when it is worn inside out (Magloff, 2021).

Temperature-regulating fabric has been developed at the University of Maryland and is made of readily available base fibre with a carbon coating (Aouf, 2019). The fabric instantly reacts to changes in body heat. The yarn contracts in hot conditions, creating larger pores in the fabric for heat to escape. In cold conditions the yarn expands, holding the radiation of the human body in the garment.

A system that can be described as a personal mini version of air conditioning has been developed by Cornell University (Hodson, 2016). This “air conditioning” is embedded in an undershirt and sensors measure body temperature and circulate hot or cold air based on the sensor readings.

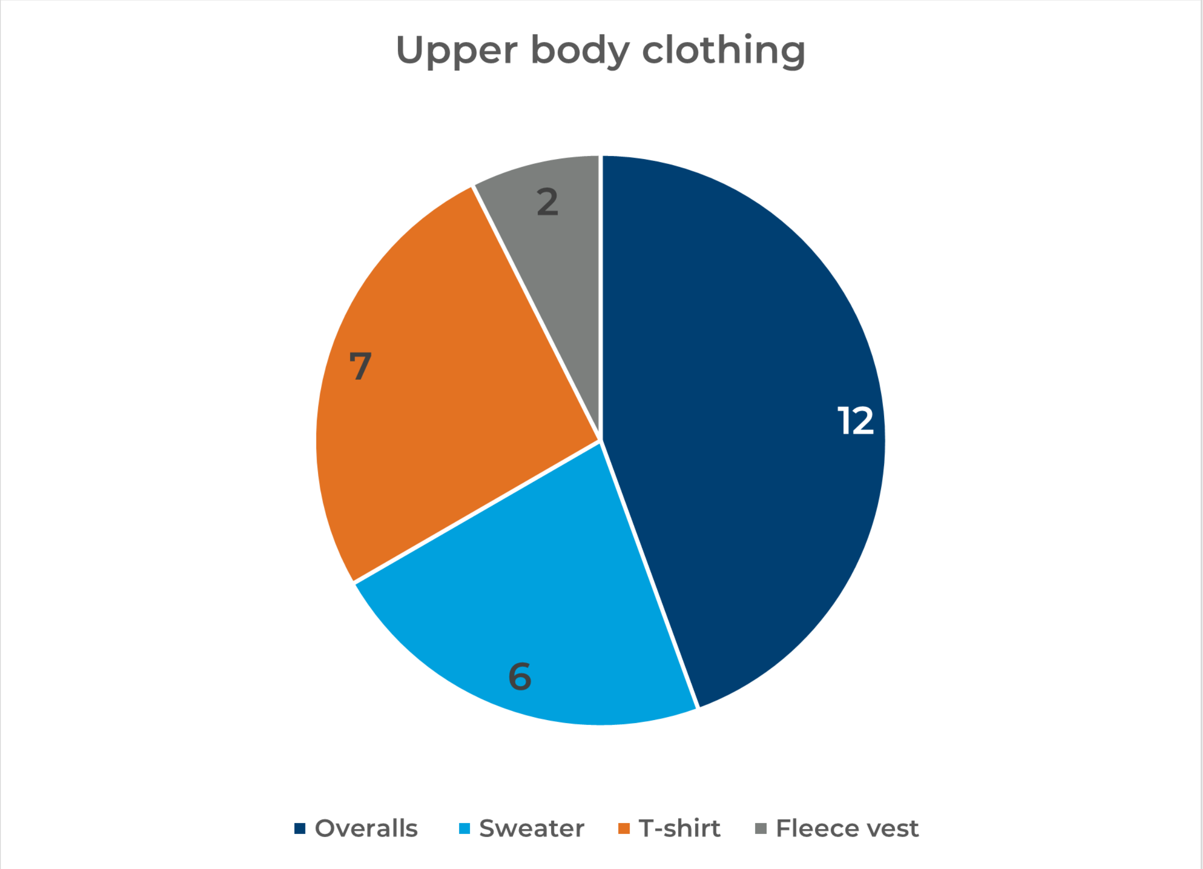
Chinese researchers have developed a fabric that either reflects or absorbs solar energy to heat or cool the wearer (Magloff, 2021). This was achieved by creating to different sides to the fabric. On the one side (warm side), zinc and copper nanoparticles were used to absorb solar energy and heat up the wearer, whereas on the other side (cold side), a very thin layer of aluminium was used to reflect the solar energy (Magloff, 2021). A shirt made out of the fabric can be worn with the warm side facing up to heat up the skin by almost 8°C and by wearing the shirt with the cold side facing up the skin can be cooled down by 6°C (Magloff, 2021).

Conclusion
Whilst developments in the field of clothing that can both heat and cool the human body are promising, none of the aforementioned technologies is currently on the market. The developments may lead to new opportunities for heated and cooled clothing for mechanics in the hangar once they reach the market. The solution in this project needs to be implementable before 2025 and for that reason it is unrealistic to be able to include any of the technologies stated above.

2.2.2 Current clothing for mechanics at KLM

At the moment at KLM, mechanics have to wear clothes that are provided to them through the company and that are part of a clothing package. Mechanics have the choice to either take the full package or to not pick certain items. The clothing package differs slightly per position, but is largely the same. Leads in the hangar for example, have clothes that have the word "LEAD" printed on them. If heated clothing were to be introduced it would need to become part of the clothing package. To introduce a new item of clothes, it needs to be approved by the Safety Compliance Manager. In collaboration with Sodexo (the provider of clothes among other things at KLM), the clothes would then be launched.

Observations done in mid-June showed that on a day with an outside temperature of 19°C the majority of the mechanics in the hangar were wearing long sleeved upper garments (see Graph 4). Pants worn in the hangar are obliged to be long legged. Multiple mechanics I have talked to on other occasions told that they are never cold and therefore always wear short-sleeved upper body clothing despite of the weather. These observations show that on a reasonably warm spring day, 74% of the mechanics working outside of the aircraft were wearing long sleeved upper garments. Even though this is just a singular sighting, it does show that on this occasion the majority of mechanics wore long sleeves. Logically, that would then also be the case on a colder day.



Graph 4: Hangar observations done in H11 and H12 14th of June 2022, mechanics upper body clothing.

2.2.3 Safety concerns - Static charges heated vests

One of the concerns regarding heated vests within KLM has to do with static charges. No specific reasons have been given to me but the following might be the case.

Fire hazard concerns – sparks from static electricity
Safety is of the highest priority in the hangars. For testing purposes, aircraft in the hangar have up to 30 tons of kerosine in their fuel tanks and apart from that there are multiple other flammable chemicals used. Static electricity could ignite a spark which in theory could ignite fuel or fumes.

The battery pack of the heated vest is a voltage source but won't be causing any sparks when it meets safety standards for battery packs.

Static electricity, however, is not something that is solely a concern when using a battery powered heated vest, it might just as well be a concern currently with the mechanics wearing fleece vests and bodywarmers. When for example touching the aircraft this can give a mild shock to the mechanic, but this will happen because of the energy that was produced through friction of the clothes and would therefore not be different very with heated vests, the shock might be .

There is also a voltage on the aircraft because of external power during maintenance. Wearing safety shoes that are well isolated may help to protect the mechanics from getting a shock, but when the mechanic touches two ground lines at the same time (such as the aircraft and a staircase) quite a shock can go through the mechanics. This shock won't be fatal, but it would be highly uncomfortable. Receiving a shock like this can be prevented by wearing safety shoes and wearing the right gloves, or even by weaving a conductive fibre in the cloth of the vests. For avionics engineers there are protocols in place to ground mechanics before and after tasks with for example anti-static bracelets.

Sensitive electronics damage concerns - Leakage current
The different voltage sources mentioned above, can produce leakage current. According to Allinterview (2022), leakage current is: *"...the current that flows through the protective ground conductor to ground. In the absence of a grounding connection, it is the current that could flow from any conductive part or the surface of non-conductive parts to ground if a conductive path was available (such as a human body)."* These are not hazardous for people (the mechanics) directly, but could be harmful to sensitive electronics such as processors. To prevent any damage to sensitive electronics caused by leakage current, the mechanics should wear safety shoes and be grounded during tasks that involve sensitive electronics/computers of the aircraft. As stated before, there are already protocols in place for avionics engineers to make sure that they are grounded during their jobs. These include grounding with anti-static bracelets, but also wearing cotton clothes to minimize their static charge from the outset.

Conclusion
There are risks with implementing battery powered heated vests, although these risks are small and superable by having the right protocols in place. Most of the risks addressed in this chapter are already present with the current clothes and for that reason no insurmountable safety concerns are expected.

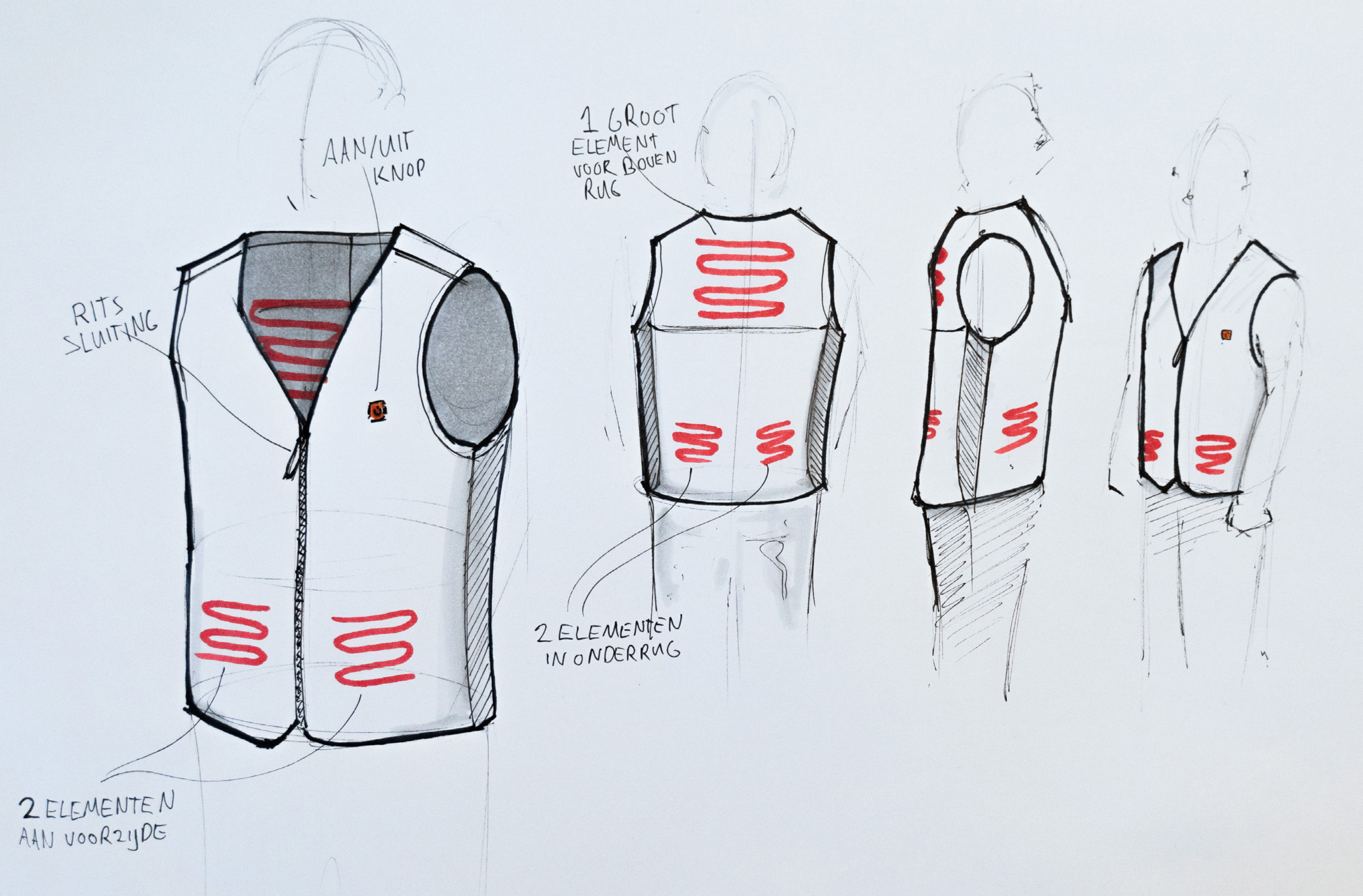


Figure 47: First drawings of a heated vest

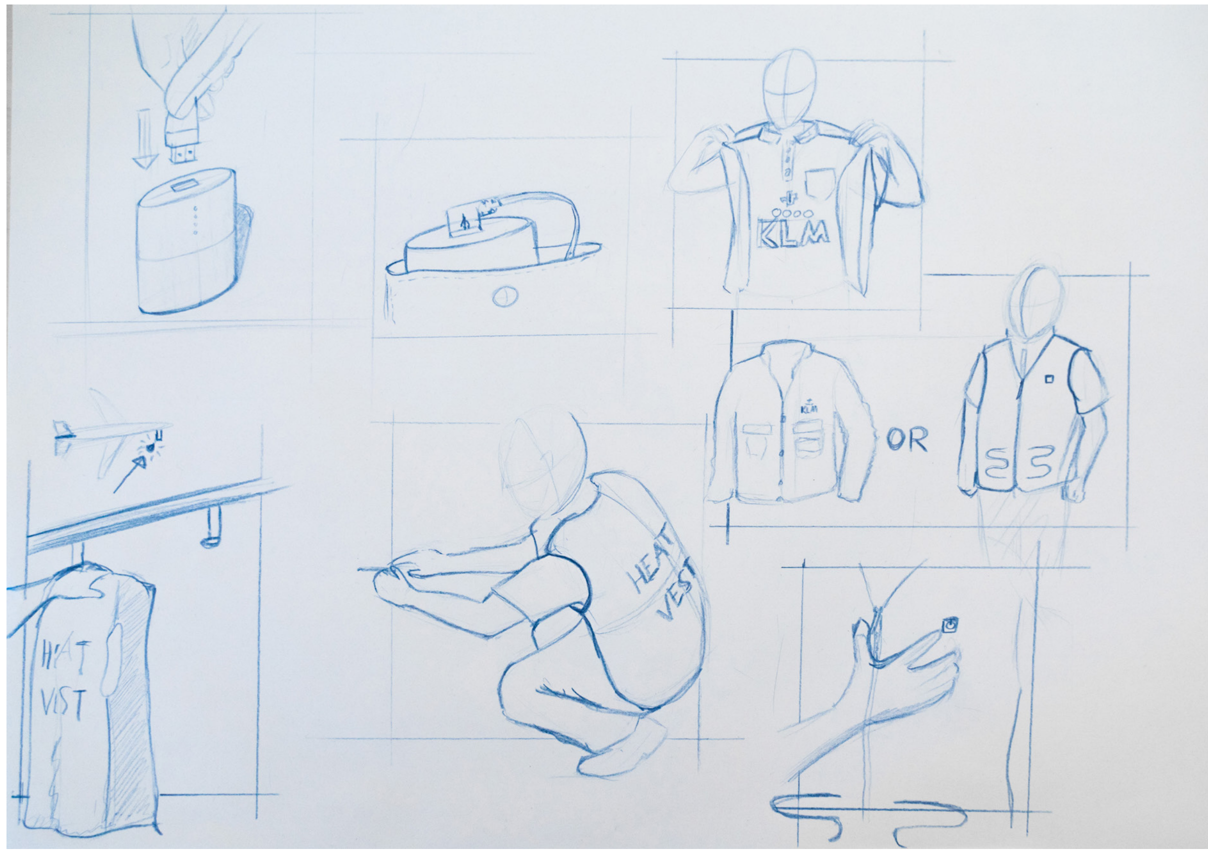


Figure 48: First drawing of a journey map

2.2.4 Heated clothing - First tests

Rrtizan heated vest

Before making a prototype for myself, I decided to buy an existing heated vest to experience it first-hand. The vest in question was bought for 44 euros and is branded Rrtizan. The vest is powered by a powerbank that can be connected via USB and can be placed in the inner pocket located at the front left of the vest (see Figure 50). The vest can be turned on by long pressing the power button. By short pressing the vest toggles between the three power modes: low (blue light), medium (white light) and high (red light) (see Figure 49).

Figure 49: Rrtizan heated vest and button controls

Figure 50: Battery placement in inner front pocket

The vest itself weighs in at 614g and the particular 10.000mAh powerbank that was used for testing weighs in at 236g (see Figure 51). With a combined weight of 850g the vest is relatively heavy for its size, however, once worn the weight did not bother me.

Figure 51: Weight of powerbank and Rrtizan heated vest

Figure 52: Me wearing the Rrtizan heated vest

The fit of the vest is troublesome. The vest was ordered in size XL, but even though I normally fit size M, the vest is a bit short for me. Around the shoulders the vest fits me well, but around the waist it fits too loosely. Flexibility of the vest is good and it feels like a regular bodywarmer. The battery placement is not ideal and the battery can be felt during certain movements.

Effectiveness and conclusion

The most important function of the heated vest is of course to actively heat your body and to keep you warm. The vest on itself is comparable to a bodywarmer and therefore quite warm without the added heating. The Rrtizan heated vest has five heating elements, two of them located in front of the front pockets, two located at the lower back and one located on the upper back. Once turned to the highest setting, I was disappointed to not really feel anything. I had multiple people in my surroundings try the vest and they all had difficulty feeling anything at all. The only situation that the heat could be felt was when sitting down with your back pressed against the back of a seat. The vest would then be fully pressed up against the back and the heat from the three elements at the back of the vest could be felt.

After reviewing the vest, not feeling the heat can in my opinion be related to three factors:

1. The vest does not fit well and the heating elements are therefore too far away from the skin.
2. The heating elements themselves are not getting hot enough to be noticeable.
3. The heated vest is worn over insulated layers and the heat cannot get through them.

The heated vest was bought to experiment with, test with mechanics and get feedback on possible improvements. Due to the odd fit and general ineffectiveness of the vest, the Rrtizan vest was returned and a more expensive vest was purchased for the purpose of testing.

ORORO heated vest

After the Rrtizan vest, a heated vest of the brand ORORO was purchased. This vest was more expensive (€120,-) but is compared with far more expensive heated apparel. The ORORO vest differs from the Rrtizan vest in a few key areas: fit and finish, material, element position and size and battery placement (see Figure 53).

<u>Fit and finish</u>

The ORORO heated vest has a normal fit and sizing that is accurate compared to European sizes (e.g. size L is a EU size L). The Rrtizan vest was short compared to its width, but the ORORO vest is longer and has a normal length to width ratio. The product is packaged nicely and comes with its own battery pack, charger and carrying case. The product feels like a quality product which is important for both the mechanics and myself to have trust in the product.

<u>Material</u>

The Rrtizan heated vest could be described as a bodywarmer with heating elements in it. The ORORO heated vest is made of a thinner material, is more flexible and can (regarding material) be compared to a slightly more flexible softshell jacket.

The type of product and the material it is made of are of importance for the way the vest is worn. A bodywarmer is most likely worn as a toplayer, whereas a vest that's more like a sweater could be worn below a jacket.

<u>Element position and size</u>

The Rrtizan vest had 5 heating elements compared to 3 elements in the ORORO vest (see Figure 53). The elements in the ORORO vest are noticeably larger in surface area and also the heat is more noticeable. The positioning of the elements seems to be more effective in the ORORO heated vest. The elements on the chest area as well as the large element on the upper back area are noticeable.

<u>Battery placement</u>

In both vests the battery is placed on the left side of the vest in an inner pocket. In the Rrtizan vest the battery is directly behind the front left pocket, where also a heating element is placed. In the ORORO vest the battery is moved further to the side (see Figure 53). The battery positioning further to the side makes the battery less noticeable.

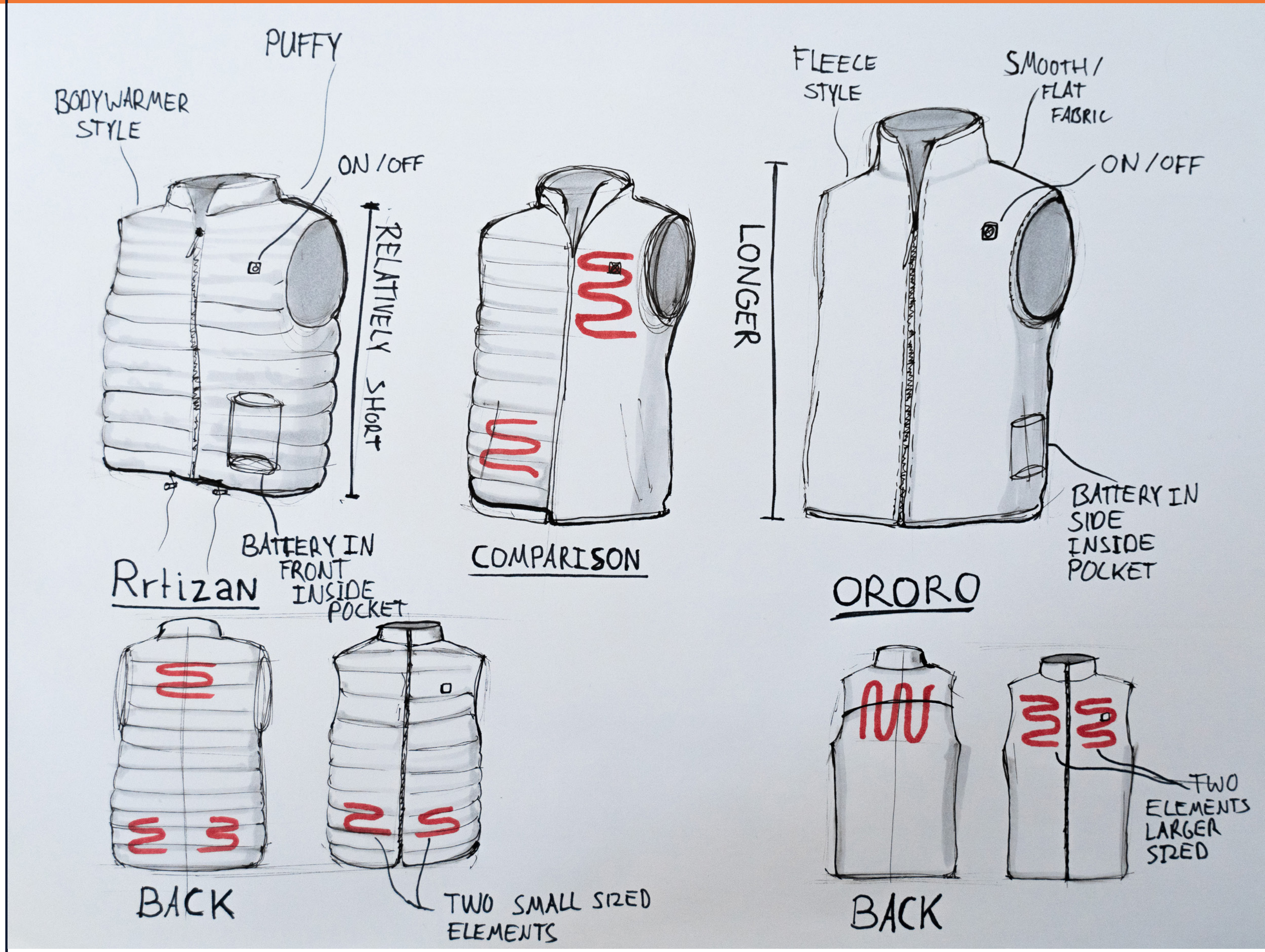


Figure 53: Comparison between Rrtizan and ORORO heated vests

Figure 54: Battery placement test positions

2.2.5 Battery pack placement test - ORORO Heated Vest

As one of the tests, I wanted to try out different battery pack positions to find out where the battery was least noticeable. For this the battery was not plugged in, but solely placed in different positions and held there using duct tape. For this test I asked my roommate for his help and opinions, so the findings would not solely be my own.

Process of deciding different positions
In order to find possible battery positions, the vest was put on whilst the other would move the battery over the vest and press down in different positioned. It was decided to try three new battery positions and compare them with the current battery position (position 3 normal, see Figure 54).

Findings per position

Position 1 – upper back
This position seemed promising, but the overall opinion after trying the vest on with the battery taped in place was: terrible. It instantly felt weird to have a hard piece pressing against your spine/neck. The weird sensation could still be felt a few minutes after taking off the heated vest. The high positioning of the battery meant that the weight of the battery pack was very noticeable when bending over (see Figure 55). Because of the high positioning, sitting with the vest on was fine on most seats, since the backrest most often does not extend that high.

Figure 55: Battery placement position 1 upper back

Position 2 – lower back
For both my roommate as myself this positioning meant that the battery pack was positioned on the beltline. Once wearing the vest standing up, with the battery in this positioning it is quite comfortable. The weight of the battery in this position pushes the vest down over the shoulders, which makes it fit tighter and presses the heatelements to the body a bit more. All opinions changed once sitting down with the vest on with the battery in this position. When a seat has any backrest at all, sitting down with the battery in this position is highly uncomfortable as this hard brick presses into your lower spine. For the sitting position it the battery position could not be a lot worse.

Position 3 – normal
The standard position for the battery in the ORORO heated vest is on the side of your body (see Figure 54). Slight discomfort can be noticed if the heated vest is a little bit to large for the wearer with the battery pack bouncing against the hip with certain motions. As a wearer you are unable to hit the batterypack with your elbow and whilst sitting the batterypack is hardly noticeable. Overall it seems ORORO has done their research as there is not much to complain about this battery positioning.

Position 4 – upper side
Due to the positive reception of the normal battery position, the battery was placed slightly higher, but on the same side. In this case the battery cannot bounce against the hip anymore, however, the wearer can bump against the pack with their arm/elbow. Even with the arms in a normal down resting position, they still touch the battery pack. Whilst sitting down, the battery position is not annoying, but more noticeable compared to the normal position. Overall, this placement is not bad, but position 3 is better in almost all instances.

Conclusion
After trying different battery positions, the normal battery position (position 3) was considered the best battery position overall. Position 1 was considered terrible and does not outperform position 3 in any instance. Position 2 was considered comfortable, but once sitting down highly uncomfortable. Position 3 was considered to be comfortable in most instances, with only slight discomfort with the battery pack bouncing against the hip if the vest does not fit the wearer quite right. Position 4 was considered alright, but worse compared to position 3 in almost all instances.

Figure 56: Me wearing the Heat Experience heated sweater

2.2.6 Heat Experience heated sweater

To try a different type of heated apparel, a heated sweater of the brand Heat Experience was purchased. The heated sweater is made to fit really snugly and although it is not cheap (€190,-) it feels very well made. The heated sweater is meant to be able to be worn comfortably as a normal sweater too, when you do not want to use the heating feature. The sweater is full of nice details and seems to be thought through.

Heat Experience is a Norwegian brand that only make heated clothing. Their assortment of heated clothes ranges from various heated vests and sweaters, to heated hunting gloves and heated insoles.

"Our ambition is to be the expert on heated clothing, we don't do anything else. This allows us to experiment with the width of the product span (product line)" – Rasmus Fannemel, Product Designer at Heat Experience (see Appendix 9.5).

Since the assortment had a large variety and the products are of quality the product designer (and co-founder) of the brand was contacted for an interview.

Interview Rasmus Fannemel

At the beginning of the interview a short presentation that served as an introduction into the context of the hangar was given. The specific use case of the hangar differs from primary use cases of Heat Experience's apparel. Heat Experience products are roughly used between -20°C and 10°C and mostly for outdoor activities. Rasmus did know of certain current use cases of their products that slightly relate to the hangar however.

<u>Examples of use cases at 10°C and in fluctuating temperatures</u>
Currently heated sweaters and vests of Heat Experience are used by truck drivers. They go in and out of the trucks all the time and so use them in varying temperatures. The most comparable use scenario is the scenario of the warehouse workers at Heat Experience. In the winter the warehouse can be 10°C and the break room is normal room temperature. The warehouse employees usually keep wearing the heated apparel but turn it off when entering the break room. Both sweaters and vests (bodywarmers) are used, this is purely based on personal preference (see Figure 57). The vests (bodywarmers) are more prone to be taken off. Both the temperatures and work intensity are comparable to the conditions in the hangar and the insights can therefore be used in the design of heated apparel for use in the hangar.


Figure 57: Heat Experience Sweater (left) and Vest (right)

<u>Different use (layering) of vest (bodywarmer) versus sweater</u>
As stated, Heat Experience provide both heated vests as well as sweaters. The different types are available partly because different people prefer different products, but more importantly they serve different uses.

Simply put, the heated sweaters can be worn like you would normally wear a sweater. It could be the top layer of your clothes, but normally it would be a mid-layer and can be worn over a t-shirt or for maximum effectiveness a windbreaker can be worn on top of it.

The sweaters are made of a thin fabric and do not have a lot of insulated layers. These types need to fit snugly in order to feel the heat of the heating elements.

The heated vests are like bodywarmers. The vests are insulated on the outside of the heating elements and can do with a looser fit to still be effective. The vest can be worn over a normal sweater, like you would wear a bodywarmer and would most likely be worn as a top layer in conditions no colder than 0°C.

Heating element positioning
The heated element positioning is the same on most vests and sweaters of Heat Experience. Two heated elements are positioned on the chest and one element is positioned on the lower back. On the chest you get very good skin contact and a good transmission of the heat. Belly fat means the belly does not really need to be heated. Customer questionnaires and trials showed that the lower back position for the back element was preferred, lab testing verified this. Furthermore, the lower back is prone to get a cold sensation easily. Inner organs are exposed there and it makes a lot of sense to warm up the kidney and lumbar area.

Heat Experience is quite happy with the current positioning of the heating elements. They get close to the body and do not obstruct movement. The positioning also minimizes the amount of cables and cable lengths.

Battery and positioning
Heat Experience use thin and relatively small battery packs with high maximum power outputs. This means that at the highest setting, the battery will drain in approximately two hours, however, the elements get seriously hot. Maximum power can be used as a boost and the other modes for longevity.

The battery positioning differs per product. In the heated vest, the battery is placed behind the left front pocket. People often have something in their front pockets and therefore are used to the feeling. The weight of the battery pack can be balanced out by for example putting your phone in the other pocket.

On the sweater it was decided to put the battery more towards the side. Because of the tighter fit, it feels like it is dragging you down when placed in the front pocket. This positioning is comparable to the battery position of the ORORO heated vest (see Figure 54 - normal).

New product with app control
Heat Experience will launch a heated vest with app control in September of 2022, according to designer Rasmus Fannemel. This vest uses an NTC thermistor to measure differences in temperature close to the heating elements. A desired temperature for the elements can be set in the app. The power is constantly changed according to the measured (ambient) temperature.

Appendix 3 – IDEA CHOICE & VALIDATION CRITERIA

Introduction
To make a fair comparison, all ideas will focus on implementation in Hangar 12. This does not mean that ideas cannot be implemented in Hangar 11 or elsewhere.

There are ideas in two categories: *Heat Conservation* and *Local Heating*. The desired solution might be a combination of multiple ideas. In this chapter, ideas of both categories will be further explored and scored in order to choose one or several ideas in each category. After this, one or multiple idea(s) will be chosen to develop further and to write a recommendation.

The ideas considered in this chapter are:

1. Heat Conservation
1.1. Aircraft Tent
1.2. Aircraft Curtain

2. Local Heating
2.1. IR Heating Panels
2.2. Local Floor Heating
2.3. Active Body Heating
2.4. Heat Funnel

1. Heat Conservation

1.1.Aircraft tent

Concerns:
- Logistical challenges
- Moving aircraft in and out of the hangar, sometimes other aircraft need to move out first
- Manoeuvring around the plane with drones, scissor lifts and other equipment
- Time consumption of putting up and removing the tent
- Fire Safety
- Hindering work tasks
- Sceptical reception within KLM

Conclusion
The aircraft tent has not got many positives going for it and has severe concerns such as an expected additional time consumption of at least 2 hours per A-check and reduced manoeuvrability around the aircraft. Next to that, the idea does not meet all requirements, was not well received within KLM and there are safety concerns. For those reasons, the idea of the aircraft tent is discarded.

1.2. Aircraft curtain

Concerns:
- Costs involved
- Is it possible to integrate this without infrastructural changes to the hangar?
- Weight of the curtain, is the current beam structure of the hangar capable of carrying this curtain?
- Wind resistance
- Effectiveness

Wind resistance
Currently, the hangar doors may not be opened at windspeeds above 9 Bft (approximately 88km/h). The limiting factor are not necessarily the doors themselves, but rather the roof of the hangar. The effect of this restriction on the aircraft curtain, could be interpreted in two ways, namely:
1. The aircraft curtain has to withstand windspeeds up to 9 Bft.
2. If the aircraft curtain is able to block wind flows that lead to the roof of the hangar and the aircraft curtain is able to withstand windspeeds of over 9 Bft, the doors could be opened at higher windspeeds, increasing maintenance capacity/usability.

Effectiveness
The aircraft curtain will save energy no matter how the hangar is heated, by preserving heat instead of adding heat. However, hangar observations reveal that the hangar doors are oftentimes opened for more than 30 minutes. In this period of time the air in the hangar is not completely stationary because of wind. In this case, the loss of heat far outweighs the conservation of heat achieved by the Aircraft Curtain (Estimation by Jo). *"Technically speaking, controlling heat flow (like with the Aircraft Curtain (1.2)) cannot be made sufficiently efficient..."* (Prof. J.M.L. van Engelen (translated from Dutch)).

Furthermore, when local heating becomes the norm, there is not a lot of (general) heat in the hangar to be preserved and the Aircraft Curtain becomes obsolete for that reason.

Conclusion
The Aircraft Curtain seemed an attractive proposition, but after a deeper analysis it is clear that in the proposed situation (where local heating becomes the norm), the Aircraft Curtain would not be effective enough to spend money and time on the development and production of this product.

2. Local Heating

2.1 Infrared heating panels

Concerns:
- Power consumption
- Effectiveness in hangar environment and whilst not working stationary
- Power connection possibilities (amount of power plugs needed or size of batteries)
- Hindering work tasks for example when mounted to scissor lift

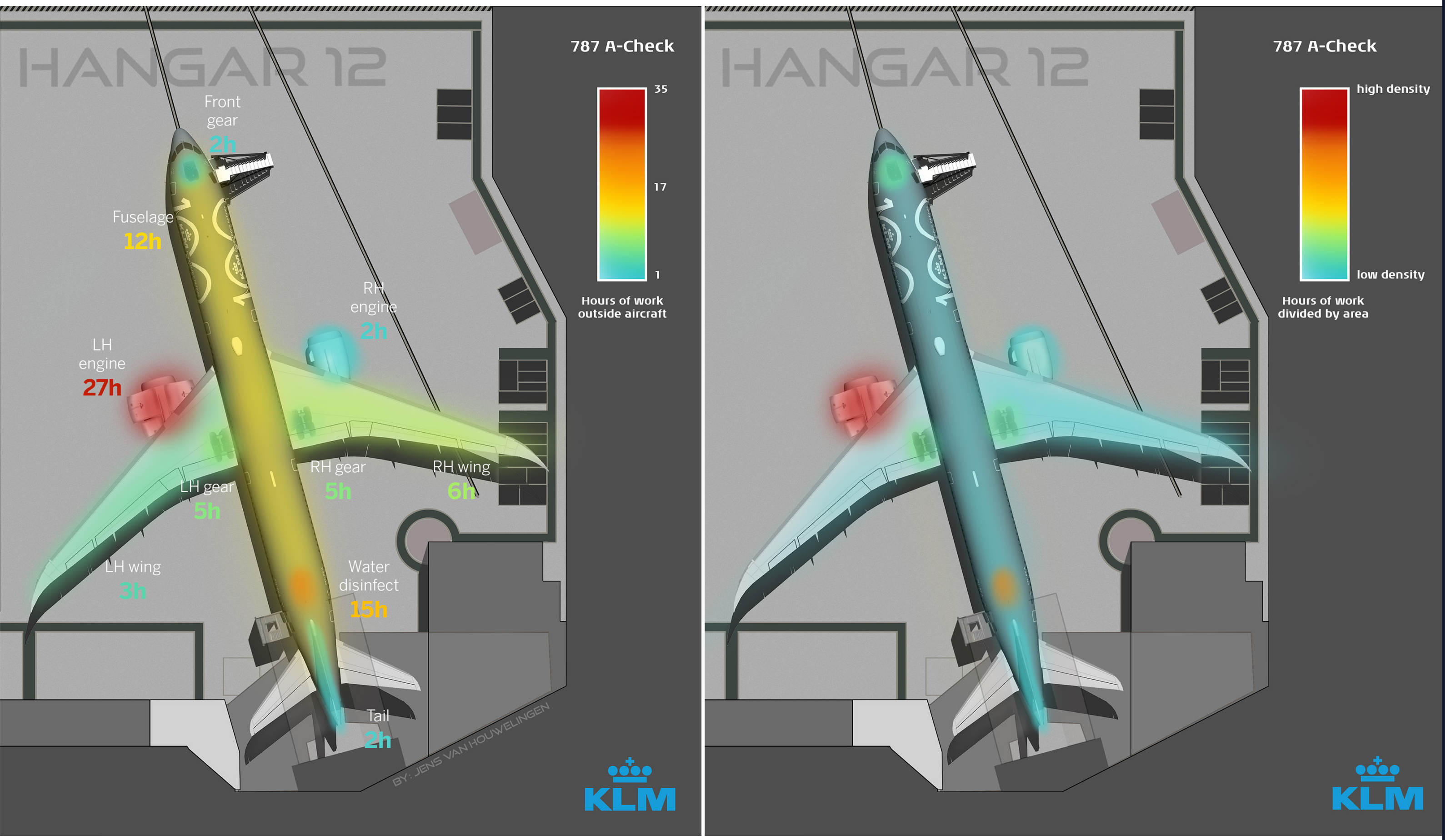


Figure 58: Heatmaps as can be found in Chapter 2.6

Number of panels needed according to heatmap
Infrared heating panels would make sense at stationary workstations. Looking at the heatmap, this would be at one of the engines and at the rear of the fuselage for the disinfecting of the water system. Also work on the landing gears takes some time in a relatively small area. That would suggest that infrared heating panels should be placed at all of these locations. However, on closer inspection, it is not that straight forward. Work done on the engines is relatively stationary, but involves work done beneath the engine and work done on stairs next to the engine. Work done on the rear landing gears involves inspections on the ground, such as wheels, tires and brakes, but more so lubrication and inspection of the gears which is done in a scissor lift. The disinfecting of the water system takes up a lot of time, but involves only one person standing there for supervision, in practice not completely stationary, so personal heating would make more sense.

For the purpose of this estimation, let's assume that every scissor lift would have an infrared panel attached to it. Let's further assume that a scissor lift is used for the tail inspection, one for each wing, one for each rear landing gear and one for the fuselage, which would make a total of 6 scissor lifts per widebody aircraft. Two widebody aircraft can be in maintenance at the same time in Hangar 12 so that would double the number of lifts to 12.
For work on the engines to have some effect there would need to be infrared panels both on the ground for work below the engine and on the staircases. Two staircases per engine are used. Let's estimate one infrared panel per staircase and two on the ground. Two widebody aircraft will make that 8 panels.

Power consumption calculation
For stationary workplaces in Hangar 10, infrared panels are already used. At these workplaces logistical work is done that is not physically intensive. The panels are mounted above workstation at a height of approximately 2,5 meters. The panels used have a power of 2000W. Let's assume the same power for the infrared panels in Hangar 12 for work on the engines. The work done on aircraft in Hangar 12 can be more physically demanding compared to the logistical work in Hangar 10, but wind is a larger factor in Hangar 12.

<u>Infrared panels at the engines (comparison with 2.2 and 2.3)</u>
Work on the engine is mostly done in the first 8 hour shift. Some work is done in the later shifts so let's assume approximately 10 hours.

$$2000W * 8\ panels * 10\ hours = 160.000Wh = 160\ kWh\ per\ day.$$
$$160\ kWh * 30\ days = 4.800kWh\ per\ month$$

With 4 months of use:

$$4.800kWh * 4 = 19.200kWh\ per\ year.$$

<u>Infrared panels on scissor lifts</u>
On the scissor lifts I will assume infrared panels of 1000W for them to be less voluminous and obstructing. Looking at the heatmap work at the tail takes 2 hours, at the landing gears 5 hours, at the wings 3-6 hours and on the fuselage 15 hours of which most on the lower fuselage. On average scissor lifts will be used for approximately 4 hours.

$$1000W * 12\ panels * 4\ hours = 48.000Wh = 48kWh\ per\ day.$$

<u>Total</u>

$$(160kWh + 48kWh) * 30\ days = 6240kWh\ per\ month.$$

Scissor lift battery sizes and feasibility determination
The infrared panels on the scissor lifts would need to be battery powered. KLM uses scissor lifts of Riwal. Their larger model has four batteries of 12V 185Ah and their smaller model has four batteries of 6V 225Ah.

<u>Panel power usage</u>

$$1000W * 4h = 4000Wh$$

<u>Panel on large lift</u>

$$12V * 185Ah * 4 = 8880Wh$$
$$4000Wh / 8880Wh * 100 = 45\%\ of\ battery\ capacity.$$

Panel on small lift

*6V * 225Ah * 4 = 5400Wh*
*4000Wh / 5400Wh * 100 = 74% of battery capacity.*

Cost price estimation + electricity costs per year

*Number of panels * cost per panel + Number of panels * rollable mounting structure + hours of usage * Power consumption * cost price electricity.*

Ecosun 1000W panel = €385,- (sanitairkamer.nl)
Etherma 2000W panel = €670,- (currently used in Hangar 10) (gereedschapscentrum.nl)
Rollable mounting structure = €280,- (rs-online.com)
Mounting bracket for scissor lifts (to be developed) estimated price = €100,-

8 x (2000W panel + Rollable mounting structure) + 12 x (1000W panel + Mounting bracket for scissor lifts) = 8 x (€670,- + €280,-) + 12 x (€385,- + €100,-) = €13.420,-

cost price electricity = €0,14 per kWh (Sodexo data 2022 doorbelasting TOTAAL)
Usage for 120 days a year:

*208kWh * 120 * €0,14 = €3494,-*

Conclusion
Infrared panels could only be a part solution to the heating problem. After calculations it is clear that infrared panels could not comfortably be used on scissor lifts assuming a 1000W panel since they would consume 45-75% of the total battery capacity of the scissor lifts. This would mean that the scissor lifts would need to be charged more than twice as often which would negatively impact the flexibility of scissor lift employability.

Another place where the use of infrared panels would make sense during maintenance (for heating people) is at the engines. Placing infrared panels here would slightly obstruct manoeuvrability around the engine and effectiveness would need to be tested. In comparison to Local Floor Heating (2.2) the IR panels can be placed in more positions and are more easily movable.

A positive of infrared panels is the fact that they have flexible employability. They could not only be used for heating of people, but also for heating of parts of the aircraft that need to be heated. This makes the proposition of purchasing infrared panels interesting for KLM.

2.2 Local floor heating

Concerns:
- Is it possible to integrate this without infrastructural changes to the hangar?
- Power consumption
- Weight resistance of on-floor heating panels, can they support a scissor lift or staircases? (Durability)
- Fluid/chemical resistance of material of these panels.
- Currently not aware of a comparable existing product for this scale of heating.
- Movability of the pads considering different types of aircraft.

Explanation and calculation of area
Looking at the heatmap it would make sense to place local floor heating below the engines, the rear landing gears and at the back at the water disinfect tube. However, upon closer inspection, it is only logical to place local floor heating mats below the engines because the work done at the landing gears is for a large part done in scissor lifts. The work done at the water disinfect only involves one person.

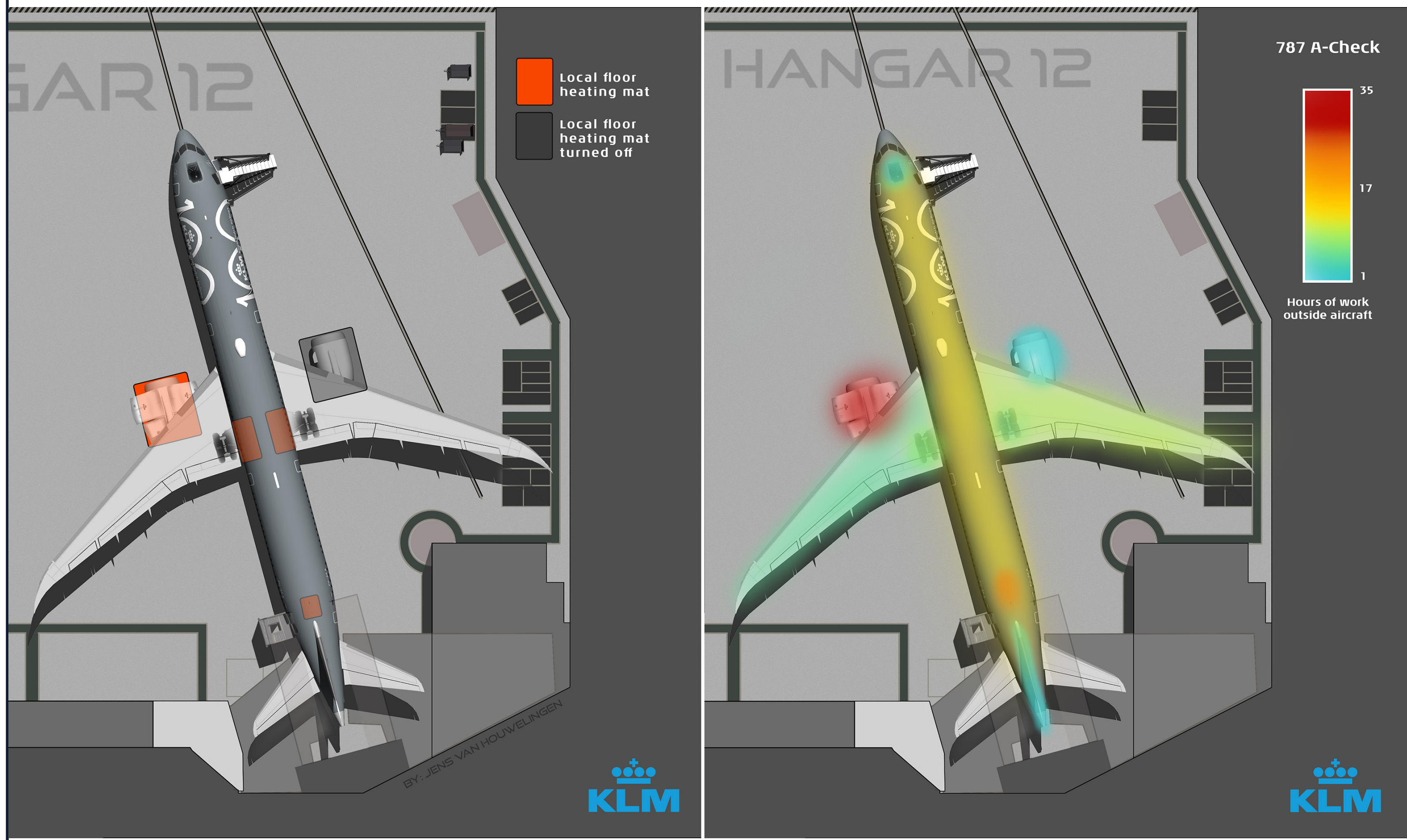


Figure 59: Possible placements for heating mats (left) based on heatmap (right)

Calculation of power usage
A company named Rimatek makes heated footboards for industrial use cases (Rimatek S.r.l, 2019). These boards can be linked together to create a larger surface (see Table 12 and Figure 61).

Model name	Dimensions	Surface Area	Power	Maximum load
Rimatek Pedi.G	95 x 95 x 2,5cm	0,90m²	300W	225kg
Rimatek Pedi.H	195 x 95 x 2,5cm	1,85m²	550W	450kg

Table 12: Rimatek footboard specifications

Figure 60 – Work being done on a B787 engine

At the engine, work is done beneath the engine but also on stairs closer to the engine (see Figure 60). The maximum outer diameter (width) of the engine of a widebody aircraft is approximately 4 meters and its maximum length approximately 7 meters. Whilst working on the engine the engine covers are opened (see Figure 60) and the majority of the work is done on the full width of the engine but less so in the full length. Therefore I would advise the pad size to be approximately 5 meters in width and 7 meters in length. To achieve a pad of the desired dimensions for the engine, it would consist of 15 Pedi.H boards and 5 Pedi.G boards (see Figure 61). According to Rimatek it is possible to put heating pads (footboards) together as proposed in Figure 61.

RIMATEK BOARDS ARRANGEMENT

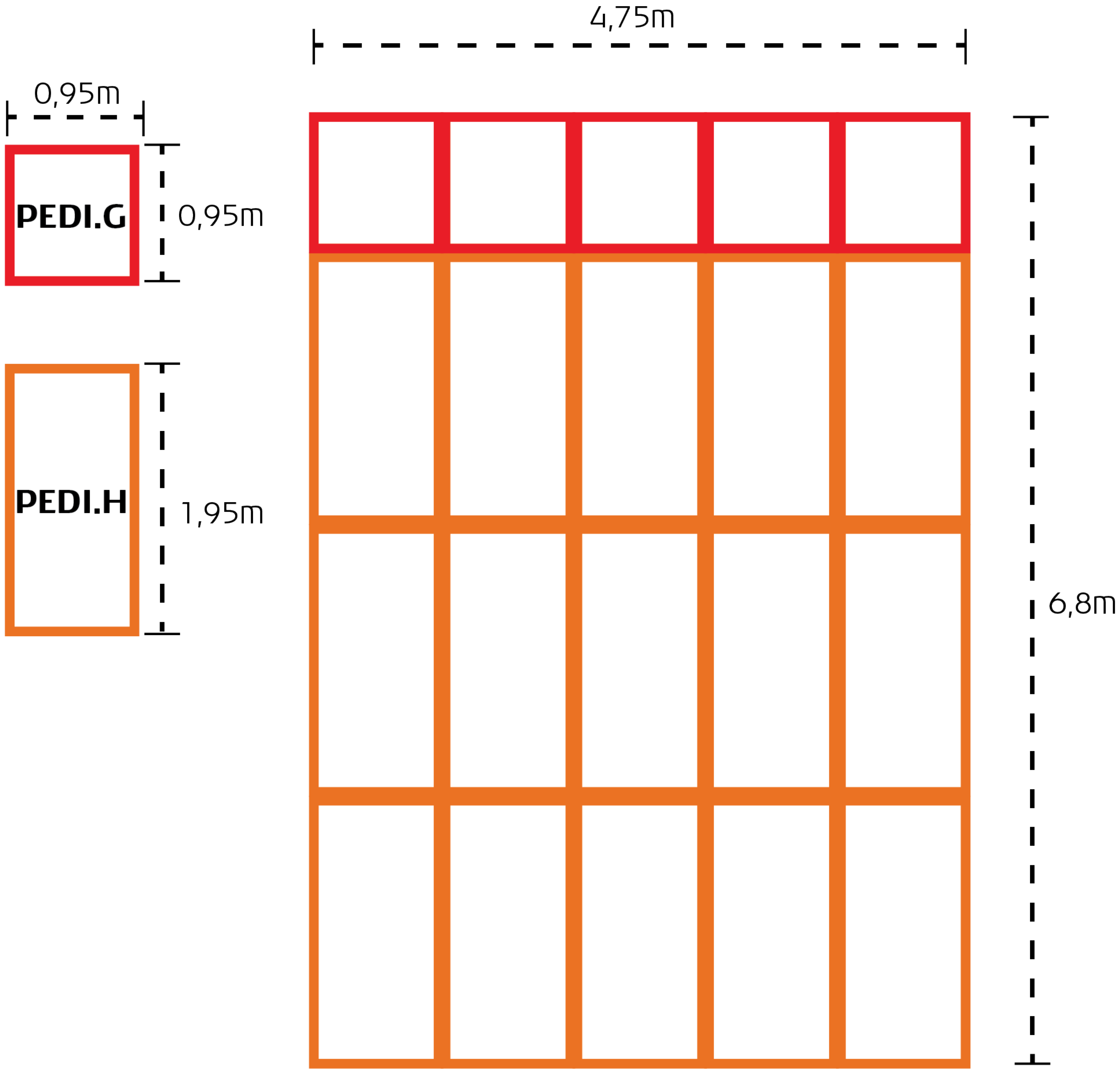


Figure 61 – Rimatek floorboard arrangement to be placed beneath one engine

Let's again assume 10 hours for engine maintenance:

*15 x Pedi.H + 5 x Pedi.G * 10 hours = 15 x 550W + 5 x 300W x 10 hours = 97.500Wh = 97,5kWh*

97,5kWh x 2 widebody aircraft = 195kWh per day
195kWh x 30 days = 5.850kWh per month.

With 4 months of use:
*5.850kWh * 4 = 23.400kWh per year.*

Cost estimation
Rimatek drafted an invoice for the proposed situation and for one engine the combined price of the footboards, platform design and custom electrical wiring would be €10.897,- excluding VAT and transport. Including VAT, that would be €13.185,- for one engine.

There are two positions for widebody aircraft in Hangar 12 (see Figure 28 position 2 and 4). To be able to heat all engines, the local floor heating would need to be installed for both engines, since heavy maintenance is done on one engine each A-check (see heatmap). That means that 4 local floor heating platforms need to be placed. The total costs including energy would then be:

*4 x €13.185,- + 23.400kWh per year * €0,14 = €52.740,- + €3276,- = €56.016,-*

Conclusion
Local Floor Heating was only deemed a valid option below the engines because only at the engines stationary work of significant duration is done consistently every A-check. However, the heat is only needed for the mechanics working at the engines and the power consumption of 195kWh per day to only heat two engines with a total of 4 to 8 people working on them is high.

2.3 Active body heating

Positives:
- Mainly positive feedback from mechanics
- Directly heating the people
- Individual control of temperature
- Relatively low cost solution
- Mechanics are heated no matter their position

Concerns:
- Manoeuvrability
- Safety, static charges
- Dealing with change of temperature, for example when entering the cabin of the plane

Energy consumption
Actively heated clothing can be powered in different ways. Most commonly, these types of clothes are electrically powered by a battery. However, there are also disposable pads available that heat up through a chemical reaction and stay warm for several hours.

To be able to compare the energy consumption of Active Body Heating with the other Local Heating solutions, in this chapter only electrically powered heated clothing is considered.

Types of heated clothing

Clothing Type	Battery size	Price
Bodywarmer	8000mAh 5V = 40Wh	€130,- (Comfort-Producten.nl)
Jacket	10000mAh 5V = 50Wh	€325,- (Gearfreak.eu)
Socks	2x2600mAh 7,4V = 38Wh	€170,- (Comfort-Producten.nl)
Gloves	2x2200mAh 7,4V = 33Wh	€150,- (Comfort-Producten.nl)

Table 13: types of heated clothing their battery size and price

An example was found for four types of heated clothing with their specific energy consumption. To calculate the energy consumption of the heated clothing, it is assumed that a mechanic does not wear every type of heated clothing at the same time. Instead, the mechanic would wear a bodywarmer and socks (40Wh + 38Wh = 78Wh), or a jacket and gloves (50Wh + 33Wh = 83Wh). On average the energy consumption would then be approximately 80Wh. Furthermore, it is assumed that in the most extreme situation fifty mechanics are working at the same time in Hangar 12. Approximately 56% of work is done outside of the aircraft according to earlier calculations (see Appendix 7). It would only make sense to heated clothing outside of the aircraft because it is hot inside the cabin. Therefore, the calculation for the most extreme day would be:

Extreme situation
*50 mechanics * 80Wh * 56% * 24 hours = 54 kWh per day*

Realistic situation
In reality, not every mechanic will wear heated clothing and there will be almost no days that 50 mechanics are working in all shifts. Therefore it would be more realistic to reduce the number by 50%.

*25 mechanics * 80Wh * 56% * 24 hours = 27 kWh per day*

*27 kWh * 30 days =* ***806 kWh per month***
*4 months of use = 806 kWh * 4 =* ***3.226 kWh per year***
*price per year = 3.226kWh * €0,14 = €452,-*

Comparison with 2.1 and 2.2
In the calculations of the IR Heating Panels (2.1) and Local Floor Heating (2.2), the only place that was heated was the engine. To make a fair comparison in power consumption, the same scenario should be applied to Active Body Heating. There are 2 to 4 mechanics working to the engine at the same time for approximately 10 hours.

*4 mechanics * 80Wh * 10 hours * 2 widebody aircraft = 6,4 kWh per day*
*6,4 kWh * 30 days =* ***192 kWh per month***

*4 months of use = 192kWh * 4 =* ***768 kWh per year***
price per kWh out of KLM payments = €0,14
*768kWh * €0,14 = €108,- per year*

Costs estimation

Realistic situation
In a realistic situation, heated clothing would be bought for all mechanics who would want to use it. For hygienic and sizing reasons clothing should belong to each specific person. Approximately 100 mechanics in total are employed in Hangar 12 that work throughout the different shifts. Several of the mechanics that I have spoken wear short sleeves even in the winter and claim to rarely be cold. For that reason, it is estimated that 75% of the mechanics would want heated clothing.

Looking at the earlier stated costs of different types of heated clothing an average combined price of €400,- per person is taken.

*100 mechanics * 75% * €400,- = €30.000,-*

Comparison with 2.1 and 2.2
In the comparison with the IR Heating Panels (2.1) and Local Floor Heating (2.2), there are 2-4 mechanics working on an engine and the scenario is that in the hangar there is worked on two widebody aircraft.

*8 mechanics * €400,- = €3.200,-*

Conclusion
Personal heating solutions only heat the person and are therefore far more energy efficient compared to IR Panels (2.1) and Local Floor Heating (2.2) for that purpose. In the comparison with 2.1 and 2.2 for only heating at the engines it is clear that Active Body Heating is far cheaper and less energy consuming. Furthermore, the choice for heating or not is put in the hands of the mechanic. Even when active body heating solutions are purchased for and used by every mechanic (realistic situation), the total costs (€30.000,- purchase price + €452,- yearly in power consumption) are lower than one month of heating the hangar in the current situation (GTL costs + rental price of heaters + gas costs).

2.4 Heat funnel from aircraft

Concerns:
- Effectiveness of heat transfer
- Comfort because of draft
- Amount of people/workstations benefitting
- Hindering work tasks because of size and location of funnel

The air in the cabin of the aircraft is 25-30°C. Whilst the cabin itself is a warm atmosphere to work in, as air to transport this is not particularly hot. Air will slightly cool down traveling through the funnel because the temperature outside the funnel and therefore of the funnel itself is lower than the traveling air.

A study by Griefahn et al. (2001) determined *"...the interaction of air velocity, air temperature, and physical activity on the sensation and evaluation of airflows at a stationary workplace."* This study suggests to keep airflows below 0,2m/s for comfort. In the case of the heat funnel, that would mean that the open end of the funnel would need to be very close to the workspace in order for the heat to actually reach it without dissipating in the cold hangar immediately. With the hangar doors open turbulence from the wind outside would make the hot air dissipate even quicker.

Size and reach of the funnel
Which workspaces could be reached with a funnel? Looking at the heatmap you would want to heat the area near the engine. On a widebody aircraft such as the 787, the engine is located 6,5 meters from the middle of the closest door in the Y direction and 3,8 meters in the X direction. Apart from that, the height difference is approximately 3 meters. This would make the funnel a large structure and the distance for the air to travel over 8 metres at least.

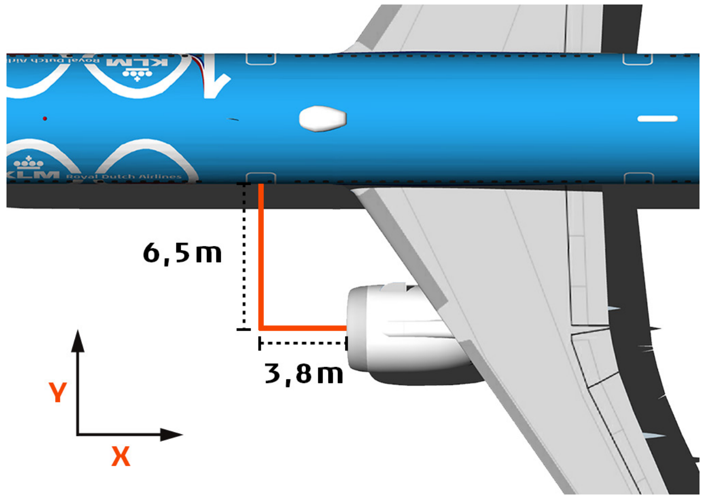


Figure 62: Distance from middle of the door to the middle of the front of the engine

Conclusion
Due to low effectiveness (only one workspace can be 'heated' per funnel) and obtrusiveness in the workspace of placing such a large structure next to a door and engine, the idea of the heat funnel is discarded. Whilst it was a nice idea to use the warmer cabin heat, it is deemed not effective enough and continuing with this idea would take a lot of effort for a low reward.

Appendix 4 – LIST OF REQUIREMENTS

General List

Performance

- The solution should reduce the current energy consumption for heating the hangar.
- The solution should provide the mechanics/people that work in the hangar space with an ideal working temperature of 16°C.
- The solution should provide enough heat to aid chemical processes that require heat locally (approximately 25°C).

Performance wishes

- *The value of the solution should be clear to everyone involved.*
- *The solution should keep the temperature within the hangar as stable as possible.*

Environment

- The solution should not require major infrastructural changes to the hangar.
- No structural reinforcements should have to be made to the hangar to implement the solution.
- The current power supply network of the hangars should be sufficient to power the solution.
- The solution should be able to flexibly provide heat to places that need to be heated at the task at hand.
- The solution should only heat the places that need to be heated at that specific time.

Product Lifespan

- The product should not need replacing for 20 years.
- Product parts that are prone to wear and tear and that degrade over time (e.g. batteries) should last at least 5 years.

Employability

- The solution should be implementable in the Hangar in its current state (2022).
- The solution should be able to be used with all aircraft types in KLM's fleet.
- The solution should still be employable with future aircraft models.
- The solution should be implementable in Hangar 12 before 2025.
- In order to implement the solution to Hangar 11, only slight adjustments should have to be made.

Ergonomics/Usability

- The product should not hinder the mechanics/people in the hangar in their tasks.
- The solution should not add more than 10 minutes for employment and deployment respectively.

Aesthetics

- The product should look robust and reliable.
- The product aesthetic should not fade in its time of operation (e.g. materials should not discolor).

Aesthetic wishes

- *The product should be distinctively KLM.*
- *The product should set an example for both employees and other airlines.*

Materials

- The solution cannot be made from flammable materials.
- The material should not discolor during its lifespan.

Safety

- The solution should comply with safety regulations within the hangar.
- The solution should be able to be safely implementable in all required areas within the hangar.

Product cost

- The solution should earn its monetary investment back within 5 years.
- The total cost price to integrate the solution should not exceed €150.000,- per year.

Heated clothing List of requirements

Battery requirements

- The battery of the heated vest should last a full shift minimally (8 hours).
- The placement of the battery of the heated vest should not hinder the mechanics in their work.
- The battery should be removeable and replaceable.

Durability

- The battery should be shock resistant and should survive a drop from a height of 2 meters.
- The vest should last at least 3 years of regular/intended use.
- The vest should be dust and water repellent.

Ergonomics, usability and comfort

- The vest should be flexible enough so the wearer can move freely.
- The vest should not have protruding parts that can get stuck on something.
- The wearer of the heated vest should be able to sit comfortably with the heated vest on.
- The wearer of the heated vest should be able to bow down comfortably with the heated vest on.
- The wearer should be able to take off the vest easily in 5 seconds.
- The vest should be able to be cleaned with water and regular detergent after removal of the battery.

Aesthetics

- The vest should have KLM branding and fit the style of the current working clothes for mechanics.

Product cost

- The vests should earn their investment back within one year.
- The vests should decrease employees complaints regarding heating of the hangar

Wishes

- *The vest should cool as well as heat*

Appendix 5 – COMPETITOR ANALYSIS – HANGAR HEATING

According to a study by Pei et al. (2008): *"Meteorological conditions, solar insolation, convection and external radiation heat transfer, heating facilities, and the hangar door opening all affect the temperature distribution."*

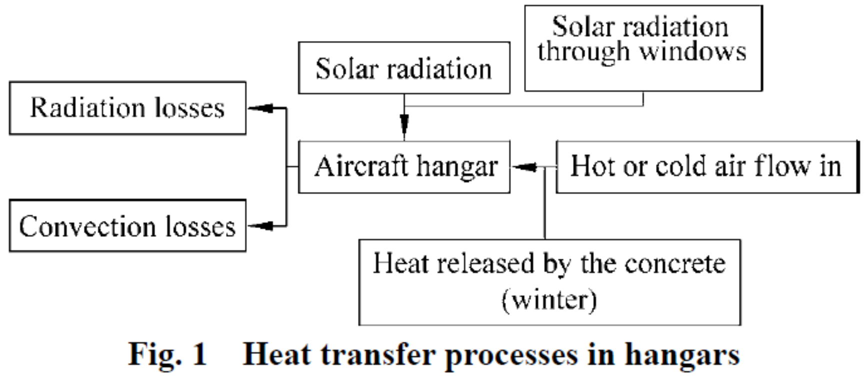


Figure 63: Heat transfer processes in hangars from Pei et al. (2008)

Apart from the hangar doors, there are no further windows in the hangar. Windows in for example the ceiling (see Figure 64) could reduce energy consumption in two ways. By letting in daylight, less lights need to be used and Solar radiation through the windows would aid in heating up the hangar (see Figure 63). The latter can become a negative side effect in the summer, however.

Figure 64: Lufthansa 747 in hangar with daylight as a main light source

Figure 65: Airbus Factory glass hangar doors

The sunstrips in the hangar are hot water radiators that do radiate heat, however unlike Infrared heaters the heat is not emitted towards the floor directly. According to Heaters Unlimited (2020): *"In airplane hangars, ceiling suspended high intensity infrared heaters or infrared tube heaters emit infrared energy downward to the floor level, just like the sun. Floors and other objects, including aircraft, people, tools, workbenches, etc. Absorb the infrared rays, which re-radiate to warm the surrounding air."*
They further state that: *"Over the past half-century or so, infrared heaters have been proven to be the most effective way to heat large airplane hangars. Nearly all new hangars in cold climates use some form of infrared heating system."*

This understanding does make a case to use infrared heaters to heat parts of the hangar that need to be heated.

Appendix 6 – Hangar Calculations

Appendix 6.1

Heating empty hangar

```
> restart;

Volumehangar := 241065 : WeightAir := 1.225 : mAir := Volumehangar·WeightAir : cAir := 1010 :
deltaT := 15 :

Eq1 := Q = mAir· cAir·deltaT;
Q := solve(Eq1, Q);

gasmonth := 13936 :
factorgas := 10.55 :

GTLmonth := 39657 :
#GTLmonth:=0:
factorGTL := 9.986 :

sunstrip := gasmonth·factorgas :
GTLheater := GTLmonth·factorGTL :

efficiencysunstrip := 0.5 :
efficiencyGTL := 0.4 :

days := 31 :
hoursday := 24 :
month := days·hoursday :

Pgemiddeld := ((sunstrip·efficiencysunstrip) + (GTLheater·efficiencyGTL)) / month ·1000;

heatlosshangar := 1.3 :
Eq2 := timetoheat = Q / Pgemiddeld ·heatlosshangar;
timetoheat := solve(Eq2, timetoheat) :

minutestoheat := timetoheat / 60;

                    Eq1 := Q = 4.473865068 10^9
                      Q := 4.473865068 10^9
                   Pgemiddeld := 311718.1731
                  Eq2 := timetoheat = 18657.95802
                 minutestoheat := 310.9659670                    (1.1)
```

Coldest day of december

#I used data of the temperature in the hangar on the 22nd of December and data on how much GTL has been tanked on the 23rd of December. The temperature data showed a lowest temperature of 4.1C and in 13200seconds it had warmed up to 12.8C (deltaT 8.7). I used the data of tanked GTL to calculate a day average usage. Once I filled in the deltaT of 8.7 and the average P of this day, I modified the efficiencyGTL until the calculated time came close to 13200sec.

```
> LitersGTL := 990.5 + 990.5 + 507.76 :
  LitersGTLperhour := LitersGTL / 23.5;
  decembersunstrip := 355·factorgas :
  coldestdaysunstrip := decembersunstrip / (31·24) :
  Pgemiddeldcoldestday := (LitersGTLperhour·factorGTL·1000·efficiencyGTL) + (coldestdaysunstrip
      ·efficiencysunstrip);
                 LitersGTLperhour := 105.9046809
               Pgemiddeldcoldestday := 423028.1742               (6.1)
```


**Note: The liters of GTL were divided by 23,5 hours, instead of 24 hours (1 day) because the GTL tanks were fueled 23,5 hours after their last fill up. This means that the liters of GTL tanked were used up in 23,5 hours instead of 24 hours.*

Appendix 6.2

Volume Boeing 787-9

```
> Length787 := 63 :
  r787 := 3 :
  Volume787 := evalf(Pi·r787^2·Length787);
                    Volume787 := 1781.283035
```

**Note: An estimation of the Volume of a Boeing 787-9 was made by simply looking at it as if it were a cylinder of 63 metres in length (the length of a Boeing 787-9) with a diameter of 6 metres. The actual maximum width of the fuselage of a B787 is 5,77m and its maximum height is 5,94m. In reality the fuselage is less voluminous towards the end (pointy end) and rounded at the nose. To compensate for the volume of the wings and vertical stabilizer a slightly larger diameter of 6 metres was taken and extruded over the full length of the fuselage.*

Appendix 7 – HEATMAP EXPLANATION

Heatmap work 787
Hours per location on the aircraft:
- The average hours per location were taken from the Prognose tool for PH-BHO, PH-BKA and PH-BKD. The fourth aircraft that was taken as a reference (PH-BHN) was not included in the average since maintenance in this particular check took place on the other engine.
- The minimum and maximum averages were calculated and divided over a colour scale.
- The location of the task was coloured accordingly.

Hours of work divided by area:
- The workspace area of the engine was taken as a reference (7m x 4m = 28m^2)
- The top view area of the fuselage was estimated to be the following. B787 Length = 63m and width = 5,77. The fuselage is not squared but more of a drop shape so the area was estimated to be: 55m x 6m = 330m^2
- 330/28 = 11,79 = ratio fuselage/engine
- The engine with the most hours of maintenance is the starting point, because this has the highest density/most work
- Hours per m^2 fuselage = hours work fuselage / ratio = 12,01/11,79 = 1 (for fuselage, so blue given the colour scale)

Conclusion:
In the first heatmap is seems like a lot of work is done to the fuselage and wings. This is logical since the fuselage and wings have a larger area compared to for example the engines. If the ratio of work and area is taken into account, it becomes clear that per m^2 significantly less maintenance is done at the fuselage and wings compared to at the engine. Since this maintenance is spread over a larger area it makes more sense to heat the mechanic instead of heating the whole area locally. What maintenance is done in what shift is not taken into account.

Ratio of maintenance inside the cabin versus outside of the aircraft:

Registration	Check	Inside [hr]	Outside [hr]	Inside [%]	Outside [%]
PH-BHO	A16	62,2	95,62	39%	61%
PH-BHN	A17	76,7	97,72	44%	56%
PH-BKA	A11	70,35	91,14	44%	56%
PH-BKD	A09	73,55	71,34	51%	49%
All aircraft	-	**282,8**	**355,82**	**44%**	**56%**

Table 14: Ratio of maintenance inside and outside of the aircraft as an average of four A-checks

Tasks of the prognose tool that were left out of the calculations because their location is unclear:
- Admin
- Final
- Preliminary
- Tests

Conclusion:
Most maintenance is done outside of the aircraft, but this varies per check. In this case task location divided per shift has not been taken into account.

Appendix 8 – OBSERVATIONS

Appendix 8.1 First observations

Hangar Door Opening
The time that the hangar door is open differs a lot. Sometimes the door is opened for a plane to go out of the hangar and the door is closed almost immediately after it has left. Whereas on another occasion the door was opened for more than 30 minutes. The door was opened for a plane to come in which took more than 20 minutes and the door was closed again approximately 7mins and 30 seconds after the aircraft tug left the hangar. In Hangar 11 (Bay 2) there are two hangar doors opening to the left and right respectively. They are operated by a technician who walks with the door and each door is controlled separately. To close one door takes 1m 30 seconds (Hangar 11 Bay 2). They are closed after each other for supposed safety reasons.

In Hangar 12 the hangar doors open in multiple parts. Each separate part needs to be opened with a button on that door. Therefore, either multiple people are needed to open the doors quickly or opening the doors will take a lot of time (approximately 13min 30sec. when done alone, according to measurements done by a mechanic (Maarten Piet)).

Appendix 8.2 Hangar observations 4th of May 2022

Time
9:30-10:30.

Weather
11°C and sunny.

Hangar 12
Only one B789 was in the hangar and the hangar doors were opened for 25 minutes to move the plane 10-15 meters forward to be able to do a tail inspection.

Hangar 11 Bay 1
Many people working on B777 in this bay. The hangar doors were opened at 9:50h. At 10:17h a second B777 is moved into Bay 1. At 10:22h the tug leaves the hangar and the hangar doors begin to close right after the tug has left. The doors are fully closed at 10:28h.

Both Hangar 11 Bay 1 and Hangar 12 felt cold after the doors had been open.

Appendix 8.3 Hangar observations 14th of June 2022

Time
14:30-15:00.

Weather
19°C and partly cloudy.

Hangar 11 (all bays) and Hangar 12
I have looked at the different types of clothing the mechanics were wearing to see if there was a pattern on this particular day. Pants are always long legged.

- Overalls with (jacket in same fabric and light blue colour and) long sleeves: 12x
- Black/dark blue sweater long sleeves: 6x
- T-shirt/Polo short sleeved: 7x
- Fleece vest 2x

Appendix 9 – INTERVIEW NOTES

Appendix 9.1 Interview 7th of March - mechanic Maarten Piet

According to Maarten, the temperature in Hangar 12 is cold in winter. According to his personal measurements, Hangar 11 is 4°C to 5°C warmer (measured in 2019 or 2020). The main problem for Maarten during colder conditions are cold hands. Wearing gloves is possible sometimes, but not always since it can be impractical.

Low temperatures can also be of influence for maintenance work. Certain tasks require a certain temperature.

During maintenance of the Boeing 787, the cabin can be between 30°C-35°C. If the cabin doors are opened and nets are placed in the doors, that could increase the heat surrounding the aircraft slightly.

In a pilot test that was done with IR heating panels to heat people around the aircraft, this solution did not yet seem ideal. According to Maarten, power cables can break if something drives over them (note: there are already often cables on the floor and they don't break if things drive over them). Other than that, according to Maarten, the panels are not very useful when working on the engines because the radiation beam is often blocked.

Maarten has timed how long it took him to close the hangar doors by himself in Hangar 12. In total from start to finish he measured this taking 13mins and 22seconds.

Apart from that Maarten has also done some temperature measurements on his own in Hangar 12. One day with an outside temperature of -6°C, the temperature inside H12 cooled off to 2°C after opening the hangar doors. From that moment, the temperature in the hangar increased with approximately 3,5°C per hour. (These measurements comply with the data I have reviewed and calculations I have done where the temperature in the hangar increased with approximately 3,3°C per hour).

Appendix 9.2 Meeting with CILs 11th of April

According to the CILs in relation to heating:

- You should take into account how many people are working in the hangar space when talking about heating. Is it worth it to heat up the hangar for a handful of people?
- Hangar 11 Bay 3 is not heated because not a lot of people work there at the same time. This leads to the mechanics working there complaining about the low temperatures.
- The A-check is moved to Hangar 12 with the idea that the doors would have to open less compared to before. At the moment, shorter checks are still moved to Hangar 12 which means the effect is not fully achieved. According to Marco Steinmetz there is a lot to be gained in terms of efficiency. If Hangar 12 would be used for longer maintenance jobs, it would significantly reduce the amount of times the hangar doors have to be opened, this in term would reduce the energy consumption. These changes would need to be implemented by the “regieleads”.
- Most maintenance during an A-check is situated surrounding the landing gears, engines and wheel wells. Inspections and maintenance on wings in comparison takes up a lot less time.

Feedback on ideas:

- An airplane tent seems a huge challenge, mainly because of the deployment time (an engine tent takes approximately 1 hour to set up and a full aircraft tent would take longer to deploy), the logistical challenges of entering and exiting aircraft and their positions in the hangar and the movement of equipment and people surrounding the aircraft during maintenance. For these reasons the CILs did not think this idea was best.
- The heat funnel is a nice idea that creates a win-win situation, namely cooling down the aircraft cabin whilst heating up the hangar space. You have to keep in mind that airstreams don’t feel pleasant/comfortable oftentimes.
- The aircraft curtain could make a difference in terms of heat preservation but this would need to be calculated or tested. The majority of the heat is probably situated in the top half of the hangar space. In principle a permanent aircraft curtain could be placed in the top half of the hangar door opening with one or multiple vertical stabilizer cut outs.
- When it comes to personal body heating solutions there have been a few pilots within KLM more so for cooling instead of heating for mechanics. In the tests cooling vests were utilized that work by pouring in cold water. In theory the inverse could be done to heat someone. Feedback showed that the vests were oftentimes received as being clumsy, uncomfortable and slightly restricting moveability of the wearer. Furthermore, the problem is not necessarily solved because the main caveat in cold circumstances are the hands.
- Infrared heating panels. Tests have been done in Hangar 12 with moveable infrared panels with the engine change team. A number of issues were found in these tests:

1. The power usage of the panels was high and the hangars are already close to top capacity in terms of electricity usage.
2. The material (the engine in this instance) does not heat up and therefore having cold hands can still be a problem.
3. The panels need to be directed quite precisely and leaving the stream will cause you to not feel any heating. During an engine change the panels were found to not be effective all of the time. The idea was suggested to put the panels on an arm attached to the wall and have them overhead instead of heating from the side.

The idea to mount the infrared panels to tool carts raises a few questions:

- Would these be mounted to the carts all year long?
- How would you charge these panels?

Concern:

- Tool carts are not always handled with care.

Other ideas that came to mind:

1. Local floor heating: rolling out floor heating mats below engines and at other “hotspots”.

Appendix 9.3 19th of April - talk with a mechanic (Roy van der Weijden team 8 H12)

Key takeaways

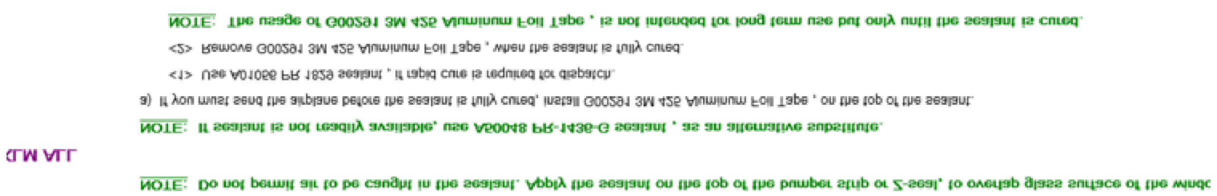
- During maintenance on the engine in Hangar 11 lights are put below the engine to be able to see better. In Hangar 12 this is not always the case because the lighting in that hangar is already a lot better. In addition to the better lighting, each mechanic has his own torch, these can also be used in case light levels are low. I asked the question to this mechanic because it might be a possibility to attach an IR panel or multiple IR panels to the light stand/construction. Lights are positioned at the place you need to be illuminated and that arguably is the same place that you are working.
- The mechanic did not necessarily like the idea of having infrared heating panels at the engine because during maintenance on the engine you’re still on the move quite a lot. This can for example be to get tools from the warehouse or to order parts in the office at a desktop. This leads to going from a warm to a cold environment and vice versa constantly which might have an inverse effect on comfort.
- IR panels on a scissor lift would need to be tested because of the reduced battery life that the scissor lift would have when the panels would be connected to the battery of the scissor lift. Also the effectiveness would need to be tested, Roy did not think he would use the IR panel on a scissor lift.

Roy really liked the idea of a heated bodywarmer or jacket. He was not concerned with having to go inside the cabin, he would just turn off the jacket or take it off altogether. I could for example design a coatrack to attach to the bottom or top of the aircraft staircase so mechanics could leave their heated jacket there when entering the plane.

Appendix 9.4 Peter Borst Technical specialist & Nova de Jong Planner Fleet Availability

Peter

- People in the hangar should not become the "Michelin man". They should not get stuck behind anything and should be able to move freely.
- Peter has 30 years of experience in the hangar.
- For repairs at the engines a radiant heater of 40-50°C is used to accelerate the curing process.
- With cockpit window repairs, Teflon tape and high speed tape can be used when curing is not fully completed (this tape sometimes is in place for as long as two weeks). There are prescribed procedures for this:



NOTE: Do not permit air to be caught in the sealant. Apply the sealant on the top of the bumper strip or Z-seal, to overlap glass surface of the windo

NOTE: If sealant is not readily available, use A50048 PR-1436-G sealant, as an alternative substitute.

a) If you must send the airplane before the sealant is fully cured, install G00291 3M 425 Aluminum Foil Tape, on the top of the sealant.

<1> Use A01056 PR 1829 sealant, if rapid cure is required for dispatch.

<2> Remove G00291 3M 425 Aluminum Foil Tape, when the sealant is fully cured.

NOTE: The usage of G00291 3M 425 Aluminum Foil Tape, is not intended for long term use but only until the sealant is cured.

- Close to the (cockpit) window you "of course" cannot heat too hot, since the window may not get that hot. (Peter was talking about a maximum of 40-50°C. This made me wonder how that could be the maximum with planes based in the Middle East, where in full sunshine the windows would be exposed to temperatures that exceed 50°C.)
- Currently at KLM no additional heating is used when replacing cockpit windows.
- In some cases, quick drying sealants are used, for example at Line Maintenance.
- For the sealing of panels, tank sealant is used sometimes. This sealant dries between 2 to 2,5 hours.
- For composite repairs at the B787 a constant temperature is necessary and therefore blankets are used in some cases.

Nova

- It is correct that these kind of repairs (referencing repairs with a curing component), are always started right at the beginning of maintenance. The curing time is the main reason for this. (This means the hangar will be cold since the hangar doors will just have been opened).
- These kinds of repairs are mostly planned at corrective (in H11). (This means that generally speaking the maintenance takes less time compared to an A-check.)
- The curing time of sealants is leading for the total time of the repair or check. This is the case because most often the repair with the curing time is the longest in duration.

Peter

- The standard for curing times is roomtemperature (21°C). At colder ambient temperatures, the temperature is estimated by the mechanics and a longer curing time is accounted for. There are no specific rules or procedures for this.
- Every adhesive has its own curing time and the curing time for each specific adhesive can be found at the number of this adhesive.
- Fleet availability could be increased when we would heat locally at some specific repairs.

Appendix 9.5 Interview Rasmus Fannemel Heat Experience

03:10
Wearing heated clothes with a safety harness will be no problem, Rasmus, he wears it all the time mount climbing with a harnass and a backpack.

04:30
"Our ambition is to be the expert on heated clothing, we don't do anything else. This allows us to experiment with the width of the productspan (product line)"

9:17
"I would say that if you don't have to worry too much about what you are wearing, if you can wear normal overalls, or another type of suit that is not particularly certified for the job (referring to fire hazards or concerns regarding static charges), then heated clothing should do the job just fine"

2. Do you have a temperature range in which your products are currently used?

13:05
Heat Experience products are roughly used from -20°C to 10°C.

13:40
The clothing of Heat Experience is designed to also be wearable as "normal" clothing when you take out the battery.

14:40
New product launch (sept 2022): app control, set the temperature of the vest from 20-60°C, The app will turn the vest on or off automatically. There is a NTC thermostat, by the heating element and measures the temperature close to the heating element. It does not measure body temperature but this gives you way better temperature control once you for example know that the temperature you like is 30°C.

15:20
Standing still in 5-10°C, crank up the heat to max. when you start walking or moving a little bit I would put it to medium or low.

3. Do you know of use cases currently, where your products are used inside?

16:50
Truck drivers wear the heated products. They go in and out of the trucks all the time and so use them in varying temperatures.

Someone working in a cooling of -20°C and then going outside in the summer temperatures, still wearing the heated vest.

Warehouse workers at Heat Experience wear their heated clothing all year round. In the winter the warehouse can be 10°C and the break room is normal room temperature. They usually keep wearing the heated apparel but turn it off. Sweaters and vests are used, the vests (no sleeves) are more prone to be taken off. The work that is done is operating fork lifts, but also some manual labor. (The physical intensity might be comparable to the hangar).

How do you decide on the positioning of the heated elements. In most of your upper garments as far as I can tell they are placed on the lower back and chest in the front. Why is this? How about upper back?

21:25
<u>Back heating element positioning</u>
If you wear a backpack the heating element on the upper back would be squeezed to much against the back, making it too hot. Customer questionnaires and trials showed that the lower back was preferred, lab testing verified this. Furthermore, the lower back is prone to get a cold sensation easily. Inner organs are exposed there and it makes a lot of sense to warm up the kidney and lumbar area.

<u>Front heating element positioning</u>
On the chest you get very good skin contact and a good transmission of the heat. Belly fat means the belly does not really need to be heated.

Heat Experience is quite happy with the current positioning of the heating elements. They, get close to the body and do not obstruct movement. Another consideration is minimizing the amount of cables and cable length.

The same question for battery positioning, how was this position decided on, because it is now in an inner pocket on the left right?

24:50
<u>Vest</u>
You are used to having stuff in your pockets when wearing a vest (bodywarmer style). For that reason the battery is placed there. In this way you can balance the weight by putting for example your mobile phone in the other pocket. Because this vest is not stretchy, you want it to fit snug around the sides and therefore the battery is not placed there. The battery is placed high enough so it does not affect bending over for example. Also the strap of a backpack around the belly is not in contact with the battery.

<u>Sweater</u>
On the sweater it was decided to put the battery more on the side. Because of the tighter fit, it feels like it is dragging you down when placed in the front pocket.

Alright and the battery size and duration, we would like the battery to last 8 hours (a full shift), would you recommend getting a second battery or a different battery?

Heat Experience uses a small and thin battery pack.

In hangar scenario: Rasmus estimates that when mechanics are getting used to how to control the settings of the heated apparel, it should last them 8 hours a day.

How important is the fit of a heated vest or sweater in your opinion for the effectiveness of feeling the heat?

The thinner garments that do not have a lot of insulated layers, require to fit snugly in order to feel the heat. The vests are insulated on the outside of the heating elements and can do with a looser fit.

I am curious about your thoughts on layering of clothes. In the product video of your heated vest it showed people wearing the vest as their top layer, can it still be effective with insulated layers beneath?

No, it is way more effective if you are not wearing many layers underneath the vest.

The vest can be worn over a normal sweater, the heated sweater can be worn over a t-shirt and for maximum effectiveness a windbreaker can be worn on top of it.

Are specific products in your line-up meant to be either the toplayer or in between/mid layer and what is the difference?

Mostly mid layers, vests could be used as outer layer.

“At 10°C this (referring to heated sweater) could be the only layer you have on top of a normal t-shirt. I would say you would be able to work pretty comfortably.”

Science says that the core needs to be heated, in reality, cold fingers remain a problem.

Some of your heated sweaters and vests have long sleeves and others have no sleeves. Is there a difference in the effectiveness of heating when you compare the two?

Insulation makes a lot of difference but having sleeves or not does not really make a difference. The vest is easier to take off.

Which type (vest or sweater) would be best in the scenario of the hangar?
Both could work, it depends mostly on personal preference. Since the temperatures are not very low it is definitely both an option.

The heat elements in vests and sweaters are the same, but the insulation is different, the fitting too (the sweater is more tight fitting and the vest is more loose).This also means that having the right size for each individual is more important with the sweaters.

Durability

The warranty of Heat Experience is 2 years and the products have been tested to 50 washes. In reality products can easily last 5 years.

Cold hands
Tips for cold hands were: put the hands close to heating elements for a while or put heat elements in the front pockets. In 10°C cold hands will be less of a problem and no heated gloves have to be used.

DESIGN FOR OUR FUTURE

TU Delft

APPENDIX 10 - PROJECT BRIEF

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: van Houwelingen
initials: J. given name: Jens
student number: 4451864
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: Prof. dr. ir. J.M.L van Engelen dept. / section: DfS
** mentor: Ir. C.P.J.M. Kroon dept. / section: DfS
2nd mentor: Jasper Rougoor
organisation: KLM Royal Dutch Airlines
city: Schiphol-Oost country: the Netherlands

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.

comments (optional): WHY? Chair (Jo): a lot of experience on the business side, board member in multiple companies, implementing changes in larger businesses. Mentor (Caroline): hands-on design experience, own sustainability consultancy firm.

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

Local Aircraft Hangar Heating: A sustainable Solution for Hangar Heating — 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 28 - 02 - 2022 29 - 07 - 2022 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, ...).

CONTEXT
KLM Engineering and Maintenance (KLM E&M) at Schiphol East, is KLM's maintenance division. 4.000 E&M employees are responsible for keeping the aircraft fleet operational. The majority of KLM's Schiphol East area is accounted for by the hangars. Including KLM Cityhopper, the area resides 6 hangar buildings, maintaining the different aircraft models and performing short to longer checks (types of maintenance). KLM hangars do have a floor area up to 27.000 square meters and a ceiling height of 30 meters. It is obvious that heating up a large space like this requires a lot of energy.
Currently, the hangars and buildings of KLM at Schiphol-East are mostly heated using natural gas. The natural gas used to heat up the hangars and buildings there, accounts for approximately 60 percent of KLM's total natural gas consumption. In hangars 11, 12 and 73 in particular a lot of energy is used, since there are a lot of aircraft movements, which means the hangar doors need to be opened, which in winter means most of the heat is lost. KLM's ground operation needs to be carbon neutral by 2030 and for that reason something needs to change.

STAKEHOLDERS
o KLM Maintenance Engineers: These people maintain and repair aircraft and the hangar is their office. The climate in the hangar is important for their wellbeing and ability to perform their work.
o KLM Bold Moves team as initiator.
o KLM Safety Officers: The solution should comply with the strict safety policies that are in place in the hangars.
o KLM E&M Central Engineering: Involved in implementing new equipment for maintenance.
o KLM E&M Purchasing / Material / Equipment / Facilities / RE & FC: Implementing a solution (product) will probably be on the budget of these departments.
o Sodexo: The supplier/regulator of the natural gas used for heating in the hangars at the moment.
o Aircraft Manufacturers (Boeing/Airbus/Embraer): If the solution involves attaching something to the aircraft or something touching the aircraft, the manufacturers are possibly involved. There are guidelines and rulebooks regarding maintenance and not complying can lead to voiding warranty. For example, only a very specific aviation-grade tape may be used on parts of the fuselage.

OPPORTUNITIES
+ Drive to invest in sustainable solutions because of climate goals to be carbon neutral by 2030.
+ KLM has been rewarded most sustainable airline for 16 years in a row by the Dow Jones Sustainability Index, this project could help to strengthen this position.
+ KLM is a large and established company and there is a lot of knowledge and expertise within the company.

LIMITATIONS
- Regulations: The aviation industry has tons of regulations that make innovating more difficult.
- Development: KLM is not a manufacturer and for that reason a prototype might not be able to be made in-house.
- Time for development and implementation: The whole ground operation needs to be carbon neutral before 2030 which leaves not a lot of time for development and implementation of ideas.
- Stakeholders: There are many internal parties involved, which means that an innovative idea needs to pass through all of these parties before it can be approved.
- Money: Given KLM's current financial situation due to the pandemic, there might not be a lot of money available to use for innovation.

space available for images / figures on next page

introduction (continued): space for images

image / figure 1: KLM Hangar 12 door open

image / figure 2: Bay 1 of KLM Hangar 11 with people for size

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.

Energy consumption in the hangar is high. With the hangar doors opening 4-6 times a day*, in winter, a lot of the heat (and therefore energy) is lost. The hangars are currently mainly heated using natural gas. A team at KLM is working on finding more sustainable solutions using green and/or renewable energy, however, implementing these kind of changes will most likely cost a lot of money and require infrastructural change.

SOLUTION SPACE
- Heating up the hangar locally when there is a plane to work on and not losing all the heat when the hangar door is opened.

IN SCOPE
- The main space in the hangar
- Heating of the main space in the hangar
- Providing the right working conditions (regarding temperature) for both engineers and the airplane

OUT OF SCOPE
- Major infrastructural changes
- Offices within the hangar
- Other buildings and the area outside of the hangar
- Energy consumption of loose equipment in the hangar

*Source: Maintenance Engineer in Hangar 12

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.

I will investigate the current situation and the "need for heat" for both people and aircraft. Apart from that, I will recommend and design a solution in the shape of a product that will improve current energy consumption regarding heating up the hangar.

The assignment as described by KLM was very broad and stated: "to collect data on the current situation, to come up with innovative ideas to reduce the energy consumption in the hangars and to develop and realize the product idea with the largest impact in the shape of a prototype."

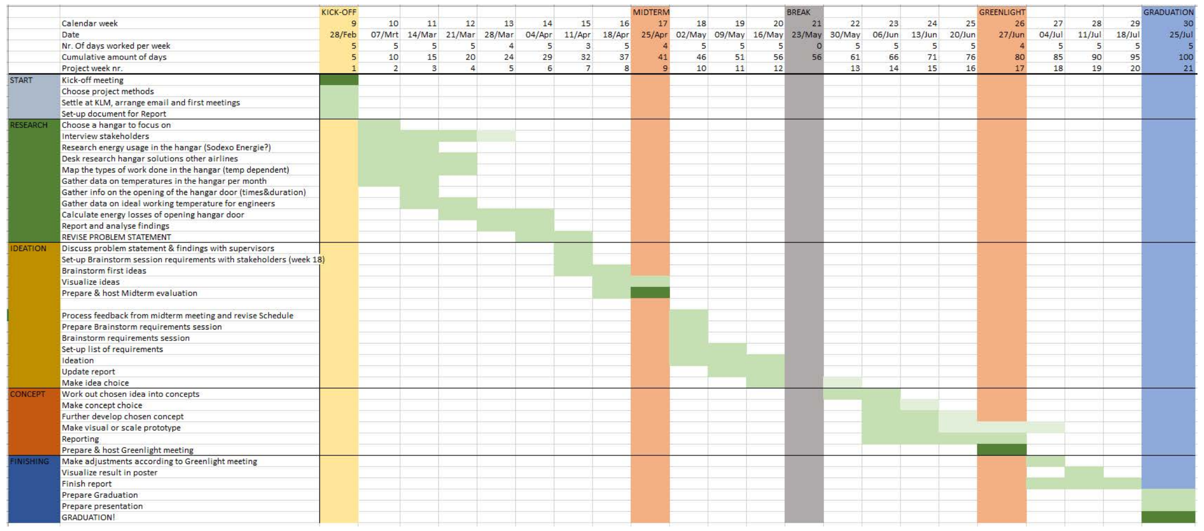
My aims and interpretation:
- Defining what is necessary in terms of temperature working conditions for people and airplane (fluids, materials and electronics during maintenance).
- Coming up with a product idea that is an addition to the current hangar and that will not require infrastructural changes. This includes researching and mapping current ideas and initiatives within KLM and their development status
- I envision a solution that provides heat for the plane and the area in close proximity to the plane and therefore also for the engineers working on the plane (such as a tent over the aircraft or IR panels). Alternatively, the solution could be focusing on heating up only specific areas of/around the plane, depending on the outcomes of the research.
- I aim to develop a prototype of the most desirable concept and make it into a feasible and viable proposal for KLM. My prototype will include a 3D CAD model, a digital visual representation of the envisioned situation and a physical prototype either scaled or in actual size.
- My solution should be implementable before 2025. (If it would take much longer to implement, infrastructural changes could already be made such as the use of green energy to heat up the hangars).

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 28 - 2 - 2022

29 - 7 - 2022 end date



I made a first version of a schedule for the whole project. I scheduled in a one-week break in week 21 as well as five separate free days on days I have other important personal venues. I have learned throughout my Master's that taking breaks is important for my personal mental and physical health (I have Type 1 Diabetes and loads of stress, less sleep and less routine, have significant negative effects on me physically and mentally). It is my aim to put in the time, but also be able to take a short break once in a while.

Not yet described in this schedule is the balance between working at KLM and working at home. Desk research, reporting and more elaborate visualization I can do more efficiently from home. Also, it is important for me to keep reminding myself to keep the report up-to-date and plan time for this throughout the project.

IMPORTANT MOMENTS
Kick-off meeting - 28th of February
Midterm - Week of 25th of April
Break - Week of 23rd of May
Greenlight Meeting - Week of 27th of June
Graduation - Week of 25th of July

Initials & Name J. van Houwelingen Student number 4451864

Title of Project Local Aircraft Hangar Heating: A sustainable Solution for Hangar Heating

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.

MOTIVATION
I was lucky to be approached by KLM with this graduation opportunity. I already had KLM in mind as a potential company to graduate, because of my love for aviation and positive previous experiences at the company during an internship.

I have a passion for aviation, but cannot deny the inherently unsustainable core of the industry. Making the whole operation more sustainable is key for the public image and the survival of the industry. Warner Rootliep (Managing Director KLM Cityhopper) said the following on the topic: "Aviation should not become the new smoking". I fully agree with this, but in order to do so, changes should actually have an impact and not be perceived as greenwashing. With this project I am looking forward to contribute my part in making KLM a more sustainable airline.

LEARN AND PROVE COMPETENCES
- I want to prove that I can operate in a large multidisciplanary environment. That I am able to find and approach the right people to help me/interview within, or outside of the company.

- I want to learn to find the right balance between being at KLM, and working on the deliverables necessary to graduate. I want to prove that I can stick to my own schedule and to plan enough time both at KLM and to work on the deliverables required by the university. I need to be wary to not lose sight of the main goal of this project which is to graduate my master.

SKILLS - VISUALIZATION
- I want to further improve my visualization skills, both analog and digital (Photoshop/Illustrator) and deploy gathered knowledge and skills learned in Msc elective courses such as Automotive Sketching and Lighting Design, but also in the Bsc elective Design Visualization. Furthermore, I want to use and expand upon my Keyshot rendering/SolidWorks or Fusion 360 3D CAD modeling skills.

MAIN AIM
- To graduate and deliver a project that I am proud to deliver to KLM and put in my portfolio.

FINAL COMMENTS

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

Initials & Name J. van Houwelingen Student number 4451864

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Appendix 11 – Map of Hangar 12 (own creation)