CHALMERS
UNIVERSITY OF TECHNOLOGY

Next Generation of Ventilated Front Seats

Improving the cooling performance of front seats for Volvo cars

Master of Science Thesis in Product Development

RAIBHAN BHOSALE
NICOLAS VOGT

Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Master of Science Thesis in Product Development

Next Generation of Ventilated Front Seats

Improving the cooling performance of front seats for Volvo cars

RAIBHAN BHOSALE
NICOLAS VOGT

Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2016

Next Generation of Ventilated Front Seats

Improving the cooling performance of front seats for Volvo cars

NICOLAS VOGT
RAIBHAN BHOSALE

Copyright © 2016 RAIBHAN BHOSALE, NICOLAS VOGT.

Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
SE – 412 96 Gothenburg
Sweden

+46(0)31-772 1000

Cover:

Chalmers Reproservice
Gothenburg, Sweden, 2016

Abstract

Volvo Cars offers seat ventilation as a feature for their cars in the upper market segment. With the development of their newest product platform, they have managed to develop a highly complex seat to complement their upcoming products. This project was initiated to gauge, and consequently improve, the performance of the ventilation system in the new front seats, while keeping the changes to a minimum.

The project was carried out by studying literature, and analysing the current SPA front seat. The seat was reverse engineered, and later was used as a prototype mule. The supplier for Volvo's seat ventilation system, was involved in the project from an early stage. In addition, competitors were studied through a teardown website, and visits to their dealerships. Vehicles from competitors were used for elaborate tests, and to benchmark against Volvo.

The improvement of the system was initiated by a discussion about the possible areas of optimisation. Brainstorming sessions generated multiple concepts, ranging from least to radical changes. They were later screened to pass feasible solutions. Due to constraints in making changes to the foam itself, many concepts were fabricated for validation. Their performance was tested in respect to the energy flux with a thermal manikin. Weak concepts were improved, and ideas were combined to form secondary concepts. Utilizing gained knowledge from both the benchmarking and generated concepts, two final concepts were chosen, and made into physical prototypes. These final concepts incorporated the idea to either maximize performance or to increase the performance with minimal changes.

Through the conduction of tests during the project, the position of the fan, and the design of the duct were found to be highly influential in regards to the performance of the system. Volvo's current setup caused turbulence, as the seat had a curved rubber duct for inlet of the cushion fan. Removing this duct improved the performance substantially. The disadvantage for this solution was the rearrangement caused in the packaging of the cushion, and related components.

The repackaging was considered to be undesirable as it was a reason for change in expensive machinery used to create the seat structures. In the backrest, a centric position of the fan improved performance considerably. For the cushion extensions two fans were added to improve the performance in the previously non-ventilated area. Factors like holes placed in a straight line towards the fan inlet, blocking of the exhaust was seen to cause problems with airflow.

Conclusively, Volvo's current system is one of the best performing systems among the ones tested. Interestingly, the previous generation of ventilated seats from Volvo was objectively weaker, but was sensibly better for the test subjects in their in-house tests. Therefore, it is important to include subjective evaluation of the seats, and not solely rely on objective numbers. The concepts generated improved the overall performance of the seats, and were better than the existing system. In order to pass on the knowledge gained from this project, design guidelines were also introduced.

Acknowledgements

Being able to participate in research and development at a world class organisation is a notable prospect. And to have been part of Volvo Cars for the past half a year, has been a dream run for the both of us. We would like to begin our acknowledgements by showing our gratitude towards Volvo Cars for giving us this momentous opportunity.

We are grateful to our supervisors – Mr. Peter Setterberg at Volvo Cars, and Dr. Göran Gustafsson at Chalmers University of Technology, for believing in us, and encouraging us through our endeavour. We thank them for providing us with their invaluable insights, and appreciate their significant association. We are obliged by the openness provided by the both of them, in shaping our thesis.

An earnest vote of thanks for Gunilla Järpsten, our Manager at Front Seats, for affording us with all the liberties. It was more than a pleasure to have been part of her team, and have such an enthusiastic environment to carry out our research. We would like to thank Dragan Rac for being a great advisor, and a friendly figure. We highly appreciate the counsel he gave us in our impromptu deliberations.

We owe gratitude to our mentors at the supplier, Rickard Gustafsson, Stefan Jakobsson, and Marcus Andersson, and Peter Öberg for giving us their time, energy, and efforts to set up, conduct, and analyse the outcomes of the benchmarking tests. We thank them for their valuable inputs, and for letting us use their machining equipment.

We extend our gratitude towards our affiliates at Volvo Cars' Climate department, Lennart Derman, Benjamin Olaison, and Fredrik Olsson, for their continued interest and helpful involvement in our work. We appreciate their guidance with Volvo test procedures. We thank Bosse Eriksson for helping with competitor materials and entities. We are appreciative of Reine Sandqvist's assistance with Benchmark vehicle reservations. We thank the entire Front Seats & Comfort team for being extremely supportive and informative throughout the handful of months that we spent in their midst.

Raibhan & Nicolas

Gothenburg | June 17, 2016

Table of Contents

List of figures

1. Introduction

Ever since it started running on roads, seats have been an integral part of the automobile. From the very early times when there existed simple benches, to the latest state-of-the-art massaging chairs, automobile seats have changed immensely over time. They have transformed from a flat horizontal plank, to contoured individual chairs capable of catering to individual needs. Heating and cooling features have turned car seats into ambient zones on-the-go. With the addition of softer and more comfortable foams, leather, massage function, they have become much more luxurious. The implementation of modern three-point seatbelt along with airbags has made seats safer. Conclusively, the plethora of features and functions on modern-day car seats turned them into an extremely complex system.

A feature to cool down seats for improved thermal comfort has been around for almost two decades. It was first introduced in a production vehicle, for the front seats, by a Swedish OEM in 1997 *(saabhistory.com, 2009)*. Since then, it has been adopted by many manufacturers, and fitted in a wide variety of vehicles in almost all market segments. This feature has been most commonly offered for the front seats. In recent times, it has been made available for the rear seats as well. Although, that remains confined mostly to high luxury brands, and their flagship model variants *(Jaguar Configurator, 2016)*.

Even after having a considerable history, sparse research has been dedicated to cooling down seats. Most research so far, was focused on utilizing Thermoelectric devices to provide a cool draft of air. But one of the most important factor for the limited research, as observed through multiple scientific articles, has been the human body itself. The complex biology of the humans combined with the uniqueness of each human body has been a challenge in creating a universally constant cooling system. Added to that, the constantly changing driving conditions, and a weather system differing from place to place has put up extreme challenges towards the development of seat ventilation.

1.1. Problem description

Limited research, and scant knowledge in the field, has led to very few advancements in regards to seat ventilation. The system has not witnesses major changes over the timespan that it has persisted on the market. Even though many manufacturers offer this feature, it is principally very similar across all competitors. Thus, in such a fuzzy market, Volvo engineers were curious to figure out the distinctiveness of their system. They were interested in finding out how good or bad their seat ventilation was in relation to other premium and luxury car manufacturers.

But internally, the engineers were also concerned with the performance of their own system. Irrespective of the competition, the engineers were interested in bettering their own system. Not only did they want to cool the occupant more effectively, but they also wanted to achieve this goal with as less changes to the current seat structure as possible.

1.2. Aim and purpose

The thesis is aimed at improving the performance of the ventilation system of Volvo's SPA platform front seats. This goal is to be achieved without compromising on existing levels of comfort, safety or quality. The increment in performance, in this context, is defined as quicker cooling in focused areas. This cooldown is directly coupled with increased airflow. By virtue of better air circulation, moisture removal is also of interest. Furthermore, the aim of this thesis is to compare the current ventilation system in the SPA seats with those offered by competitors.

The thesis serves the purpose of identifying areas, or components, where changes can be implemented in the existing ventilation system. This aspect of the thesis is targeted towards the improvement of the ventilation of the system of the SPA seat. It is motivated by the presence of dissatisfaction over the existing system performance, internally. The purpose of this thesis is also to justify the effectiveness of the current ventilation system. It is intended for the study of how good or bad the ventilation system is, in relation to solutions offered by rival OEMs.

To help achieve the goals of the thesis, a few research objectives were set to streamline the authors' efforts. They can be listed as follows:

- An analysis of current ventilation systems in use.
- A study of the SPA seat ventilation system in production.
- Identification of system components that can be improved.
- Recognition of challenges affecting changes, and how to overcome them.
- Evaluation of changes employed to a standard seat.
- Recommendations for enhancing the current ventilation system.
- Discussion of effects of implementing these recommendations.

1.3. Scope and limitations

This thesis is focused on the ventilation system utilised by Volvo Cars in their front row SPA seats. It includes an analytical comparison between the Volvo Cars' system, and that of its competitors. It extends to both, subjective and objective methods, for the comparison between these systems. The scope of the thesis also concerns changes required to be made to the ductwork in order to enhance performance. Complimentary changes to other components in the system are also a part of this thesis. The thesis also involves working in collaboration with the supplier, for testing, and research and development for performance improvement as well as benchmarking.

Excluded from this project is the development of the fan. Any design, structural, control, or performance changes to the fan have not been part of this thesis. The component, has been used as-is for all intents and purposes. Along with the fan, no chemical changes have been executed on the material of the foam. The metal seat frame and any changes to it – except the tilt pan, have not been included in the thesis for structural reasons. The control of the entire system has been kept intact, and no changes have been made to the existing inputs. The materials comprising the upholstery have been kept intact without alterations.

New testing setups or methods were not developed for the thesis. Although discussed briefly, no major changes to the existing ventilation system were involved in this thesis. Only available vehicles from Volvo Cars were used for benchmarking. No external customers were involved with the development efforts of the system, and the trials were conducted with internal employees.

1.4. Outline of the Thesis

Based on suggestive guidelines published by Chalmers University of Technology, this report is divided into sections similar to an IMRaD format. Since a part of the thesis was a competitor analysis, and part of it was to improve the existing system, the chapter describing the results has been divided accordingly, for easy comprehension. The chapters, in order of reading should be as follows:

- Introduction – *brief background, problem description, purpose, and scope of the thesis.*
- Overview – *introduction to stakeholders.*
- Theory – *explanation of theoretical concepts, principles of operation, and test procedures.*
- Methodology – *elaborate account of how the activities were carried out through the thesis.*
- Results – *three-part division of findings from the outcomes of planned activities.*
- Discussion – *critical review of the findings, test methods, and uncertainties.*
- Conclusion and recommendations – *closing remarks, suggestions based on the findings, and future courses of action.*

2. Overview

The word *Volvo*, in Latin, means "I roll". It was initially incorporated in 1915, as a subsidiary of Swedish ball bearing giant, AB SKF. But it was almost a decade later that the name was used in its current context, when two Swedes from the company decided to create a Swedish automobile. Assar Gabrielsson and Gustaf Larson were those two founders. And with the rollout of their first car ÖV 4, affectionately known as *Jakob*, Volvo commenced operations on April 14, 1927. *(volvocars.com, 2016; volvogroup.com, 2016)*

Since then, the Gothenburg-based company has grown to become an international entity, with presence in major markets all over the world. Not only are the cars sold in multiple countries, but manufacturing and assembly takes place in Sweden, Belgium, Malaysia, and China. A brand new manufacturing plant is scheduled to be opened in the USA by 2018. *(volvocars.com, 2016)*

Through the years, Volvo has been highly innovative in the automotive sector. But when Nils Bohlin, an engineer at Volvo, developed the three-point seatbelt as we know it today, the company name became synonymous with safety. In use since 1963 in a production vehicle, Volvo waived patent rights for this innovations for benefit all over the world. Arguably the most important safety feature in a modern car, the innovation is attributed with saving an estimate of more than a million lives. Since then, they have been pioneers in the field for nearly half a century. *(media.volvocars.com, 2016; volvocars.com, 2016)*

But in 1999, the cars division was broken off from the AB Volvo, and was acquired by Ford Motor Company. The company continued to be a part of Ford's Premier Automotive Group for eleven years, and was pushed up in higher market segment by the new parent company in this time. But the financial crisis in the latter half of 2000's shook Ford Motor Company, the result of which was sale of Volvo for the second time. It was subsequently bought by Zhejiang Geely Holding of China in 2010, and has been under their ownership since. The company continues to operate from Scandinavian shores. (*volvocars.com, 2016)*

With a new owner, Volvo set sight on transforming both, its identity and its line-up. In the most recent past, it took advantage of its new owners' freedom and fortunes, and invested heavily in new technologies. The result of these unhindered efforts can been seen in their first offering since the changed ownership in the new XC90, pictured in Figure 1. Launched in 2014, the second generation of their mid-sized premium SUV won many accolades and awards. The interiors of the new SUV were highly celebrated across global media. In the short timespan that it has been on the market, it boosted sales for Volvo to an 88-year high. *(media.volvocars.com, 2016)*

Figure 1: (L-R) XC90; Interior of XC90.

The success of the XC90 has been followed by the unveiling of the brand-new S90 sedan, and V90 station wagon. These premium segment vehicles have followed suite in impressing the global media with their design, drivability, on-board tech, and safety features. Pictured below in Figure 2, the sedan and the estate not only borrow styling cues from the SUV, but the structural underpinnings as well.

Figure 2: (L-R) V90; S90.

Scalable Product Architecture

> "This *product platform* has been defined (…) as a set of subsystems and interfaces that form a common structure from which a stream of related products can be developed and produced efficiently." *(Halman, Hofer, and Van Vuuren, 2003)*

A product platform is a collection of common elements across multiple products. These products may be offered in the same or different market segments. The platform forms the 'core' of these distinct products. A platform can also be linked to individual products in certain cases. It typically is defined by an architecture, its interfaces, and the rules that govern the design and interactions between these modules. *(Halman, Hofer, and Van Vuuren, 2003)*

> "*Global platform* is the core standardized offering of a globally rolled-out product. (…) The goal is to have the application different locales without modifying the source code." *(Halman, Hofer, and Van Vuuren, 2003)*

From the perspective of automobiles, a global platform can be said to be a mix of two types of modules. First, a set of constant type of modules that stay common to all products rolled out all over the world, irrespective of the markets. Second, a set of modules that are country-specific. These modules are functionally similar, but are changed to conform to various regulations in different markets. They can also be present or absent based on market needs, brand identity, pricing, and services offered. *(Halman, Hofer, and Van Vuuren, 2003)*

> "The function of the product is what it does as opposed to what the physical characteristics of the product are." *(Ulrich, 1995)*

> "In informal terms, the architecture of the product is the scheme by which the function of the product is allocated to physical components. I define product architecture more precisely as: (1) the arrangement of *functional elements*; (2) the mapping from *functional elements* to *physical components*; (3) the specification of the *interfaces* among interacting physical components." *(Ulrich, 1995)*

The architecture is the basis of working of the product platform. It connects the various components, defines what each of them does, and plots how it is done. It provides a product platform with its characteristic flexibility. Changes to the product itself can be easily facilitated with the help of a sound architecture. *(Ulrich, 1995)*

An architecture can either be integral, where each function is mapped to one or a few physical components, or modular, where there exists a one-to-one mapping of functions to physical components *(Stone, Wood, and Crawford, 2000)*. Both these approaches to devising a product architecture have their own benefits and detriments. But evaluating and analysing customer needs, and coming up with a sound architecture is an important aspect in platform development *(Stone, Wood, and Crawford, 2000).*

Developed over a time of almost four years, the Scalable Product Architecture was introduced by Volvo towards the end of 2013. The highly flexible, global platform has been developed in-house by Volvo. It has been one of the key facets of Volvo's $11 billion transformation process since its changed ownership. This new platform has provided Volvo with the opportunity to exploit economies of scale, while offering distinct models in different market segments. *(media.volvocars.com, 2016)*

The new platform is highly advanced, and provides huge improvements over its predecessor, and unique characteristics for the future line-up. It is built to be flexible, and is optimised for both conventional and hybrid cars. The only inflexible region of this architecture is the distance between the front axle, roughly the centre of the front wheels, and the beginning of the dashboard. This distance has been demarcated in the first image of the following Figure 3 cluster with yellow lines. Except for this axle-to-dashboard distance, all other dimensions are changeable. Thus, the new product architecture gives Volvo the freedom to stretch or shorten, or widen or narrow its vehicle line-up without many restrictions.

Figure 3: (Clockwise from Top-Left) Scalable Product Architecture; T8 Twin Engine on SPA; T8 Twin Engine Electric AWD; XC90 AWD.

The platform standardizes the engine and related powertrain components. But additionally, it provides the option of including an electric propulsion system in conjunction with a conventional fossil fuel one. As pictured in the image cluster of Figure 3, green-coloured elements form a conventional drive system. It can also be seen that the addition of the blue-coloured electric system is easily applicable. No major changes need be made to the architecture.

The unique characteristic of this new architecture is that it extends the concept of modularity to the electrical components as well. The four major domains of the electrical systems in an SPA car – vehicle dynamics, safety, car body, and infotainment, are all connected. Yet, the architecture has been designed in a way to ease the adoption of new advancements in these fields.

The Scalable Platform Architecture made its market debut with the second generation XC90 in 2014. This model was followed by the introduction of the S90 sedan, and more recently, the V90 station wagon. Both these cars are based on the new platform. Along with the 90 cluster vehicles, viz. XC/S/V90, the platform will also form the basis for upcoming offerings from Volvo in the premium and luxury segments. The upcoming 60 cluster refreshment will be based on this same platform, borrowing heavily from the high-end 90 cluster cars.

3. Abbreviations

AWD – All Wheel Drive

CFD – Computational Fluid Dynamics

DOE – Design of Experiment

HVAC – Heating, Ventilation, and Air Condition

IMRaD – Introduction, Method, Research, and Discussion

OEM – Original Equipment Manufacturer

SPA – Scalable Platform Architecture

TED – Thermoelectric Device

4. Theory

The theory of seat ventilation can be split into two parts. In one, the ventilated air is either actively cooled and in the other it is passively transported through the seat. The active cooling is mostly done with TEDs owing to their small size and strong cooling power. Most articles about seat ventilation investigate on their use, while the reality looks slightly different. Most OEMs used to implement active cooling systems, but are now deriving to a passive system with a fan. The passive systems again have two major subprinciples, which is either pushing or pulling air through the seat. Within these principles, neither is favoured over the other based on airflow. Almost half of the OEMs use a push system, while the rest use a pull system. *(Leu, 2016)*

Seat ventilation is a complex system. It has many parameters that can change the thermal comfort, and it is subjective in nature. As an example, one of the first ventilated seats was an experiment in 1993 before a Swedish OEM made it commercial. The experiment was to test two different covers for the seat to prove that they play substantial role in providing thermal comfort *(Lund Madsen, 1994)*. Another experiment with different covers was done with a Rami-blend foam placed inside a car seat. To measure the performance of the ventilation, four different test series were conducted. They consisted of simulations, manikin lab test, lab and road tests with human subjects. The test came to a conclusion that ventilation was especially useful for long term drives and that the skin wetness played a more significant role than the ambient temperature. Even before that experiment, Cengiz & Babalık mention the importance of the real road conditions, including traffic *(Cengiz & Babalık, 2007; 2009)*.

The use of ventilated seats has remained controversial *(Thomas, 2013)*. The main purpose is to cool down seats with perforated leather covers. It could also be used as a safety feature for people sitting in a parked car, where the focus is more towards children left inside a car. An experiment with two TEDs has been conducted on a child seat *(Vinoth & Prema, 2014)*. Compared with an HVAC system, seat ventilation is able to operate in a much more energy efficient manner. On the other hand, it can also support the HVAC by cooling the backside of the body *(Ghosh et al., 2012)*. Another application was also experimented, where researchers built ventilation in an office chair to increase thermal comfort *(Watanabe, Shimomura, & Miyazaki, 2009).*

Rutkowski *(2010)* was the first one who did research to quantify seat ventilation as a system. Different factors were introduced to mathematically model a ventilated seat. Also, the energy dissipation from a human body was discussed. The greatest energy dissipation came from lower back and under thighs, and the buttocks had the least energy dissipation.

For active ventilated car seats, an important factor is the ambient temperature, and the corresponding range that fit it best. An experiment found out that if the ambient temperature is 26°C, about 99% of the test subjects were satisfied with a range of +/- 3°C. Another interesting fact is that energy could be saved if the ventilation had an increase in the air speed *(Chludzińska & Bogdan, 2015)*. It is also vital to consider that the body should not be undercooled. An optimal temperature for the seat should be between 34°C to 36°C *(Rutkowski, 2010).*

4.1. Thermal comfort

The main goal of the seat ventilation is to improve thermal comfort. It is incredibly difficult to quantify, and many factors like air temperature, humidity, clothing insulation, and metabolic rate influence the overall comfort. Considering the interior of a car, the window size and the physiological differences are significant to the feeling of thermal comfort *(Walgama et al., 2006)*. When air is circulated to cool down a person, it can be perceived as pleasant in the beginning. But, after the person is cooled down, it can be perceived as an unwanted draft. The most sensitive area is the lower back, where a strong cooling can cause cramps *(Kagerin, 2016)*. Another critical aspect is that spot cooling can cause thermal discomfort *(Walgama et al., 2006)*.

4.2. Spacer layouts

To ensure air flow through the foam, a spacer material is used which consists of polyester fibres and knitted textile. The idea is to have a stiff material that does not compress when force is applied. Yet, it ensures low resistance to airflow. In the cushion foam, these materials are used on both sides. The occupant sits on the A-side, and the side where the fan is mounted i.e. B-side. Most OEMs use the spacer material only for the B-side. An alternative to A-side spacer material are grooves around the holes, which can support the direction of the air flow. In some cases, the A-side spacer material is completely removed without guiding the air in a specific way from the hole.

4.3. Passive Cooled System

Until now, the only way to move air in a commercial product was by using a fan, where the difference lay between radial and axial fans. The opinions of OEMs are split; either axial or radial fans are employed to push or pull air. According to the supplier, the trend is to use a radial fan for a pull system. The main advantage is that radial fans have better efficiency while axial fans are used in greater numbers to compensate for this disadvantage.

4.4. Active cooled System

Thermoelectric devices or Thermoelectric coolers utilize the Peltier effect between two materials to create a temperature gradient. One side of the TED is heated, while the other is cooled. The effect can be easily switched if the current changes direction. This is especially interesting for car seats because the heating and cooling can be implemented using just one principle. Another big advantage is that they are very small in size. The main backdraft is that these systems are not very energy efficient to this day. *(Bell, 2016)*

Many experiments have been conducted on seats, utilizing TED-powered cooling systems. For example, a seat utilizing TEDs and a fan to push out the cooled air. For heating, a temperature of about 50°C, and for cooling, a temperature of about 10°C was achieved within 30 seconds after running the system *(Choi, Yun, & Whang, 2007)*. A different principle was used by Menon & Asada *(2006)* to use TEDs and shape memory alloys to control the distance of cooling surface. This removed the need of a fan, and was a silent solution. But it did not transport humidity away. Another advantage was that the massage function could be built in as well.

As an important aspect of today's product development, simulations are significant tools for analysing and optimizing a system. Gao *(2005)* did simulations of parts of a human body. They came to the conclusion that it was impossible to simulate a human body, due its complexity. This implied, simulations have to be done without a model of the human body. Another aspect of modelling seat ventilation was researched in combination with HVAC systems. The complexity increased because the clothing insulation had to be taken into account *(Ghosh et al., 2012)*.

Using TEDs also has a few disadvantages, especially high costs, and reduced design freedom. The limitations to design arise because the length of the ducts have to be as short as possible. The high costs are not possible to be avoided since a TED needs a cooling unit that is similar to fan in a passive system. Half of the air flow is used to cool down the heating side and goes as exhaust under the seat, while the remaining flow can be actively used for the cooling system itself. *(Leu, 2016)*

4.5. Duct Design

To optimize the airflow through the system, a significant factor is to understand the design of the ductwork. Even though the B-side is not strictly pipes, it can be assumed to be so, for engineering purposes. Crucial parts are the outlets, inlets and areas where the flow separates. Most literature focuses on fans with as pushing system. Throughout the system, it is not relevant if the fluid is pushed or pulled through the pipe. *(Cory, 2005)*

Included in performance enhancements, one factor is to reduce the noise. This increases the performance without compromising airflow. The noise is not the most essential part for this project, but it cannot be increased. If the noise reaches a lower level the comfort increases. An essential factor is that the noise is directly coupled with duct design. This means that a good duct can improve both airflow, and reduce the noise. *(Tsai, 1982)*

4.6. Patents

The first patent for seat ventilation that went into production was filed in 1997. The system utilized two fans, one for the backrest and the other for the cushion, which can be seen in Figure 4. The circulation of the airflow was done with a diffuser on the B-side that had straight holes through the foam *(Lear Corporation, 1999)*. OEMs from Japan and Germany use this principle even today.

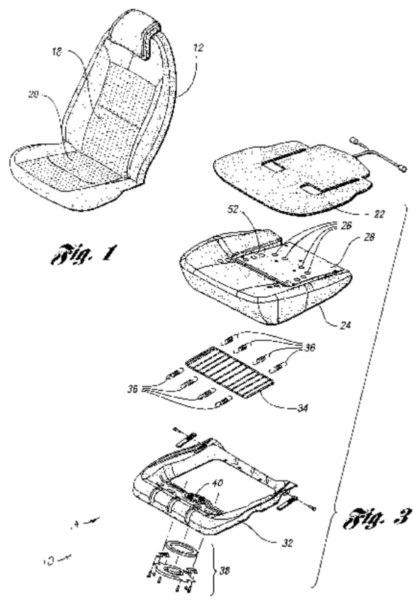


Figure 4: Patent of the first ventilated seat, source: Lear corp.

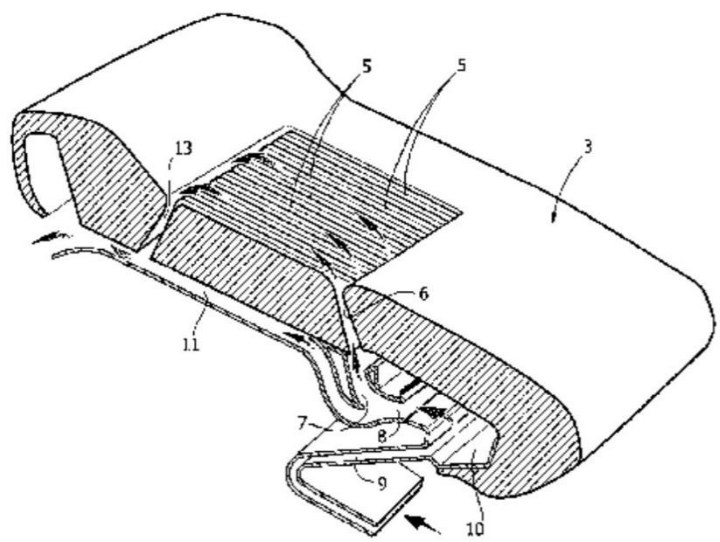
A German OEM has gone even further with the A-side spacer material with air bridges. The idea is that the upholstery is connected to the spacer material and will not be compressed with the attachment of hog rings. This allows the spacer material to completely extend over the seating area, without compromising the diffusion of the air flow. *(Bayrische Motoren Werke Aktiengesellschaft, 2011)*

The spacer material is an inexpensive solution to construct ducts on both sides of the foam. As an alternative, a supplier in the automotive industry holds a patent for an air box. This box serves as a duct and is moulded in the foam. The weight of the occupant does not compress this duct, facilitating air flow through the foam. This is especially interesting for the cushion area where the load is greater than on the backrest. The patent also ensures an even distribution of the airflow. The same supplier also has a patent where the distribution of the air flow is entirely inside of the foam. When holes are blocked by the occupant, the flow will be around the occupant, always providing a draft. *(Johnson Controls Technology Company, 2002; 2004)*

To increase the performance of the duct on the A-side, an American automotive company came up with the idea to use a diffuser material with dedicated channels, leading to holes along their path. This principle can be compared with the inside of a catalyst *(IGB Automotive Ltd., 2015)*. Another technology, similar to a plastic bag, is a layered diffusor to embrace a sandwich structure. The main advantage is that this technology assures a simple assembly, but only one fan can be used *(Johnson Controls Technology Company, 2005).* Sealing the spacer material can also help gain better performance, with less losses in pressure and leakage. Witchie *(2006)* holds a patent to seal the spacer material with a plastic bag, including a blowing fan and heating matt. A similar principle is used by an American OEM.

From the control side, the supplier holds a patent for the seat ventilation, where the fan speed is reduced when the temperature reaches a defined low value. This technology is used in Volvo's Y20 system, but not in the SPA platform *(Kongsberg Automotive AB, 2005)*. A similar technology is used by a German OEM to avoid overcooling *(Daimler-Benz Aktiengesellschaft, 1999)*.

A more ambitious patent uses the Coandă Effect around the foam, and below the upholstery, to provide ventilation. Using this principle, air flow parameters like pressure and velocity can be easily changed to their optimal value *(C.R.F Societa Consortile per Azioni, 2009)*.



An OEM is investigating towards a hybrid system that uses both, pulling and then pushing. An American patent goes even further, by using a radial fan that pulls in a centred location and leads parts of the exhaust back to the occupant. Employing this technology, a high effectiveness can be achieved. The disadvantage is that the system blows heated air back to the occupant, resulting in a cooled area and in a warmed area. *(IGB Automotive Ltd., 2015)*

When considering a ventilated seat, one of the first thoughts would be connecting the seat with the HVAC system. This would increase the performance substantially without implementing new systems in the seat, or adding weight. This system could be even upgraded by using the seat as a duct for the HVAC, offering the possibility to have vents for the rear seats, in a similar location as the front seat *(Atieva Inc., 2015)*. To enhance the comfort of the occupants in the car, a patent has also been filed for a system with ventilated seatbelts *(The Regents of the University of California, 2015)*.

Considering actively cooled systems, TEDs can cause condensations along the air flow. To overcome this problem, a Korean OEM has developed a system that can drain the water out of the cushion *(Hyundai Motor Company, 2011)*. TEDs are useful to increase the step response of the seat ventilation. In the year 2000 it was a popular solution for many OEMs. Today, most of the manufacturers have turned to passive ventilation systems. A competitor of the supplier still uses TEDs in their solutions where a TED cools a fluid, which is circulated through the seat, allowing cold fluid to be transported towards the seat, take away heat from the occupant, and then flow away *(Gentherm Automotive Systems (China) Ltd., 2013)*.

4.7. Methods

Through the project many different methods were used. The focus was set to concept generations and optimization. Using a classical product development approach, the first step is to carry out a requirement specification. This was not done, due to small outline of the problem and Volvo defined their requirements for seats with ventilation already. The same problem emerged with the function mean tree and morphological matrices. For the project only two functions could be defined without any sub-function. To generate concepts, brainstorm was chosen as a suitable method.

4.7.1. Brainstorming

Concept generations is one of the most essential parts in product development. A popular method is Brainstorming. Where as many ideas as possible are created and documented. In this project a white board was used to document these ideas. During a brainstorming session no criticism is allowed. The more ideas that are generated to more it encourages people to share their ideas. Brainstorming sessions strive towards quantity instead of quality. Also infeasible ideas should be mentioned, where the other team member can "fix" the idea or solution. This helps to explore the limit of the solution space. Figure 5 gives an example of brainstorming using a white board. The example focuses on ideas how to improve the existing solution with new designs. *(Ulrich and Eppinger, 2012)*

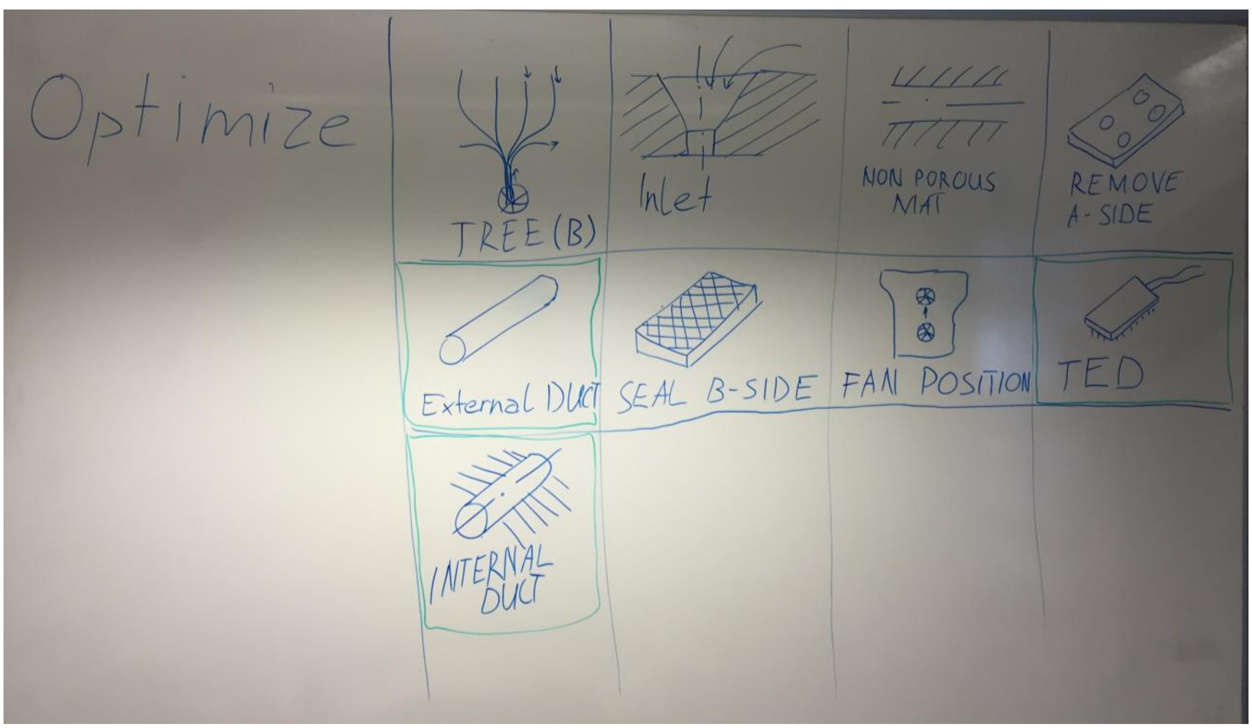


Figure 5: Brainstorming session about optimization principles

4.7.2. Prototyping

Prototyping is the next big step after concept generation. It can help screening out ideas. Prototyping is differentiated in physical and analytical prototypes. Analytical prototypes are usually cheaper and can explore a greater design space. Therefore, analytical prototypes are the predecessors of the physical prototypes. During this project both versions of prototyping were used. Physical prototypes are used to anticipate unexpected phenomenon, which cannot be detected with analytical ones. Prototypes reduce the risk for the final concept by decreasing the uncertainty. The amount of prototypes is determined by the knowledge about the technology and the cost and time spent for one. Thinking about this particular project for example. The prototypes can be fabricated with production foams without seat ventilation from Volvo. In addition, the prototyping needs only a long, sharp knife and can be completed within one to four hours. In this case Ullrich and Eppinger *(2012)* suggest to build many prototypes. Analytical prototyping includes CAE and CAD, where analysing the result of a prototype can be done swiftly. With these analytical prototypes also optimizations can be run through.

5. Methodology

The methodology implemented followed that of a classical product development project. Most work was carried out at Volvo, on- site. This decision was made due to the knowledge present at the offices, and the possibility to use the prototype workshop. Tests, and parts of prototyping involved in the project were carried out at the facilities of the supplier. This was justified by the equipment and machinery involved. To keep stakeholders informed, a presentations were held during Front Seats' weekly group meetings, once in a month.

5.1. Literature study

The literature study was kicked off by a discussion, outlining the components of a seat and the ventilation system. Trends & technology, principles & theory, methods of evaluation, and laws & standards formed subdivisions for the research. These subtopics gave an early direction to searches for relevant material. To access more specific literature, trends & technology was further dissected into material, vent, manufacturing, current solutions, and innovations. Principles & theory consisted of CFD, and HVAC. Acoustics was also mentioned but was not focused on.

The search began by picking a subtopic and investing time and efforts at finding literature. It consisted of scientific articles, technical papers, previous theses, patents, and textbooks. The purpose of the study was to get acquainted with the history and current trends of seat ventilation technology. Key word combinations like: car, thermal, seat, ventilation, ventilated, principle, thermodynamics, CFD, Computational Fluid Dynamics, HVAC, and air quality were used. To gather better results hard AND operators were used during the searches. The gathered electronic data was put together in a central location for ease of access. For this purpose, a cloud service associated with the school's email was chosen. A shared folder was created that would play a central role in sharing information, and facilitate all further searches and discussions.

The material was read through, and made short summaries of. These articles and papers were discussed after topic wise search ended. Based on relevance and contents, irrelevant search results were crossed out, and pointers were made for further reading. After having established a primary understanding of the subject, a second wave of searches was carried on. In this second search for additional literature, key words like: clothing insulation, heat and mass transfer, duct, fan, seat, car, comfort, cooling were used. The focus of this literature study was more on the missing details rather than to obtain knowledge about the system in general. It also served the purpose of giving better insight for idea generation in the later stages of the project. Laws & standards relating to the structure and safety of seats was not looked into as it lay outside the scope of the project.

Consultations with people from the Seat department were held to gain understanding about the systems in the SPA seats. Certain patents found during the searches were brought up in these discussions, and were compared to the actual system in place. An introductory seminar was held by the thesis supervisor at Volvo to introduce, and explain industry terminology regarding car seats. This seminar focused on seats in general and was not in particular about the ventilation system. Also in the initial weeks, a meeting was held with the supplier, to provide knowledge about the SPA ventilation system and its components. Ongoing advancements by the supplier were discussed along with current issues and problems. A pilot presentation was also handed out that summarised the seat ventilation systems provided by the supplier with justification.

5.2. Data gathering

Through the days of literature study & research, a plan was made for collecting data. The process was divided into two parts: disassembling an SPA seat, and conducting field tests of ventilated seats from competitors. It was decided to look into an SPA seat before the field tests to have an idea about what to look for.

The procedure was started with a simple subjective test on an SPA seat in the prototype lab at Volvo PVH. Different seating positions, and fan speeds were studied. To test the humidity reduction ability of the system, another test was conducted with a sweating test subject. The test subject was made to sprint from the entrance lobby at PVH and back, clocking about 10 minutes, in order to start sweating. The sweating subject sat down on the seat inside the lab with the seat ventilation system turned on, and set to maximum. An additional short test for humidity reduction was carried out after the sweating subject test. A tissue paper was soaked in water and placed on the seat to understand how quickly the dampness was reduced in a more objective manner. The paper, once placed on the seat, was let to dry off using the ventilation system at maximum and the time was taken.

When these simple and introductory tests were concluded, the entire seat, except the frame, was taken apart. A multitude of tools were used for the disassembly, which included wire clippers, pliers, screw drivers, spanners, and a ball-peen hammer. The main objective of the task was to see how the ventilation system and other relevant components were assembled. The location of the fans and ducts used for the ventilation system was studied. The foams were removed and studied. The performance of current foams was tested subjectively to get a feel of the system with and without the leather upholstery.

The decision to use the disassembled seat as a mule for future tests was taken. For the purpose of simplifying future installations and running changes, the seat was kept in a stripped state with parts relevant only to the ventilation system intact. To facilitate easy mounting and dismounting of the perforated leather upholstery, hog rings that were clipped while stripping the seat were not re-attached to the foams. Although provided with three seats initially to use for tests, only one was taken apart. The others were kept intact for the purpose of comparing future prototypes with a standard specimen.

The first stage of data gathering concluded with the teardown of an SPA seat. The next step, involving rival ventilated seats, was begun with a search for companies offering the option. Manufacturer websites were visited in order to look for models, variants or trim levels that offered a ventilated front seat. With the search limited to the presence of a seat ventilation system, a list was compiled of cars that were found out to have this particular feature. Complimentary to manufacturer websites, online forums, technical websites, and automobile magazines were scouted for information about ventilated seats.

Checking with dealerships or car rentals in the vicinity offering listed or similar makes and models, the list was shortened down. Following a finalised list of competitors to look into, it was planned to borrow/rent cars for evaluation and testing. The initial plan was to do two tests – short and subjective at a climate chamber at Volvo, and long and objective drive-by over a duration of two hours.

Visits were undertaken to dealerships in and around Gothenburg and Mölndal, Sweden. Even though a manufacturer provided the feature, a model with that specification was not stocked by many of the dealerships. Additionally, the staff at some of these dealerships was unaware of their models offering ventilated seats altogether. Of the number of enlisted models, only five models, present at dealerships, were found to be equipped with ventilated seats. None of the dealerships agreed to provide us high-end specimens for the two-day test plan. Hence, subjective evaluations were made at the dealership itself on the show car. The ventilation system was run and surveyed for a brief time, about 5-10 minutes. A short description was noted down for further reference. In response to advice from a couple of dealerships, the head offices for Sweden were approached. Contact was established with offices in Gothenburg, Stockholm, and Malmö, Sweden. Test specimens were unavailable from head offices as well. Considering the unavailability of competitor cars to evaluate, the initial two-test plans were scrapped.

The notes from the dealership visits were used to discuss the various systems on the market, and the subjective feeling caused by them. Through the notes, and brief experiences, areas of focus were identified for the systems. Of these five systems, a descending order of performance was formed. But due to constraints of specimen availability, it was temporarily decided to continue the benchmarking with only two systems – the old ventilation system from a Volvo V70 and the new ventilation system from a Volvo XC90. In due course, it was found that Volvo was in possession of a few competitor cars, used internally for general evaluation and benchmarking. The cars were part of the systems that were initially considered. It was decided to reserve these cars at later instances and run the benchmarking tests on them. With two competitors to compare the Volvo systems against, a plan was made to carry out three objective tests on each of the four systems at the supplier.

The tests spanned over three months, from March until May. The cars, one at a time and depending on their availability, were driven up to the supplier through this time period. The tests consisted of a noise test, power consumption test using a thermal manikin, and temperature mapping using a Mahöle mat. The temperature mapping was also accompanied with a subjective analysis. A human subject was placed on the mat, on the driver's seat. Throughout the duration of the test, the person was told to evaluate the performances subjectively. In order to be as consistent as possible, the same test subject was used for all four cars. A standard test procedure was defined for all the three tests in consultation with the supplier. At the end of the test procedures, the generated data consisting of power consumption graphs and thermal maps, was used as a basis for benchmarking the four systems.

5.3. Data analysis

The three tests yielded heaps of unprocessed data. Partly because of the location of analysis software, and existing expertise, the raw data was processed by team members at the supplier, and sent over to Gothenburg. To be efficient, the processing was done at the end of each test. Essential and required information was outlined before the initiation of the analysis. For example, the thermal manikin graphs for comparison were to consist of only the mean power consumption over the backrest and cushion, including extension.

Recorded data from the temperature mapping was in the form of a video. It recorded the gradual workings of the ventilation system, over the backrest and the entire stretch of the cushion and extension. To be able to analyse all the results side-by-side, and not spend as long as the video to draw conclusions, the supplier converted it into static images. Since the mapping was done on distinct occasions, a coherent and relevant temperature scale was set up by them. This step was taken in order to visualise same colours, across all recordings, corresponding to a particular temperature. A video frame was taken from points in time at substantial intervals, and a presentation was created to describe the progressing cool-down of the seats.

The noise test results were more straightforward than those from the other two. The levels were plotted on a bar graph, with the y-axis denoting noise levels in sones. The tests were carried out under 11 conditions, and the outcomes from every scenario were grouped together to gain perspective. Data processing was followed by comparing the results from all three tests. It was carefully laid out, and all the systems were analysed against the SPA system. Conclusions were drawn from these visual aids and subjective evaluations, and the benchmarking was finalised. The results, especially the temperature maps from the SPA seats, were studied further to help in coming up with concepts that focused on critical areas of the backrest and the cushion.

5.4. Concept generation and evaluation

Concept generation begun with a review of the findings from the literature review. The first brainstorming session was about various optimisation strategies that could be thought of prima facie. They were described on a whiteboard with rough sketches as aids. The sessions continued, coming up with more features for the seats. An ‘over the top’ features list was made. It consisted of features that were imagined and were thought to add novelty and value to an existing seat.

Seeing that the sub-system being dealt within the thesis was rather small and had a clear function. Since a morphological matrix is concerned with combining sub-function concepts, it was decided not to create one. This was motivated by system constraints and a lack of sub-functions. Through more brainstorming sessions, theoretical principles from fluid dynamics were discussed and sketched to affect a completely new ventilation system. These principles were later expanded to include inspirations from other sources like an air hockey table, aerofoil, and phase change material to name a few. All inspirations and their respective modifications for application in a car seat were described, sketched, and discussed.

After a brief stint of brainstorming sessions, a first screening was made for the primary strategies and ideas generated so far. Ambitious or progressive ideas were screened out owing to complexities in implementing them in the given timespan or unproven advantages. The screening resulted in mostly quick fix changes, but also included a couple of technologies requiring radical changes. The surviving ideas were then re-enlisted, and were considered in-depth, one at a time. Further concept generation was carried out on the enlisted concepts in an ascending order of number of changes required. The concepts that required less than or equal to two changes to the complete system were discussed, followed by consultations with the supervisor, and team members at Volvo and the supplier. Along with discussions, existing components were modified to assess the effectiveness of the concept. These quick fix change suggestions were either retained or discarded based on a subjective evaluation and flow measurements.

Next, solutions that would generate a multitude of secondary concepts were taken up for consideration. For the purpose of simplicity, the seat was split into three parts: backrest, cushion, and extension.

Meanwhile, contacts to alternative materials suppliers was provided by the supervisor. These suppliers, providing spacer fabric, were contacted for provision of test specimen for assessment. In response to the inquiry, only one supplier agreed to send their product for further use.

The second leg of idea generation begun with the backrest. A generic template, without exact measurements and excluding all of the features was created. The ideology behind this template was to provide creative freedom. With a wide variety in hole layouts, sizes, and fan positions, almost 20 concepts were generated. The cushion followed a similar procedure. A basic template was created, followed by sketching and changing of attributes of the holes and fan position. Upwards of 15 concepts were sketched for the cushion. The extension concepts, relatively less in number, were also sketched and discussed. Names were given to the sketches to ease recognition.

With generation of more than 35 different secondary concepts for the backrest and cushion, and a further handful for the extension, it was decided to filter and optimise the existing list. Due to vast design constraints, not many ideas were possible to implement. Since the number of concepts for ventilating the extension was less, a decision was made to pursue all of them. A table of pros and cons for all other secondary concepts was created. The pros and cons were enumerated based on findings from previous research, as well as realistic considerations. A screening was undertaken, and a decision on each concept was made. Based on their pros and cons, these secondary concepts were either kept for further development or deleted. Furthermore, a few similar secondary concepts were decided to be combined to yield new and improved tertiary concepts. About 10 tertiary concepts were derived, a few novel, rest a combination of old.

The next, and critical, screening was undertaken by considering all the features on the foam templates. This lead to a substantial reduction in the number of secondary and tertiary concepts. Backrest concepts that interfered with features on the foam, especially the massage bladder layout, were filtered out. A similar screening was made with cushion concepts. The layouts that demanded changes in upholstery were screened out. A decision was made to test these filtered concepts on standard foams. To facilitate the mock up, 10 each of the backrest and cushion foams were acquired from Volvo. To avoid interference during fabrication and proving, blanks – foams without any holes or features, were ordered.

Evaluation process of shortlisted concepts and layouts began with measurements of flow velocities across a standard configuration foam. An airflow meter was borrowed from the team members at the climate department for the purpose. The measurements were made with the sensor held over the mouth of the duct, on the A-side of the foams, at close proximity. This measurement was set as a baseline for quick evaluation of concept mock-ups. The aim was also to have a velocity distribution as evenly spread as possible across the conceptual layouts.

The fabrication of the blanks was initiated with unwrapping of two backrests, and precisely marking the feature outlines before drawing the configuration. Two conceptual configurations were chosen, and were decided to be transferred onto the blanks. Due to lack of complex machining tools for working on the foams, different types of cutting blades and knives were used. An attempt was also made to retrofit a power drill for making holes in the foam. But the improvisation proved to be futile. Long knives were chosen as the tool of choice for their ability to pierce through the entire depth of foam in one go. In addition to the foams, appropriate adjustments were made to the tilt pan, and the plastic plate on the back. They were done to accommodate changed ducts in few of the configurations.

The downside of using knives or blades was inaccuracy in cut holes. At a later stage, a simple fix was found to this problem. 30 cm long PVC pipes of desired diameters, with one end having a sharpened circumference, were used to make accurate and high quality holes. The pipes were rotated vertically, with the sharpened mouth cutting down through the foam.

These first concept foams were set up on the stripped mule, and the ventilation system was powered up for taking airflow measurements. The first run was done without the leather upholstery to gauge the effectiveness of the new changes and modifications. The measurements were noted down on the foams themselves. The foams were then covered in upholstery, and the flow meter was used again to get a number on the flow velocities across the seat surface. Both runs were accompanied with short subjective tests. A quick evaluation was made for both fabricated foams by comparing them with the standard specimen.

With better acquaintance of fabrication tools and techniques, more complex concepts were cut into shape. Impromptu changes were made to these concepts, after studying the quick tests. They were assessed for performance changes with these tweaks. The concepts that showed promise in the quick tests were then taken to the supplier, and were tested using a thermal manikin. The resulting graph was analysed in order to gain more insight into the behaviour of new configurations. After an exhaustive conceptualisation and testing, two favoured backrests were selected to be used for the final prototyping phase.

The same ordeal was repeated by fabricating cushions, followed by quick sampling with and without the upholstery. But, subjective and airflow measurements failed to provide enough data for making any decisions. Hence, all the concepts were taken to supplier for further analysis. Although already halfway into concept evaluation phase, the results for the cushions were not consistent with the expectations. Due to this discrepancy, a decision was made to generate new concepts for the cushion. As a result of insufficient experience, a CFD analysis had not been made so far in the project. Acquiring knowledge for such an analysis was a challenging task. But to help with it, a course in CFD at Chalmers was taken up. It was, thus, decided to employ the recent coursework knowledge, and try and evaluate the conceptual layouts, and optimise them.

Due to the level of complexity, the CFD analysis was begun with a simplified model. The idea was to start as simple as possible and then work up the complexity of the model. To simplify the analysis, a low end calculation software was used. Starting with a 2D analysis to understand the simulation principle, the analysis was later extended to a 3D model. Where 2D calculations had less problems in general, the 3D analysis encountered convergence problems most of the time. All analyses were made only for airflow without convection. An idea about the pressure of the airflow and the velocity was given by these calculations, but not the actual cooling capacity. Conclusion of the simulation shed new light on a fact that had been previously overlooked.

In order to further confirm the theory, a single concept was created, and then put to test. The fabrication was also made more precise with the help of pneumatically-powered, hand milling machine. This allowed for more accurate generation of spacer impressions on the foam. A quick assessment showed significant improvements. A couple more concepts were generated, incorporating minor to moderate tweaks to the CFD-optimised concept. All these concepts were then tested using the thermal manikin, and the results were compared against the previous.

The newly enhanced concepts were then assessed, and two were selected for use in the final prototypes based on the results from the manikin tests. The first prototype was with the highest expected performance and the other with the least amount of changes. Extensions were taken from other available test seats for concept evaluation. Given the limited number of concepts to be evaluated, a direct analysis was done with the extension mules. They were paired with the newly optimised cushions to generate overall ratings for the entire cushion area. After this scrutiny, and similar to the backrest and cushion, two extension concepts were carried forward.

5.5. Prototype

Two each of the backrest, cushion, and extension that were carried through from the previous proving stages were assembled onto seat frames. Two seat frames were reduced to bare essentials. All fitments, except for the electrical harness, were removed. The foams and the upholstery was fastened with hog rings for a near-perfect mock-up of a production seat. In parallel to this, a short study was initiated on request of the supervisor. The study was to assess implications of ductwork changes alone, and have absolutely no changes to any and all other components. This addition increased the tally of prototypes to three. The authors then drove to the supplier with an XC90 for final objective analysis of all the prototypes.

The test mules were powered up, one at a time, and thermal manikin test was done on them. All three prototypes were tested on a test rig, inside a temperature controlled room. This was done due to technical restrictions on replacing a production seat from a production XC90 with one of the authors' prototypes. It was advised that such a replacement would lead to the car giving warnings and alerts, and not functioning as desired.

The thermal manikin results were assessed, and the prototype with the best score was decided to be tested with mahöle mat. In addition to this choice, the prototype with the least modifications was also tested. This step was taken to show the Seats department, the implications of minimal changes. The two prototypes were then placed inside a climate chamber, one at a time, with the mats laid over them.

The chamber was heated up, and the seat was soaked for an hour. A human subject was used for the temperature mapping. The subject was also soaked for 5 minutes, before being seated on the chair, inside the chamber. The test was carried on for 30 minutes. The results were recorded, and later on analysed for the effectiveness of the prototypes' cooling performance.

5.6. Test procedures

Throughout the thesis, the testing of concepts and prototypes was dominated by four main tests – three objective, and one subjective. The objective tests were modified from the supplier's standard procedure to suit the needs of the authors. This was done to simulate real-world conditions as closely and as possible. All objective tests were joint efforts, carried out at the supplier's technical centre, and using their testing equipment. The subjective test was undertaken in the clinic using Volvo rating scale, in a climate chamber at Volvo. The engine was kept at idle through the duration of all tests, with the AC turned ON. It was set to 23°C on Auto speed.

5.6.1. Noise test

This test was the shortest test to be carried out on the ventilation system. It was aimed at measuring the level of noise created by the system. The test was split in two parts. Part one was running the ventilation system alone, whereas the second part was in conjunction with the central HVAC. This test was carried out using microphones placed around the test subject's head. A data logger was used to record the generated information. Both these devices were connected to a laptop, which had a sound analysis software installed on it.

For the tests, eleven different settings were enlisted in Table 1. Levels of generated noise were measured for each of them. The test snippets were set to be recorded for 15 seconds. The car engine was kept on idle during all tests for uniformity of conditions. It was justified by the fact that some test vehicles had operational ventilation systems only with the engine running. The doors were kept closed, and windows rolled up.

Two people were present inside the vehicle during testing. The test person was positioned on the driver's seat for 7 tests. The remaining 4 tests were carried out with the test person positioned on the rear seat behind the driver's. The second person was the operator, and recorded the microphone sounds on every instance.

Table 1: Test procedures

Test Person Position	***Ventilation Level***	***AC Level***
DRIVER	0	OFF
DRIVER	1	OFF
DRIVER	2	OFF
DRIVER	3	OFF
DRIVER	0	AUTO
DRIVER	0	MAX
DRIVER	3	MAX
REAR	0	OFF
REAR	1	OFF
REAR	2	OFF
REAR	3	OFF

5.6.2. Thermal Manikin test

This test was used to analyse the effectiveness of various concepts and prototypes, by measuring the power consumption of a thermal manikin. The results of this test were numbers indicating energy flux, in W/m^2, for the manikin to stay at 38°C against the cooling effect from the ventilation system.

The thermal manikin was an L-shaped apparatus, made to mimic a human torso in sitting posture. It consisted of heating elements and 36 thermal sensors laid out on the upper and lower part of the manikin.

These elements and sensors were covered by light padding and a denim cloth. The manikin was connected to a power source, a data logger, and a laptop. A live readout, recording, and analysis of the setup was made through a software, installed on the laptop.

The manikin was conditioned, i.e. the heating elements were brought up to 38°C, before the test was begun. An observation was made before putting the manikin in place, on the driver's seat for carrying out the test. Once placed on the seat, under test conditions, it was let to reach an idle readout before starting the ventilation system.

The manikin was then allowed to acclimatise to this setting. According to the procedure from the supplier, the manikin was let to idle for 3 minutes during the initial logging. At three minutes, the seat ventilation was turned ON at LEVEL 3. It was kept at LEVEL 3 for five minutes. At eight minutes, the ventilation speed was stepped down to LEVEL 2. At 13 minutes, speed of the ventilation system was lowered further to LEVEL 1, the lowest setting, and maintained there for five more minutes. Finally, the ventilation was turned OFF at 18 minutes. The manikin was let idle again for three more minutes, and the test was concluded at 21 minutes from start. It was removed from the driver's seat after the conclusion of the test, and all vehicle systems were shut down.

The results being logged, and shown on the laptop, consisted of raw data from all sensors. This readout was studied to identify performance of the system in different areas. But since that incorporated individual signals from each of the (number of the sensors) sensors, it was a high amount of data for being used to benchmark different systems or concepts. To simplify assessment, the mean readings for both the backrest and the cushion were used.

5.6.3. Temperature Mapping

Temperature mapping test was used to visualise the temperature gradient resulting from working of the ventilation system using Mahöle mats. It was used to corroborate the findings from the thermal manikin test.

A Mahöle mat is a delicate grid of temperature sensors, arranged in a 16 × 16 layout. Each mat, thus, has 256 individual temperature sensors, that can be monitored independently. The mats were wired to a data logger, and a laptop for visualisation. The installed software was used to set a temperature scale and a corresponding colour scheme for the gradient visualisation, and record and analyse the generated information. One each of the mats was placed on the backrest, and cushion. To avoid misalignment, they were taped to the leather upholstery.

The test was set up by heating the insides of the car with a portable heater. The 'soaking' was done with all doors closed, and windows rolled up. The heating was continued for one hour before commencing the test. A steady temperature of 43°C was achieved with this soaking. Two desk fans were run inside the car to spread the heated air. Two Mahöle mats were used to see the uniformity of the heating over the seats before commencing the tests. The ventilation was used at LEVEL 3.

A test subject was used for this test to subjectively opine about the ventilation for each vehicle. The same subject was used for all tests carried out, including the clothing. The clothing consisted of a pair of denims, and a cotton shirt. The subject was not soaked prior to testing. The tests were carried out post lunch hour, with the start usually around 13h00.

The test duration was 30 minutes, with an additional 60 minutes for soaking of the car, before the test. At the end of soaking the vehicle interior, and shortly before the subject entered the vehicle, the heater and fans were turned off. The subject was made to enter as swiftly as possible and the doors were shut. The logging started with the subject sitting in the driver's seat. The engine was turned on by the subject after getting in the car, along with the AC and ventilation. The temperatures were recorded in a video spanning the entire duration of the test. The subject remained seated for the duration of the seat, without making major changes in posture. The test was concluded with turning off all vehicle system, in parallel with end of data logging.

For analysis of the mapping video, snapshots of frames at set intervals were taken. This was done to shorten the time needed for assessment. The coloured visualisations were then placed side-by-side to make comparisons at the given intervals, and to note the areas of interest.

6. Analysis of an SPA Seat

A standard ventilated SPA seat is covered with perforated leather upholstery. Not only do the perforations facilitate airflow for the ventilation system, they also provide the seat with a premium feel. Figure 6 shows an upholstery of a backrest. The leather upholstery is supported with a spacer material which is similar to the one used for channelling through A- or B-side of the foam. The main difference is that the knitting is denser and contains more fibres. It has an additional function as a diffuser, and also aids to soften the haptic of the seat. The upholstery is separated into two parts – the backrest, and the cushion including the extension. Both parts of the upholstery can be assembled and disassembled independently. Hog-rings are mainly used to attach the upholstery to the centre of the foam. When looking at the sides of the upholstery, polymer fasteners are used to attach it directly to the frame.

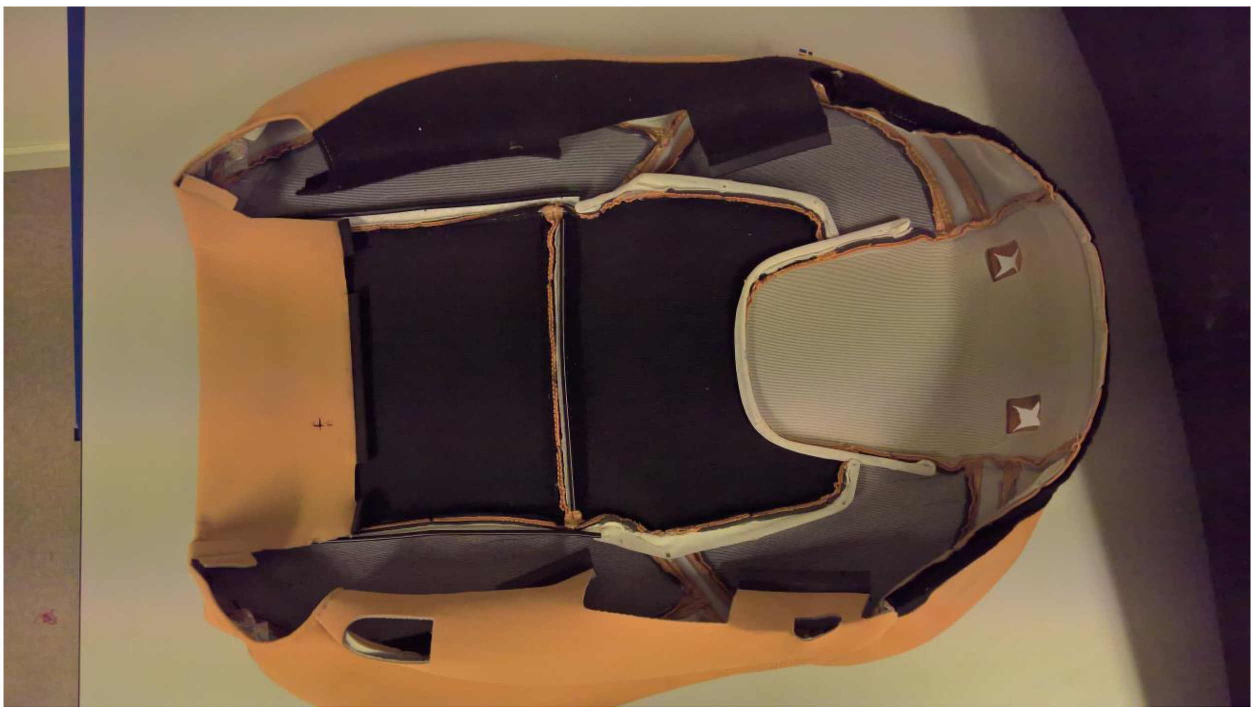


Figure 6: Backrest upholstery

The foams itself build the main part of the seat, which are unlike the upholstery. They are separated in three parts: the backrest, the cushion and the extension. An important thing is to know that there are several versions for backrest and cushion foams. Ventilated seats have channels inside the foam as discussed in chapter *6 Analysis of an SPA Seat*. Figure 7 shows a ventilated backrest from an SPA seat without massage function. The bigger cluster of holes is in the upper back area, while the lower back area has only four small holes. Another typical feature is grooves around various holes. These help to guide the flow in a desired direction and are also often used by Volvo's competitors. Figure 7 shows an SPA seat cushion, where the spacer material is clearly visible. These spacer materials are positioned where the occupant applies pressure while sitting on the cushion. If the seat has a heating feature, a mat is layered on top of the foams, eventually hindering the airflow.

Figure 7: Backrest of an SPA seat, Source: a2mac1

Figure 8: Ventilated cushion of an SPA seat, Source: a2mac1

When removing the foams from the frame, the only attachment is a rubber duct for seat ventilation. These two parts, like the upholstery, can be quickly assembled and disassembled without any special tools.

The frame contains the attachment for the foams. The backrest is mounted to a plastic plate, where valves for the bolsters and massage bladders are. The duct for the seat ventilation goes through the back plate and the lumbar support. Figure 9 shows the structure of the seat without the foams. The cushion fan is mounted to a tilt pan and moves with the pan when the seat is adjusted. Having a bellow structure for the rubber duct allows to adjust in every seating position.

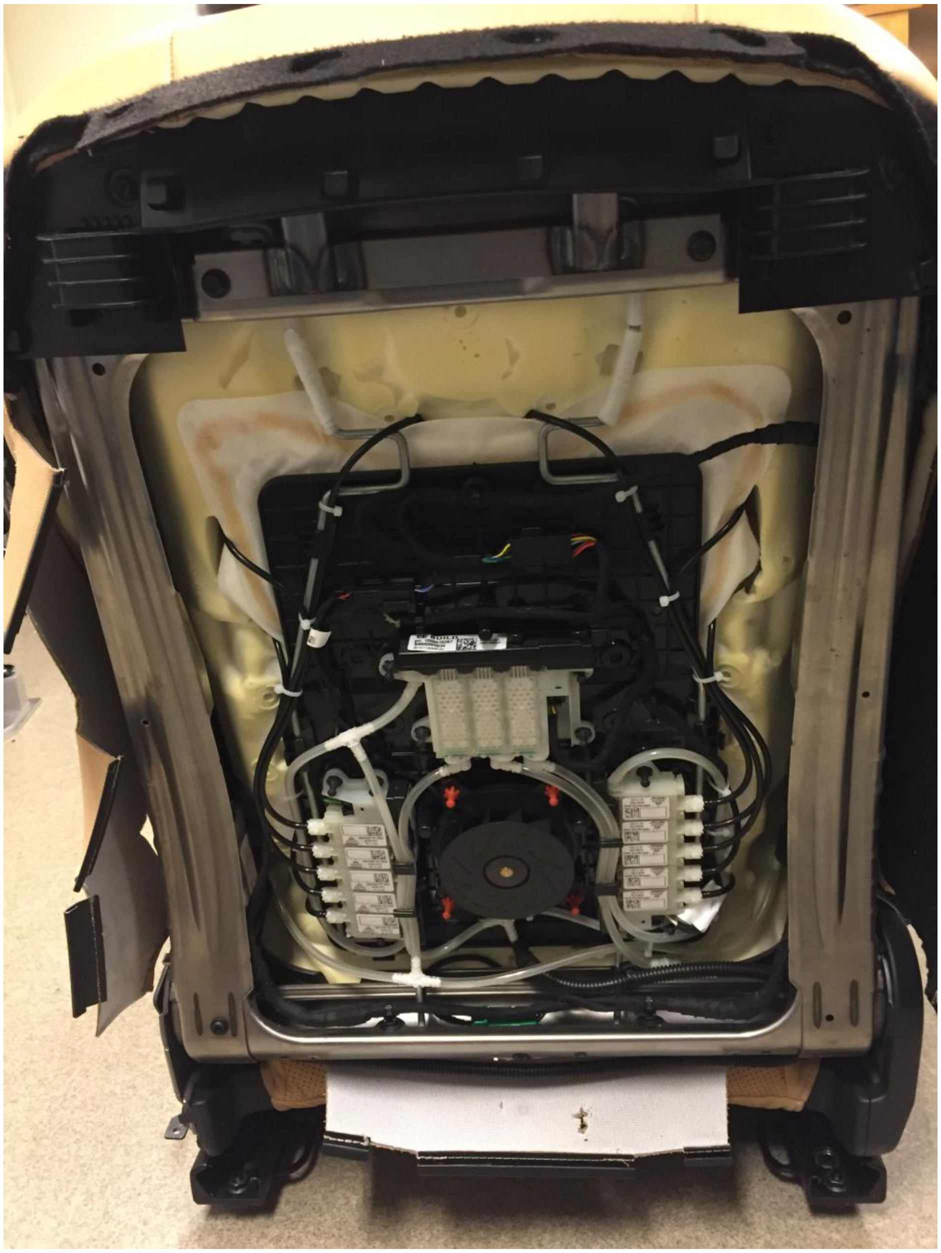


Figure 9: Packaging of the backrest

The ventilation system has a radial type fan, with two different casings for the backrest and the cushion. The backrest casing is a simple design with an open exhaust. The air is pulled through a rubber duct from the backrest. This duct ensures a connection even when the lumbar support is fully extended. Figure 10 shows an asymmetrical blade design for reduced noise. This design is not yet in production, even though all tests were carried out with the new fan. When looking at the current fan, the blades are symmetrically arranged. The cushion duct and casing are very different, which comes from packaging restrictions. The mounting system is similar to the backrest. The only difference is that the cushion has an additional mounting part. The duct on the other hand is more complex in shape, where the air flow has to do a 180° turn, and the inlet changes the shape from obround to circular.

Figure 10: SPA fan 1.20.1 of a backrest

One of the essential parts from the seat ventilation is the spacer material. It is two knitted textile layers connected with polyester fibres, creating a very light, stiff and air permeable material. There are several suppliers for this material, but only one supplies a majority of OEMs with the material.

7. Competitor analysis

The seat structure and working principles for all competitors are similar, and are discussed in the previous chapters. The main difference lies in the hole-layouts, fan positions, and diffuser materials. Most of this information is not available publicly, and has been used from a website where technicians reverse engineer the cars, and create a detailed account of all components. Most of the enlisted rival manufacturers have a car in the same market segment as Volvo's S90, and XC90. Table 2: Overview of Benchmarking gives an overview of the competitors analysed during this project.

Table 2: Overview of Benchmarking

Brand	Model year	principle	Fan type	Fan count	Size [mm]
Competitor 1	2005	Passive push	axial	6	80x80x27
Competitor 2	2010	Passive pull	radial	2	119x105x53
Competitor 3	2005	Passive push	axial	9	54x75x35
Competitor 4	2012	Passive push	radial	2	110x122x39
Competitor 5	2010	Active push	radial	2	240x250x46

7.1.1. Competitor 1

This competitor uses six axial fans with a pushing system similar to the competitor 3 as seen in Figure 11. The amount of fans is decreased, but the fan size is larger. In the backrest, two fans are placed inside the foam around the middle. In the cushion the remaining four fans are equally spread. It is the only OEM that uses this information as a selling point on their website. The benchmarking for this competitor can be found in the chapter *0*

Benchmarking Results.

Figure 11: Seat ventilation of Competitor 1. Source: Competitor 1

7.1.2. Competitor 2

The first competitor has a push system with two radial fans, similar to the ones supplied for the SPA seat. The fans have comparable performance in terms of volume flow and static pressure. Having the fan for the backrest at a low position, the inlets are distributed primarily in the upper back area. Figure 12 shows the position of the fan. The fan is mounted with a similar system, which includes a short rubber duct to avoid gaps when the lumbar support is fully extended or the massage function is used. The diffuser system is built up with a comparable spacer and wind breaker material, but includes a different diffuser material on the A-side, which improves the seating comfort. The cushion with the A-side diffuser can be seen in Figure 13.

Figure 12: Seat structure of Competitor 2, Source a2mac1

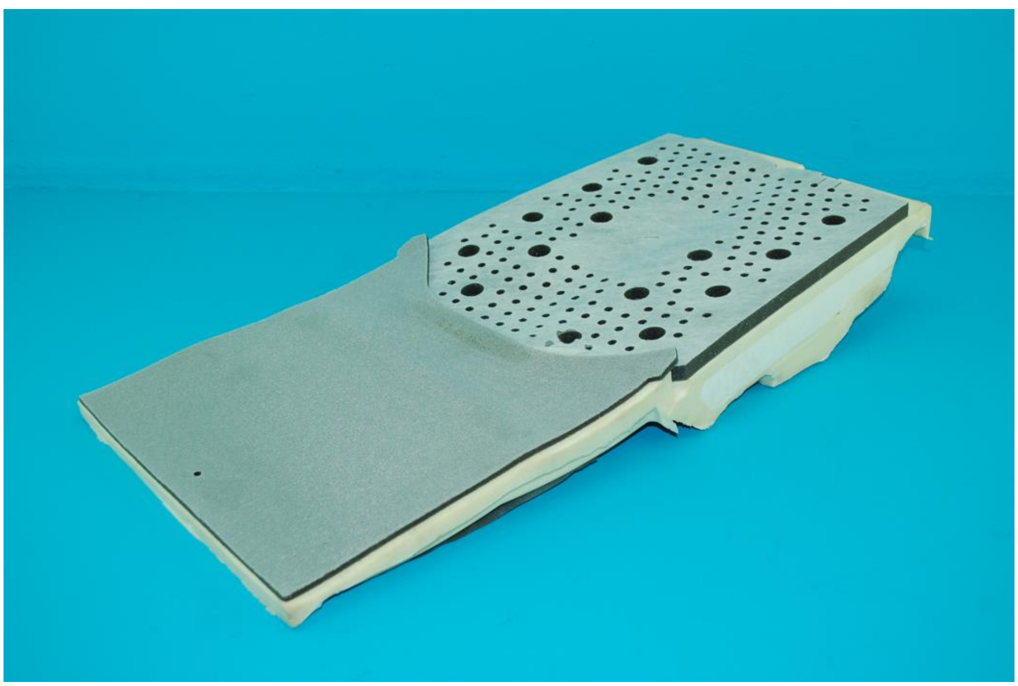


Figure 13: Cushion of Competitor 2, Source: a2mac1

The cushion fan is placed directly under the buttocks, and has an identical assembly as the backrest with the diffuser material. It has an extension that rolls under the seat, ensuring a simple and guaranteed ventilation over the extension, whereas Volvo cannot implement such a simple system. The spacer material and inlets are reduced in size the farther away they are from the outlet, defying the laws of simple pipe flow. Inlets placed at the cushion extension have a high flow resistance, and are not be able to pull air through the system. The benchmarking result can be found in chapter *0*

Benchmarking Results.

7.1.3. Competitor 3

Competitor 3 uses a push system with nine axial fans, with four fans in the backrest, four in the cushion and one in the cushion extension. In the backrest, the fans are spread out over the upper back and shoulder area. Figure 14 shows the fan placement of the backrest. This arrangement prevents unpleasant draft in the lower back area. The cushion fans are spread over the buttocks area, and the extension fan is placed centrally. This is one of the simplest designs for seat ventilation without a duct system or a diffuser, having the fan placed where the intended flow is. To ensure no harm is done to the upholstery, the fans have a metal casing that allows to carry high loads.

Figure 14: Fan layout of competitor 3, Source: a2mac1

7.1.4. Competitor 4

This competitor uses a push system with two radial fans, one for the backrest and the other for the cushion. The backrest has the fan in an asymmetric position and a duct guiding the air to the upper back area. The A-side contains grooves to ease the transport in a certain direction. The major cluster of holes is in the middle of the backrest, leaving the lower back completely unventilated. Figure 15 shows the seat with the backrest grooves. To holes are located close to the spine area, with grooves leading outwards.

Figure 15: Shows the seat of Competitor 4 with the grooves on the backrest, source: a2mac1

The cushion has an off-centred fan, which seems to be there for packaging reasons. A rubber duct directs the airflow to the desired area. The inlets of the cushion are clustered around the thigh area to give a great perception of the seat ventilation. Figure 16 shows a picture of cushion ventilation. To use a centrifugal fan, it is impossible to use a direct inlet for the cushion, due to the lack of space.

Figure 16: A seat from Competitor 4 Source: a2mac1

7.1.5. Competitor 5

One of the supplier's competitors holds a patent that utilizes TEDs in their systems. This patented system is used by competitor 5 in their seats. It has two radial fans that push air. Both the backrest and the cushion area have inlets in a central area, and a rather even seat surface. As the theory suggests the systems needs a diffuser on the A-side, which this competitor uses accordingly. Figure 17 shows the placement of the ventilation system from the competitor. The system takes up a large amount of space.

Figure 17: The seat frame of Competitor 5, where the arrow shows the placement of cooling system

8. Concepts and Ideas

The concepts mainly consisted of variations of the foam. The initial idea was to test each factor individually with a DOE and then define the optimal concept. Most of these ideas were simple modifications. Table 3 gives an overview of the initial DOE. Due the small amount of material and timely matter the DOE was not performed. Instead each factor was tested individually to see the difference from the original product. Each of these factors either had a significant impact or were negligible. All these ideas were based on a pull system with one fan, and were applicable on both the backrest and the cushion. All of these concepts were named for identification and are individually explained. The results of the performance can be found in chapter *9.2 Findings from Concepts and Prototyping*.

Table 3: Initial DOE

Factor	Status 1	Status 2
Inlet	Conic 60	Conic 30
A-side	Absent	Present
Fan position	Central	Standard
Holes	Configuration 1	Configuration 2
Spacer material	Coarse	Fine

The only idea factor that was not tested, was a conical inlet. Implementing conical inlets for the foam would have led to a complication in the manufacturing process. The tool would have blocked the moulded foam from being pressed out.

8.1. Backrests

The backrests were the first prototypes to be built. The prototypes were mostly to test out different hole configurations. With restrictions from the massage bladders, and an already good working backrest from the production, all concepts were very similar. The biggest difference was made when the fan was moved in a more central position.

8.1.1. Heinz

Heinz was a concept which involved a different configuration. The idea was to move the focus upwards, around the upper back. An additional change was to decrease the diffuser on the B-side, to reduce turbulence and pressure losses. Figure 18 shows the first version of the concept, with a slim channel of diffuser around the inlets of the lower back. While testing the concept subjectively, the performance was weak, especially where the diffuser was slim. To fix this weakness, the diffuser size was increased. This lead to a better performance and was then tested with the manikin at the supplier.

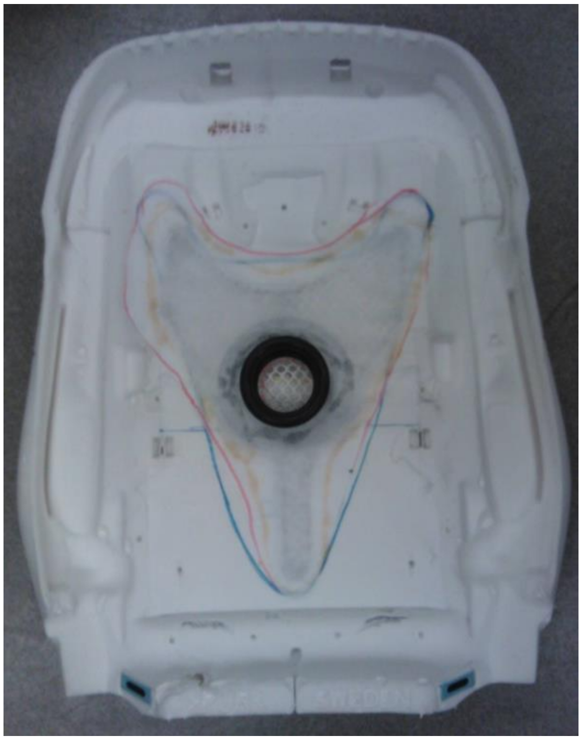


Figure 18: Backrest Concept Heinz

8.1.2. Hans

Concept Hans was an experiment to see how much of a performance increase a second fan could contribute. For this concept a standard ventilated foam was used and was left unchanged. Figure 19 shows the changed backrest which was created for concept Hans and then later used for all concepts that included a different fan position.

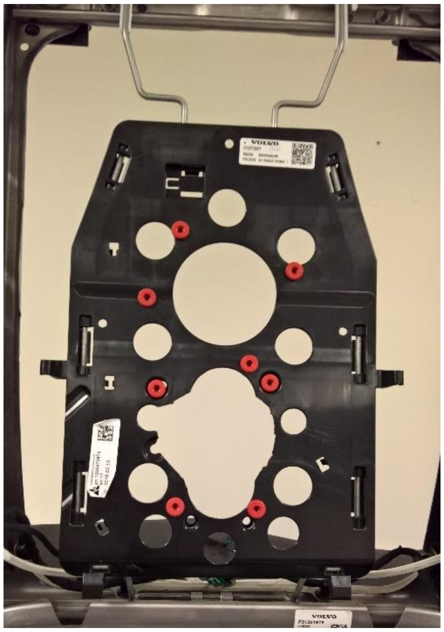


Figure 19: Prototype back plate with two intakes

8.1.3. Arnold

Arnold was a combined concept, where the hole configuration and the fan position was changed. The hole layout was similar to the one from concept Heinz. The fan position was moved upwards, where the valves for the lumbar support are. If this change was going to be used, the positions for the lumbar support valves and the ventilation fan has to be swapped. The redesign would also involve the pneumatic bags of the lumbar support system, because the rubber duct interferes with it. That change will be more complex since it is not possible to move it. The concept was the best performing one subjectively and therefore two variations were created: Concept Ferdinand and concept Arnold with spacer. Arnold with spacer has a diffuser on the A-side of the foam along the spine, which can be seen in Figure 20.

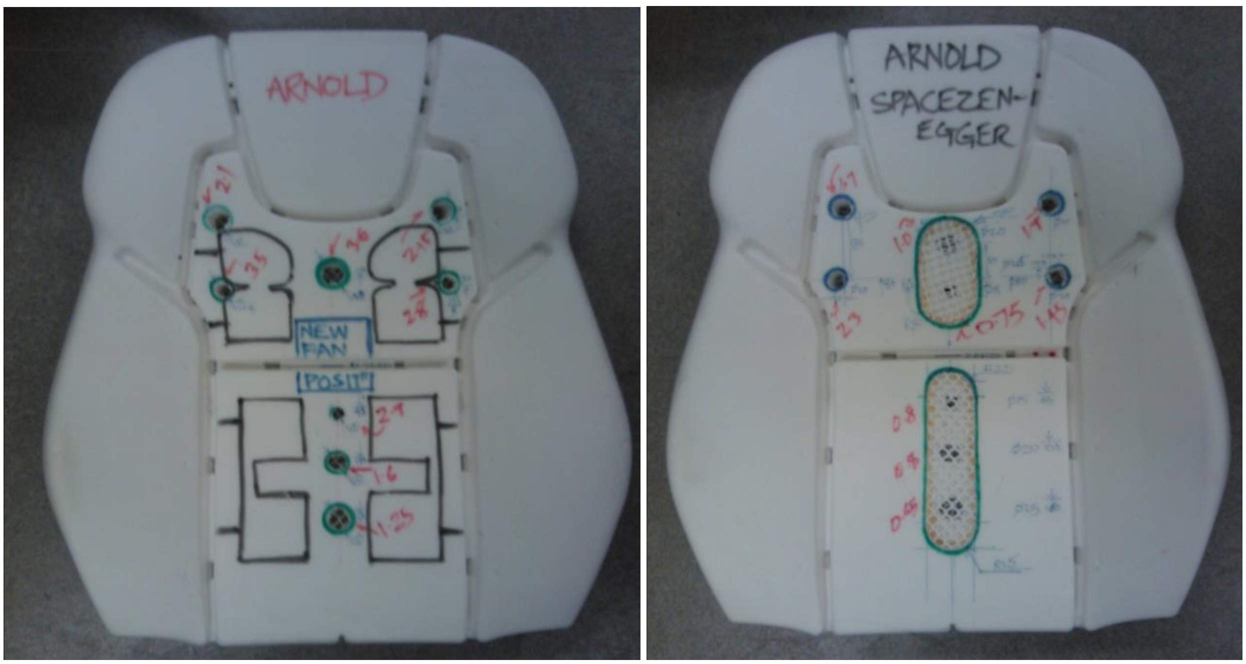


Figure 20: (L-R) Concept Arnold; Concept Arnold with spacer material.

8.1.4. Ferdinand

This variation of Arnold implemented grooves similar to the production version. The grooves were created to support the flow along the spine and around the upper back. The B-side diffuser and the fan position was used from Arnold. Ferdinand included all possible features to increase the performance for the backrest. Figure 21 shows the concept Ferdinand from the front. It could be possible to optimize the grooves and improve the comfort even more.

Figure 21: Concept Ferdinand

8.1.5. Moritz

Moritz was the last created prototype with the similar idea as Heinz. The hole configuration was calculated to account for pressure losses. The concept also included grooves since it was a good working principle from the concept Ferdinand. Figure 22 illustrates concept Moritz with an asymmetrical hole configuration. The idea there was to avoid a cluster of hole in the central back area. The grooves have a symmetrical layout so the difference cannot be noticed when sitting.

Figure 22: Concept Moritz

8.2. Cushion Concepts

With the cushion concepts many different parameters were tested. Due to many possibilities and ideas, small changes were not tested. For example, a concept with grooves was tested but not with different grooves layout.

8.2.1. Emma

The concept Emma was to test a similar idea to that of Arnold. Here the idea was to remove the rubber duct and replace it with an ideal duct for the airflow. Since the backrest duct was already a straight and simple design, it was used as duct for the cushion as well. Figure 23 shows a cut through the tilt pan, which had to be made to implement the duct. The fan position was moved directly over the intake. Considering these changes, an implementation to a production seat involves repackaging around the fan. The configuration and the diffusers production specification.

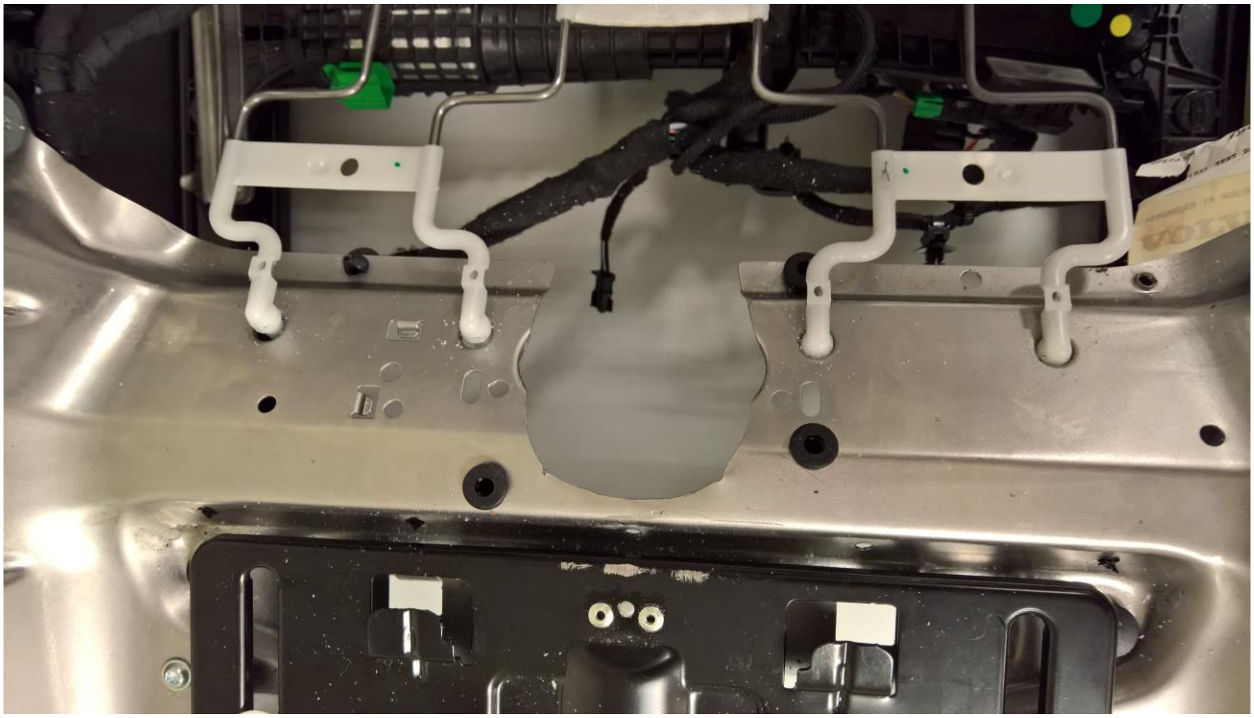


Figure 23: Modified Hole for the backrest duct

8.2.2. Hannah

When consulting the supplier about the seat ventilation for the cushion, it was mentioned that the air struggled to be pulled through the foam as the occupant blocked most of the surface. The avoid this phenomenon, a hole configuration with a large amount of holes was created. In addition, the diffusers on both sides were modified. After a short subjective test, the concept did not perform as intended, and therefore the hole sizes were increased and tested again.

8.2.3. Claudia

Concept Claudia was created to test different spacer materials. A standard ventilated cushion foam was taken and only the A-side spacer material was replaced. With an asymmetrical arrangement, two spacer materials were tested. A new supplier provided various specimen, only two had the desired properties, and hence were implemented in a prototype. One was similar to the Müller-mat already in use, with slightly less polymer fibres and the other had a finer knit finish on one side. The finely knit side was faced upwards to the trim, as seen in Figure 24. The B-side diffuser was the standard configuration.

Figure 24: Concept Claudia

8.2.4. Daniella

The idea behind Daniella was to reduce the B-side diffuser to a minimum. Out of geometrical reasons from the foam, it was not possible to remove the B-side diffuser completely. Therefore, it had a diffuser over the seams. In order to avoid a concentrated draft from the transition from A-side to B-side, the inlet was covered with windbreaker material. It can be seen in Figure 25.

Figure 25: Concept Daniella

8.2.5. Bianka

Concept Bianka was used to test external pipes, which were also intended for the cushion extension. To ease the creation of this concept the rubber duct from the backrest was used, along the same principle as Emma. The first version of the concept consisted of pneumatic pipes with inner diameter of 4 mm. They had the advantage of being flexible and small. But the overall performance was unsatisfying and were later changed to bigger pipes. The second version of concept Bianka used water hoses with an inner diameter of 10 mm. The advantage of the flexibility was lost, and the pipes were substantially larger. Without the design freedom of the pneumatic pipes, the amount of pipes was reduced to 3. One of them was for the cushion extension. It was tested with a thermal manikin. The result remained unsatisfying and therefore was not pursued further.

8.2.6. Andrea

The second iteration of prototypes was done with new tools and the knowledge from the first one. None of the concept from the first iteration delivered satisfying results. With all improvements combined into one concept, Andrea was fabricated. The configuration included larger holes for ensuring effective airflow and no inline hole. The configuration included larger hole sizes for ensuring effective airflow and no two holes in a straight line to fan. Also the duct system from Emma was implemented. Figure 26 shows the configuration of the concept Andrea. Spacer material was added around each hole to incorporate the idea of a conical inlet. The subjective performance was pleasant, but a slight draft persisted in the lower back region. In order to fix this, concept Anita was devised. The only difference was that the holes in the back of the foam were moved about 5 cm forward. The concept Andrea was later used to add a ventilated extension, through external pipes. It was a better implemented version of the idea behind concept Bianka.

Figure 26: Concept Andrea

8.2.7. Heidi

Concept Heidi's purpose was to use grooves and it was the counterpart for concept Ferdinand. The position of the holes was slightly changed to increase the airflow in the thigh region at the cost of reducing airflow around the buttocks. The B-side diffuser was modified with channels and no hole in a straight line was made. Figure 27 shows the concept with the grooves.

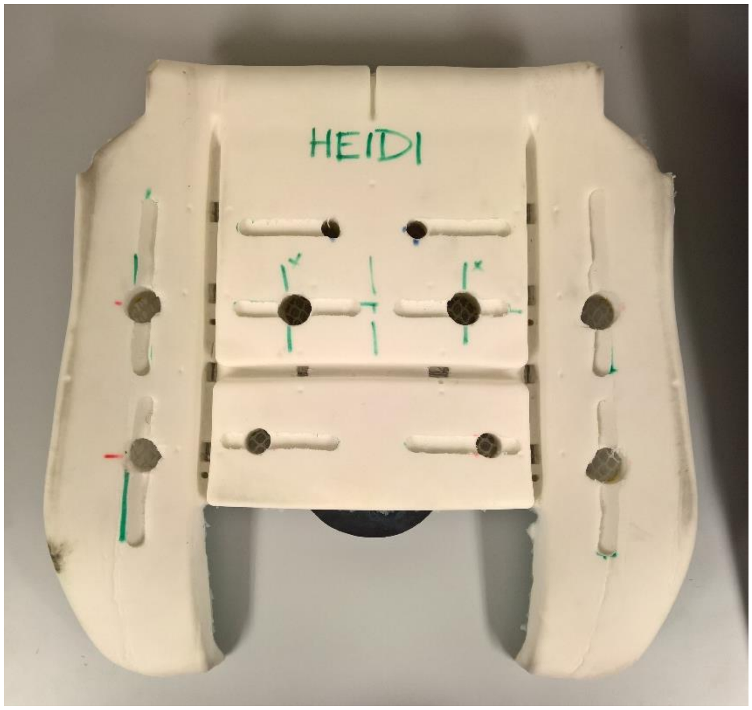


Figure 27: Concept Heidi

8.2.8. Klara

Klara was the final prototype to have the least amount of modification to the seat and is the counterpart to the concept Moritz. Thus, the original fan casing and duct was used. The configuration was calculated the same way as Moritz. The diffuser on both sides remained in the original status and the placement of the holes was similar to Andrea's. Figure 28 shows the concept Klara from A-side.

Figure 28: Concept Klara

8.3. Cushion Extensions

For the cushion extension two different principles were used and tested, which includes piped solutions and additional fans in the foam. The idea behind the pipes is to reduce the cost and have a simple implementable solution. The costs for additional fans are higher than implementing pipes, but the assembly for pipes is more complex.

8.3.1. Heike

Concept Heike was the only piped solution and the principle was derived from Bianka. At first small pipes were implemented under the seat structure. Encountering the same problems as the concept Bianka with small pipes, the concept was reworked. Bigger pipes were used and were mounted at the front surface of the cushion, instead of a direct connection to the rubber duct. This solution was paired with concept Andrea. Figure 29 shows the

Figure 29: Concept Heike

8.3.2. Kim

The supplier built a prototype with a fan from a competitor and modified several parts of the seats. These changes are rather costly and arduous to implement. The prototype was performing very well. To avoid changes in the seat structure, two smaller fans were used. These fans were taken from Volvo's car radio of crashed cars. Additionally, a mesh for the fans was created to keep the upholstery away from the fan blades. Figure 30 shows the layout of the fans.

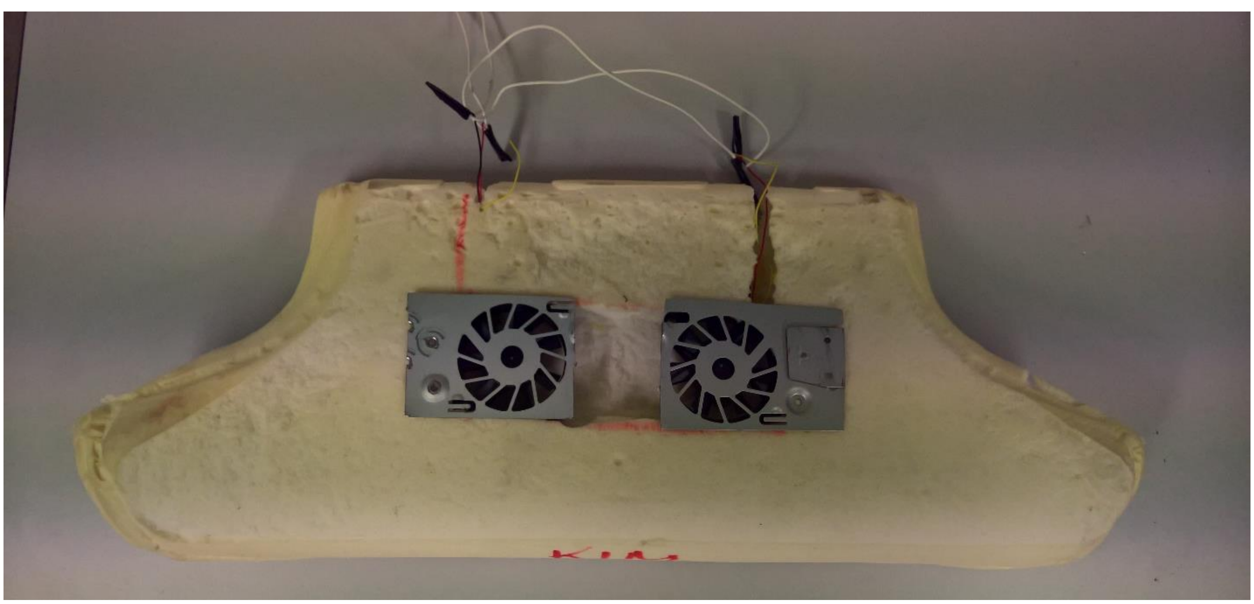


Figure 30: Concept Kim

8.3.3. Alex

The second concept with a fan was named Alex. The same fan was used as the first prototype from the supplier, but to avoid changes in the seat, it was used as a push system. The fan originally was designed for a push system. When testing it subjectively it was the strongest performing solution in terms of airflow. Due to the strong performance, spot cooling around the inner thighs occurred, which is unpleasant. Besides, the noise level was higher than the already implemented fan in the cushion and backrest. Hence, the concept was not pursued. Figure 31 shows the cushion extension with a competitor fan.

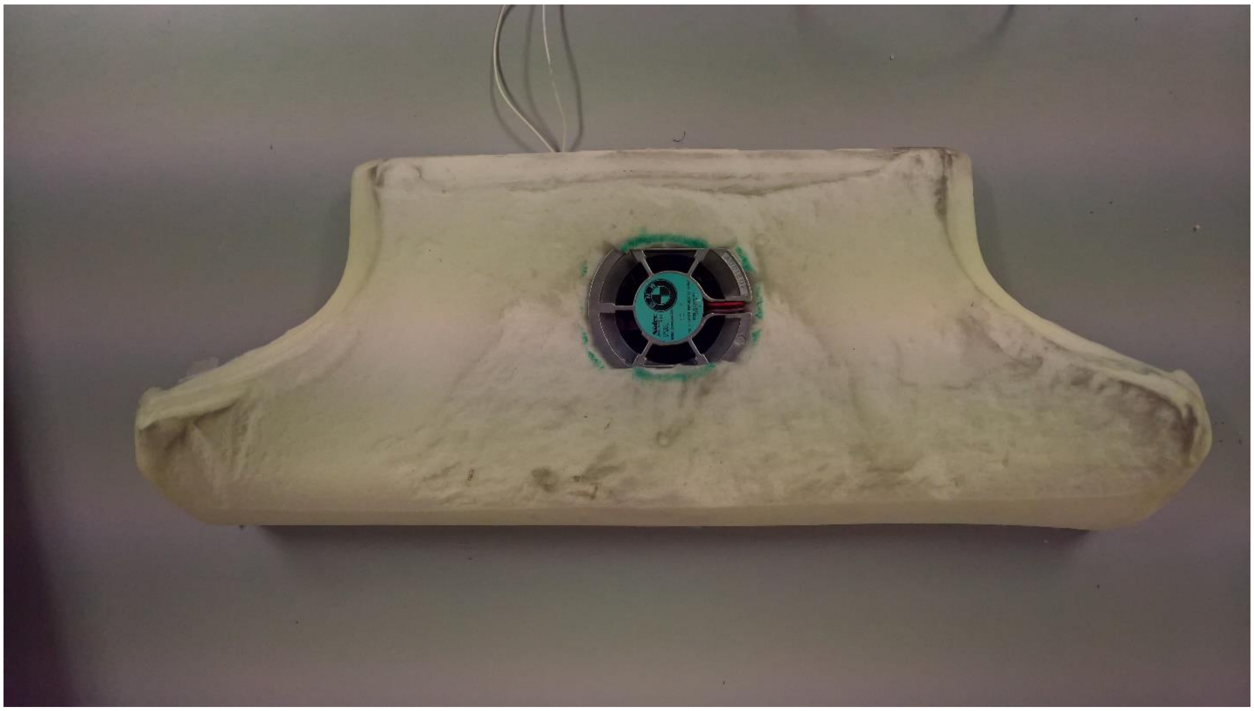


Figure 31: Concept Alex

8.4. Various concepts

Most of the concepts were intended to use a fan and also embracing different physical laws. Figure 32 shows the result of the brainstorming. These ideas were screened out due their complexity. Most of the systems were intended to use known parts.

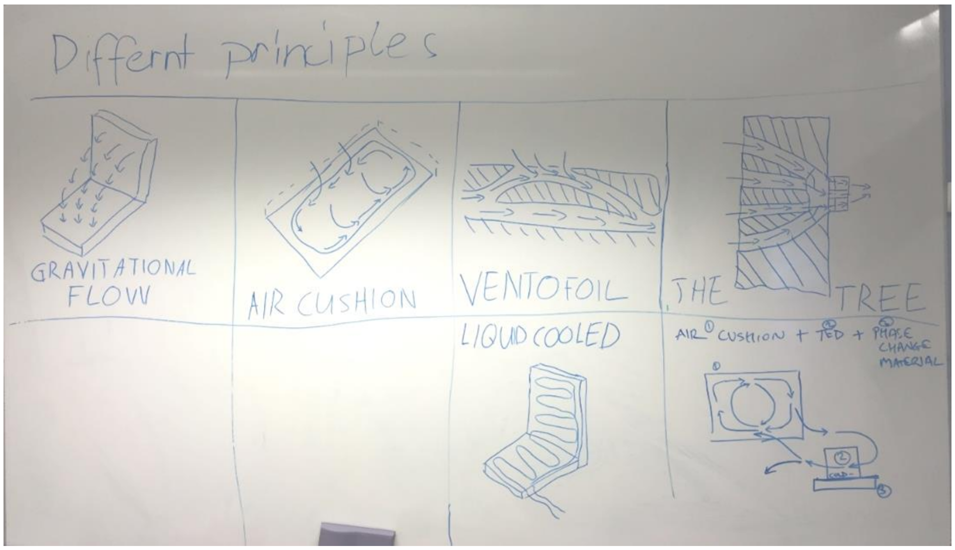


Figure 32: Concepts with different physical working principles

The idea behind Gravitational Flow was to use a push and pull system combined, leading to a circulation of air around the seat area. Looking at the second principle, it was intended to have a circulation inside the cushion. Pushing air out of the lower area of the cushion, would have contributed to a pull from the upper area. This idea did not seem feasible or beneficial for a ventilated seat. The third idea was inspired by a patent for an air cushion using the Coandă effect. The idea was to accelerate the air over a wing shaped profile, by lowering pressure, creating a venturi nozzle. This nozzle was intended to pull air into the foam. The idea of the tree was implemented with the concept Bianka, explained in chapter 0. Ideas like liquid cooling and combining all these concepts to a solution were discussed as well, but screened out very early due to their progressive nature.

9. Results

All of the results are from one measurement only and therefore giving no statistical data. This compromises the validity of the results. It is important to know that the numbers are not directly corresponding with the subjective nature of the seat ventilation. This applies to the manikin and the Mahöle mat test, when the results are in a close range. For example, the values from benchmarking of the V70 were lower than the XC90. The test subject reported that the V70 felt better performing compared to the XC90.

9.1. Findings from CFD

The 2D analysis clearly shows what happens when the ducts are not optimally aligned. When pulling air through the system, it is clearly visible that holes in a straight line will cause non-homogenous airflow, resulting in spot cooling. Figure 33 shows a cross section with a simple configuration, explaining this phenomenon. The hole to the right is not pulling any air. This is a very basic problem from pipe flow. This problem was not observed until the simulations were made. Transferring this knowledge to the fabricated foams, it is important that holes within a straight line towards the outlet of the foam have certain design parameters. If the hole diameter is greater than the duct channel leading to the main inlet for the area, the resistance to airflow in the hole is less. The hole behind will not pull a significant amount of air through the system.

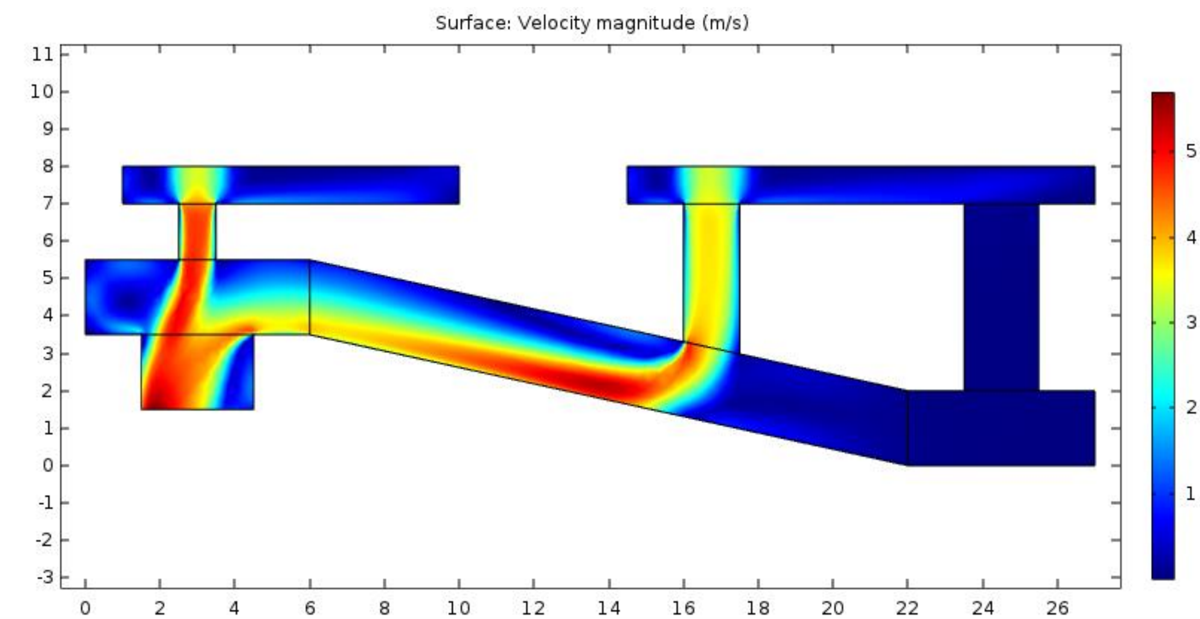


Figure 33 2D simulation of a simple configured cushion

To develop an equally distributed flow through all instances, the pressure loss has to be equal for all channels, allowing to optimize the duct system mathematically. If it is assumed that the flow through the system is laminar the Hagen-Poiseulle equation could be used for pressure loss. *(Kothandaraman and Rudramoorthy, 2011)*

$$\Delta P = \frac{128}{\pi} \cdot \frac{\mu L Q}{d^4}$$

Where L is the length of the channel, Q is the volumetric flow rate, μ is the viscosity, and d is the diameter of the pipe. In this case the B-side duct is not round and should be approximated over the circle area. This gives a simple idea how to model the channels, but the reality is more complex. When the channels on the B-side are not completely closed or include curves, the pressure loss is bigger. Another factor is the geometry of the channel especially concerning the turbulent flow. *(Rennels and Hudson, 2012)*

The 3D simulation got a similar result, where convergence problems occurred when using more than three separate inlets. This made it highly difficult to simulate the backrest. Figure 34 shows the result of the 3D simulations. It is visible that the airflow is focused on just one hole. Having this outcome, a further step would be to run an optimizer over the configuration. This was not done due to insufficient time and knowledge.

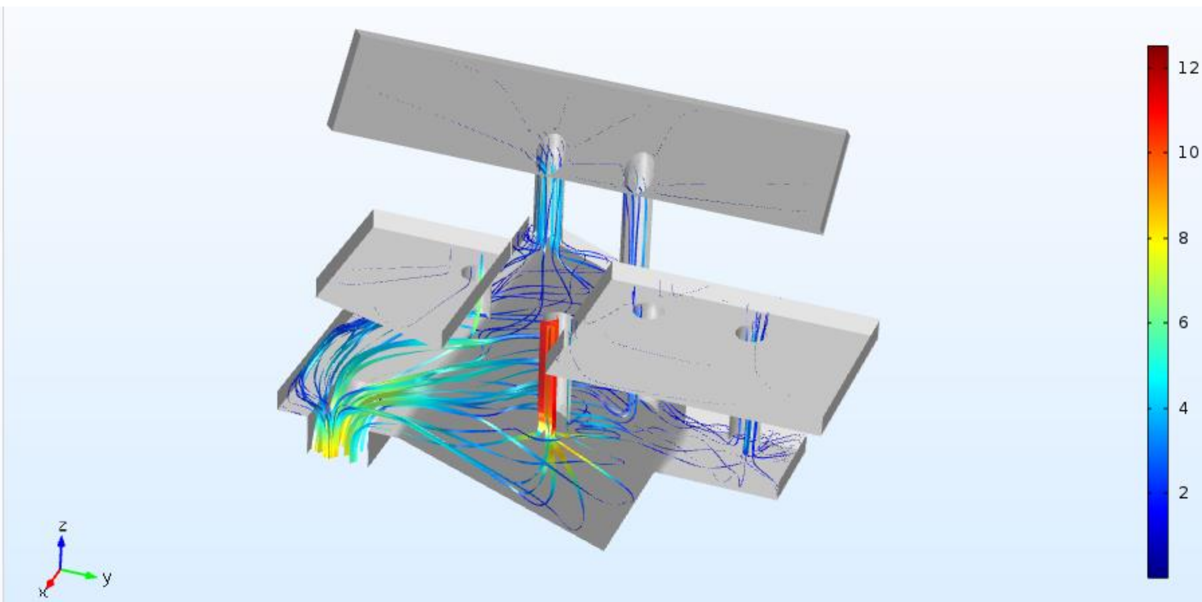


Figure 34: 3D Model of the ventilated cushion

9.2. Findings from Concepts and Prototyping

Quite a severe number of insights were found from the concepts. When comparing concepts against each other, the only used value was the energy flux from the manikin. Table 4 shows the results of the backrests. This made it straightforward to compare them. A higher value indicated better performance. When the tests were conducted in the second iteration the upholstery was attached to the foam with hog-rings. The concepts are explained in chapter 8.1 *Backrests*.

The winning concept for the backrest was Hans, with the two fans. The problem with this concept is the packaging for the back cover and presence of strong vibrations. The two fans will also increase the cost of production substantially, while the performance gain compared to the second concept is fairly low. The concept was not a satisfactory solution and therefore not chosen as a proposal for future projects.

When cutting out Hans as a concept, the winning concept is Arnold with or without spacer. A small suboptimal solution from Arnold with spacer was that the holes were in a straight line, allowing spacer material to be placed. This led to the decision that Arnold without spacer is the preferable solution. Also, it will be uncomplicated to fabricate.

Table 4: Test results of the backrests with change towards original

Name of the concept	Energy flux in [-]	Test iteration number	Tested with
Arnold	1.06	1	Bianka
Arnold with spacer	1.06	1	Hannah
Heinz	0.98	1	Emma
Hans	1.44	1	Claudia
Ferdinand	1.06	2	Heidi
Original	1.00	0	-
Moritz	0.61	2	Klara

Concept Heinz was especially interesting because it had the fan in the original location, hence the changes were only concerning the backrest foam. Implementing this is a cost effective solution and requires minimal changes. The performance was comparable with the winning concept Arnold, and also as strong as the already implemented solution.

Concept Arnold was a concept which underwent to test iterations. The first result was 1.06 while the second one was 0.92. This change made it less powerful than the original, while in the first test it was better. Another important factor is that the original was tested in a car and the concepts were in a lab. During the test in the car the air condition was on, which helps the seat ventilation cooling down the manikin. Therefore, it is important to compare the concept of the second iteration with an SPA seat that was tested in lab conditions as well. The winning concept from the second test iteration was Ferdinand. With 1.06 it was better performing than the original.

The results from the cushions were in a broader spectrum as it can be seen in .

Table 5 and are quite apart from the production foams. Since the test had to be done in a timely manner, the upholstery was not properly attached with hog-rings. In the area of the cushion extension, this could have led to leakage. The more critical approach to this is in the chapter 10.3 *Prototypes*.

Table 5: Test results of the cushion concepts with change towards original

Name of the concept	Energy flux [-]	Test iteration number	Tested with
Bianka	0.22	2	Arnold
Heidi	1.17	2	Ferdinand
Andrea	1.03	2	Arnold
Emma	0.77	1	Heinz
Daniella	0.11	1	Arnold
Claudia	0.17	1	Hans
Anita	-	-	-
Hannah	0.45	1	Arnold with spacer
Original all sensors	1.00	0	-
Klara	0.66	2	Moritz

The winning concept regarding the cushion is evidently concept Emma. Concept Emma's modification was the repacked fan directly to the cushion, and was the only concept which utilised this adjustment. Realising that this had such a big impact, it was used for all prototypes created afterwards.

Looking at the theory of ducts, it is clear that the design has potential to optimise. The first one was, the many turns that the air has to go through before reaching the fan. Every turn that the air has to make before reaching the inlet, increases pressure losses. Another aspect of the duct design was the geometry. The implemented duct is an obround, encountering another weakness. The optimal solution would be a circular tube.

The third design optimisation is the exhaust of the fan, which is a rather small area compared to the fan. In thermodynamics, a system will eventually reach equilibrium, when the mass flow into the system is equal to that out of the system. Applying this to the cushion fan casing, it reduces the mass flow if the exhaust is smaller than the inlet. All these principles are applied in the backrest casing, where it is already an optimal solution.

The second best performing concept of the first test iteration was Hannah, where the main idea was to increase the amount of holes and therefore ease the air flow through the cushion. While the idea was an improvement, the decision was made to increase the hole size with the same layout. The result suggested that a concept with larger holes have better performance.

The concept Claudia was a standard configuration, but with changed spacer materials. The interesting part is that the performance should be close the original, since the spacer material was very similar. A factor that could have been the reason for this huge gap between the results, is the cushion extension. The original had an unventilated cushion extension, while the first iteration of tests had no extension at all. Another crucial factor was the unattached upholstery, where it seems to have higher impact on the cushion than the backrest. With the two spacer materials used on, it seems that both spacer materials perform equally, while the spacer material with the number 56-100-150 positively increases the haptics.

For the extension, there were basically two different ways of solving the problem, as discussed in chapter *8.3 Cushion Extensions*. The concept Gabi was an overall weak concept in terms of performance. The weak performance was mainly because of the thin pipes and the bad fabrication.

Table 6: Test results of the cushion extension concepts

Name of the Concepts	**Energy flux [W/m^2]**	**Test iteration number**	**Test partner**
Gabi	0	1	Bianka
Kim	80	2	Andrea
Alex	100	2	Heidi
Alex	8	2	Klara

The result of the cushion extension was varying mostly with the test partner. This is clearly visible when looking at the test results from Alex. The performance was strong when tested with Heide, but weak when tested with Klara. Considering this strong variance of the results, the validity of these results is not given. The results for the cushion extensions were therefore analysed with the Mahöle mat test.

9.2.1. Mahöle mat tests with concepts

Two final prototypes were tested with the Mahöle mat at the supplier, to have detailed results on their results. These concepts were compared with an SPA seat which was done in the same matter. Figure 35 shows the result of the Mahöle mat test between the final prototypes. The colour spectrum ranges from red to green. Red indicates a high temperature and green a low temperature. The ideal solution would have an even distributed temperature. It is unlikely that the seat will reach a temperature below 30°C where the occupant sits. It can be noticed that the right side of the mat is always hotter than the left side. This could come from the heating element of the climate chamber, which was always on the right side of the test subject. Left shows the cushion and right the backrest.

The most relevant factor is where the fan is placed for the backrest. This can be seen in Figure 35 on the right top and right middle. The top is concept Ferdinand and the middle is Moritz. Concept Ferdinand has a cooled upper back and has less cooling on the spine. This might be because the test subject was putting more weight to the lower back and not leaning entirely to the chair. When looking at concept Moritz it can be seen that the fan has a lower position. The upper area of the seat has not a strong cooling performance. Therefore, Heidi and Ferdinand are favourable in terms of performance where Klara and Moritz have a similar performance like the production seat.

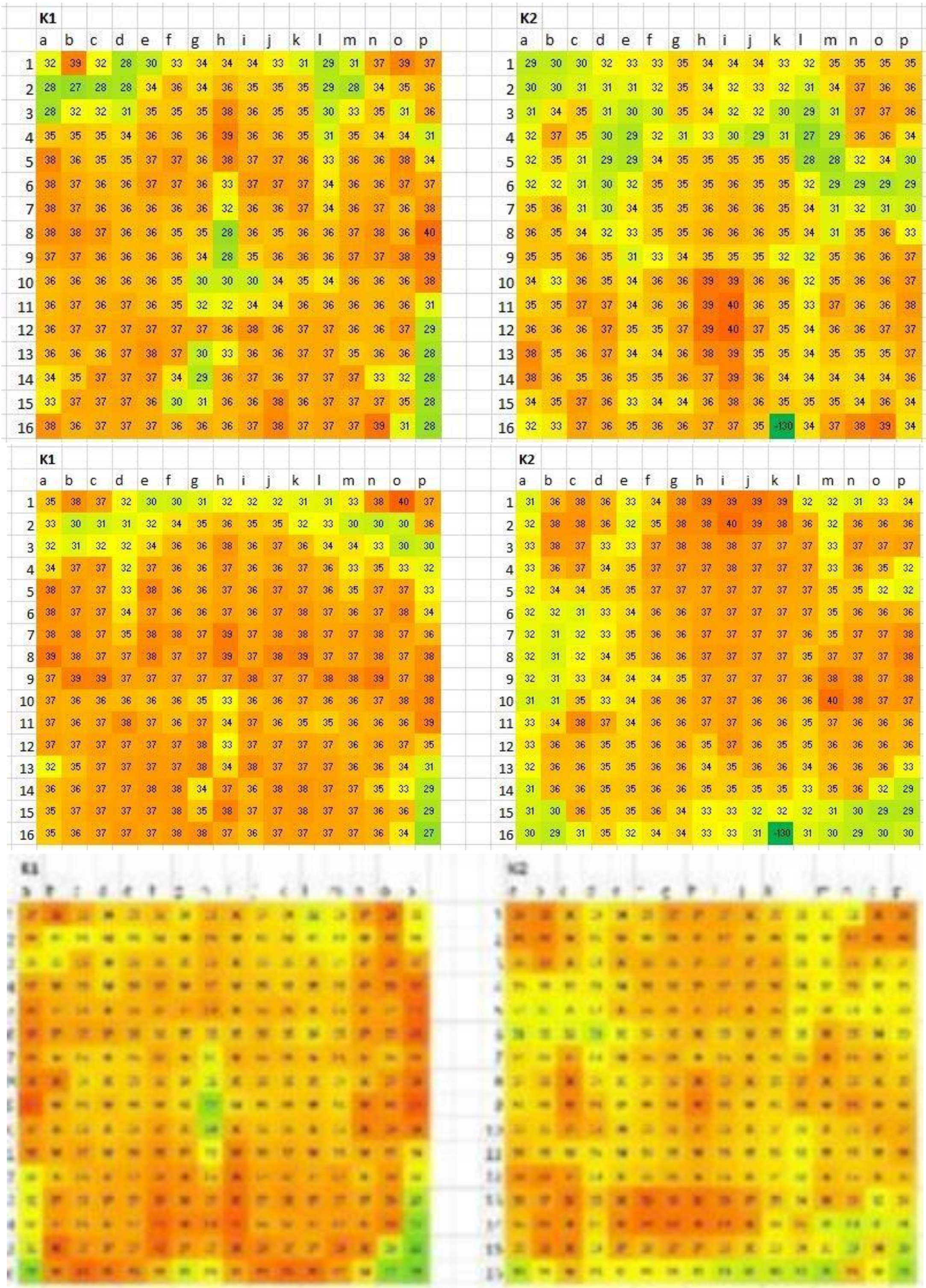


Figure 35: Mahöle Mat test after 1 min with Concept Heid & Ferdinand i (top), Concept Klara & Moritz (middle), and original SPA (bottom)

9.3. Benchmarking Results

Table 7 shows the result of the benchmarking for the energy flux. The numbers are for the difference from idle to maximum performance. It seems that both Volvo systems were the stronger solutions than their competitors. Competitor 1 used a push system, which had a gradual impact for the energy flux. While the maximum energy flux reached a higher level than competitor 2, the step response was a weak performance. Figure 36 shows the difference between competitor 1 and the SPA system. For a short period of time the push system even heated the manikin resulting in a reduced value than the starting condition. The three steps represent a different level of ventilation. This shows the difference when using the seat ventilation in a lower level. The results for reduced levels can be found in the appendix C.

Table 7: Benchmark results

Car	**Energy flux cushion** [-]	**Energy flux backrest** [-]
Y20 Volvo System	0.84	0.91
SPA 1.20.	1.00	1.00
Competitor 1	0.72	1.14
Competitor 2	0.35	0.79

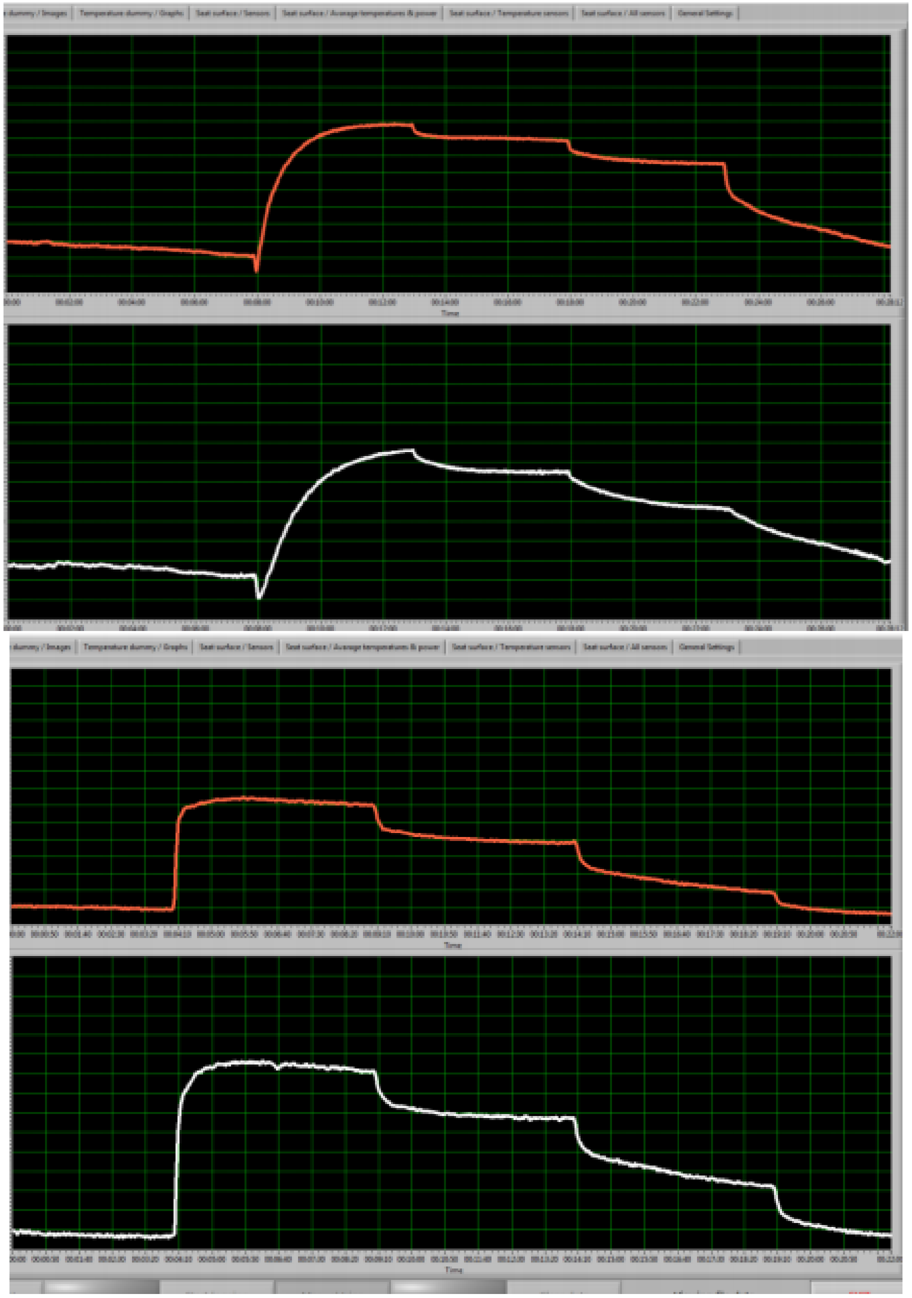


Figure 36: Difference between a push (top) and pull (bottom) system

9.3.1. Mahöle-mat test

Figure 37 shows the result of the Mahöle mat after 30 min of cooling. The result gives a better overview of the seat ventilation than the energy flux. The left matrix shows the cushion and the right matrix the backrest. It can be clearly seen that the SPA 1.20.1 has no ventilation in the cushion extension where the temperature has not been decreased. Around the ventilated areas the SPA seat has a strong performance. Compared to the Y20 system, the SPA seat is similar in performance, even though subjectively the Y20 was better performing. Competitor 1 had the push system and it can be clearly seen that the temperature gradient is smaller in both the cushion and the backrest.

In the Section 4.3 Passive Cooled System, it was discussed that a push system heats up the occupant instead of cooling them down. Considering that Competitor 2 has a very similar system to Volvo, it is interesting that the ventilation performs poorly. It should be noted that one of the sensors on the backrest-mat malfunctioned, and showed -130°C while testing competitor 2.

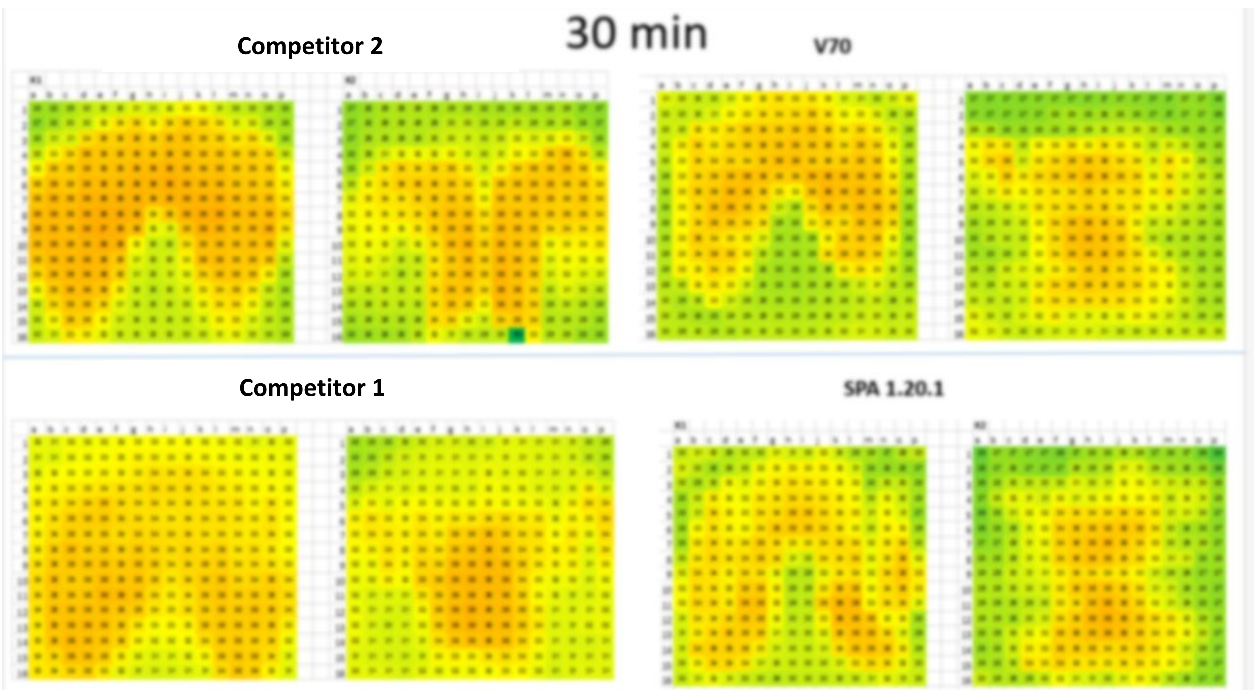


Figure 37: Result Mahöle mat test after 30 min testing

It is also important to consider the Air Condition when using the seat ventilation. This means if the AC is well performing the seat ventilation performance will increase as well. In addition, it is also important to consider that the Mahöla mat does not always fit in the same position. It can be seen that the occupant sits further back in the V70 compared to the SPA seat.

9.3.2. Competitor 1

Competitor 1 clearly shows the disadvantages of a push system. The Energy flux shows a slow step response of the system. Having an almost three minutes' time to reach the maximum performance, the competitiveness is not assured against a push system. With six fans used in the seat and no ducts through the foam, the solution is simple to implement and having as well a silent solution. In a subjective matter the ventilation was not satisfying.

9.3.3. Competitor 2

The performance gap between Competitor 2 and Volvo's system is unexpected. Both systems are very similarly built, having the same performance for the fan, similar diffusers on B-side and a similar duct system. The main difference is the diffuser on A-side, where this competitor uses a 20 mm thick soft foam. A plausible reason for the weak performance could be this soft foam, which expands when the occupant sits on it and closes the holes. In addition, the cushion fan is placed directly below the buttocks of the occupant, cooling where the sensation is least perceivable. The cushion extension, which is made out of one part together with the cushion foam, is also unventilated. Thus, the implementation would not require any extra fan or pipe like the Volvo system.

10. Discussion

All concepts were tested just once and giving no statistical data. When comparing the results, it could be possible that a result was influenced by several factors. The greatest factor is the subjective matter of the seat ventilation. This could mean that a high number in the results is still a bad concept. For example, if the draft at the lumbar is excessive. The results could give high numbers but it is perceived badly.

10.1. CFD

Modelling with the Hagen-Poiseulle equation, is a strong simplification, knowing that the flow in certain regions is turbulent. As an example for a hole with likely turbulent parameters, the Reynolds number is calculated using the following equation:

$$Re = \frac{\rho V L_d}{\mu}$$

Where the density ρ is approximately $1.18\ \mathrm{kg/m^3}$ for air, V the velocity, which was 4 m/s in the highest case measured from the prototypes, L_d is the hydraulic diameter for the largest hole approximately 0.02 m and μ is the viscosity for air $1.81 \cdot 10^{-5}$ Pa·s. Using these values gives a Reynolds number of 5215, which is clearly a turbulent flow through that part of the system. When considering a hole with a velocity of 1 m/s and a diameter of 0.01 m, the Reynolds number is 651, which is a laminar flow by definition. When the Hagen-Poiseulle equation is used for optimizing the system, the problem only gives inaccurate results, but can be still used for testing. A bigger problem emerges when the system is modelled in CFD, due to the fact that it has to be modelled either as laminar or as turbulent flow, where the real issue is the transition. When the system was analysed with CFD during the project, k-ε, k-ω and SST models were used to reduce convergence problems, even though none of these models could calculate the transition between laminar and turbulent. It could have been a reason why the 3D analyses did not work. *(Andersson, 2012)*

10.2. Test procedures

The test procedures were taken from the supplier, due their experience in the field of seat ventilation. Cengiz & Babalık also advise to do long road tests with seat ventilation up to two hours. This could not be done, in Sweden due to moderate weather conditions and long span of the project. The subjective test was therefore held in a climate chamber with 45°C. The supplier also tests the ventilation with jeans as standard clothing, to have a stronger insulated ventilation and the difference can be easier noticed. It was suggested that the clothing has an important impact for result. Seat ventilation was mostly developed for summer times and it seems that jeans is an unlikely piece of clothing for these conditions. This led to the decision that the subjective tests from the climate chamber were to be carried out with summer clothing. It is likely the result of this is perceived differently as a clothing factor.

The mahöle mat tests were carried out directly in the car, while most results were previously made in a separate climate chamber. The results appeared to alter substantially when the car involved more realistic condition with AC on and the doors closed. This testing procedure required the infrastructure, such as a climate chamber. Instead the cars were heated up with an electric heater. Heating up a car in the chamber takes up to 12 hours, while for the test only one hour was used. This probably altered the result, with an accelerated rate of cooling of the seat. It may seem also unlike to have an outside temperature of 45°C during 12 hours, and the car would be heated from the outside. A factor that probably impacted the results is the soaking of the test occupant. Cengiz & Babalık state it is important to soak the person before using the seat ventilation and is included in the standard procedures for both the supplier and Volvo. When the modified tests were used, the test occupant was not soaked and sat directly in the car. For a subjective matter this will likely change the perception of the cooling (Cengiz & Babalık, 2009). This might also alter results for the difference between pushing and pulling systems, where pulling system would theoretically give better results. The push system will lead the hot air towards the occupant and the pull system takes the air from the colder occupant.

A factor that is difficult to explain, is movement on the seat. The results of the Mahöle mat show that the region outside of the cooling area, cool down faster. It might be possible that the occupant is not leaning against the backrest, altering the result.

10.3. Prototypes

Due to time constrains at the supplier, the concepts were tested without a properly attached upholstery and without a cushion extension. It appears to have a great impact on the result. The backrest seemed to have similar results, while the cushion tended to suffer in performance. Another aspect of performance loss could lead from the fabrication of the concepts, where sometimes the sealing had poor quality or did not align with the rubber duct.

11. Conclusion and recommendations

The objective of the thesis was to compare current ventilation system offered in Volvo's SPA platform vehicles against the competition. The motivation behind this was to gauge how good or bad the system was in relation to others. Conclusively, based on the results and findings of tests carried out on these systems, the Volvo system outperformed its rivals. The SPA front seats performed better, objectively, in terms of cooling effect, and thermal distribution. Interestingly, the older generation of the ventilation system performed as good as the new one.

The purpose of this thesis was also to identify areas of interest, in regards with improving the overall performance of the ventilation system. The various tests, accompanied with research and analysis of the existing seat showed the levels of performance for the backrest and cushion. The cushion has been found to have room for improvement, in particular the duct design. The backrest has been found to be optimisable as well. The location of the fan has been found to influence performance. The extension, lacking ventilation altogether, has also been identified as an area that could be exploited for overall performance improvement of the seat.

In order to achieve an increased performance in the ventilation system, a subjective evaluation has to be done. The concepts generated for the minimal changes to implement, still have flaws in the area of the ventilation. Therefore, it is important to optimize these concepts further before implementing it into an SPA seat. As well it is recommended to do several tests with one concept to have a statistical value. This aids the comparison between the performance.

Conclusively, in order to conserve the knowledge gained in this project, a few recommendations and guidelines for seat ventilation have been introduced. They have been compiled to help in future efforts. The purpose of these recommendations is to save energy and efforts while in the development phase, and save time and cost to the stakeholders. The authors have suggested an overview of these guidelines, to avoid implementation of previously unimproved system configurations.

- **Pull-type ventilation system**
  The response at start-up of such a system is better. It also avoids the problem of pushing hot trapped inside the seat itself towards the occupant.
- **Areas of focus: Thighs and Upper Back**
  The thighs and the upper back dissipate more heat than the buttocks. Such areas of focus would also reduce the amount of energy required to make the occupant 'feel' cool.
- **In-line hole placement**
  Hole layout on the foam should be such, that no two holes form a straight line towards the suction inlet. And if in an unavoidable case they happen to do so, appropriate pressure losses and airflow separation should be considered while calculating the duct size.
- **Least possible turns on suction inlet duct**
  There should be as less turns on this particular duct as possible. A desired layout would be a straight and direct connection, without any turns.

- **Circular inlet duct**
  A circular inlet duct provides better performance in comparison to the existing obround duct.
- **Focused fan placement**
  The placement of the fan closer to an area of focus improves performance, and distribution.
- **Unblocked fan exhaust**
  An unblocked exhaust aids in providing proper ventilation.

12. References

Andersson, B. (2012). *Computational fluid dynamics for engineers*. Cambridge: Cambridge University Press, p.83.

Atieva Inc., (2015). *VEHICLE SEAT VENTILATION SYSTEM*. US 2015/0140915.

Bayrische Motoren Werke Aktiengesellschaft, (2011). *ACTIVELY VENTILATED VEHICLE SEAT*. US8038222.

Bell, L. (2016). *Cooling, Heating, Generating Power, and Recovering Waste Heat with Thermoelectric Systems on JSTOR*. *Jstor.org*. Retrieved 23 May 2016, from http://www.jstor.org/stable/20144792

C.R.F Societa Consortile per Azioni, (2009). *SEAT, IN PARTICULAR A VEHICLE SEAT, WITH MEANS FOR DEVIATING A VENTILATION FLOW BASED ON COANDA EFFECT*. US 7527329.

Cengiz, T. & Babalık, F. (2007). An on-the-road experiment into the thermal comfort of car seats. *Applied Ergonomics*, *38*(3), 337-347. http://dx.doi.org/10.1016/j.apergo.2006.04.018

Cengiz, T. & Babalık, F. (2009). The effects of ramie blended car seat covers on thermal comfort during road trials. *International Journal Of Industrial Ergonomics*, *39*(2), 287-294. http://dx.doi.org/10.1016/j.ergon.2008.12.002

Chludzińska, M. & Bogdan, A. (2015). The effect of temperature and direction of airflow from the personalised ventilation on occupants' thermal sensations in office areas. *Building And Environment*, *85*, 277-286. http://dx.doi.org/10.1016/j.buildenv.2014.11.023

Choi, H., Yun, S., & Whang, K. (2007). Development of a temperature-controlled car-seat system utilizing thermoelectric device. *Applied Thermal Engineering*, *27*(17-18), 2841-2849. http://dx.doi.org/10.1016/j.applthermaleng.2006.09.004

Cory, W. (2005). *Fans & ventilation* (pp. 63, 76). Amsterdam: Elsevier in association with Roles & Assoc.

Daimler-Benz Aktiengesellschaft, (1999). *VEHICLE SEAT WITH TEMPERATURE AND VENTILATION CONTROL AND METHOD OF OPERATION*. US 5934748.

Gao, N. (2005). CFD Study of the Thermal Environment around a Human Body: A Review. *Indoor And Built Environment*, *14*(1), 5-16. http://dx.doi.org/10.1177/1420326x05050132

Gentherm Automotive Systems (China) Ltd., (2013). *VENTILATION SYSTEM*. WO 2015/100591.

Ghosh, D., Wang, M., Wolfe, E., Chen, K., Kaushik, S., & Han, T. (2012). Energy Efficient HVAC System with Spot Cooling in an Automobile - Design and CFD Analysis. *SAE International Journal of Passenger Cars - Mechanical Systems*, *5*(2), 885-903. http://dx.doi.org/10.4271/2012-01-0641

Halman, J.I., Hofer, A.P. and Van Vuuren, W., 2003. Platform-driven development of product families: linking theory with practice. *Journal of Product Innovation Management*, *20*(2), pp.149-162.

Hyundai Motor Company, (2011). *HEATING AND COOLING SYSTEM FOR VEHICLE SEAT*. US 8061824.

IGB Automotive Ltd., (2015). *AIR MANIFOLD FOR VENTILATED SEAT OR BED*. US 9055820.

IGB Automotive Ltd., (2015). *THIN VENTILATED SEAT FOR A VEHICLE AND ITEMS OF FURNITURE*. US 9061617.

Jaguar Configurator (2016). *This is my Jaguar. Configure yours today.* [online] Available at: http://rules.config.jaguar.com/jdx/en_xi/cj_jscwl01b/3c669/a-50ps-510_a-jt6_a-x351lwb/bapa_ner/jdxother.html [Accessed 4 Feb. 2016].

Johnson Controls Technology Company, (2004). *AIR DISTRIBUTION SYSTEM FOR VENTILATED SEAT*. US 6786541.

Johnson Controls Technology Company, (2002). *SEAT PADDINGS FOR VEHICLE SEATS*. US 6481801.

Johnson Controls Technology Company, (2005). *VENTILATED SEAT*. US 7229129.

Kagerin, J. (2016). *Discussion about seat ventilation*.

Kongsberg Automotive AB, (2005). *SEAT WITH TEMPERATURE CONTROL AND VENTILATION AND SAFETY SYSTEM FOR A VEHICLE*. US 6892807.

Kothandaraman, C. and Rudramoorthy, R. (2011). *Fluid mechanics and machinery*. 3rd ed. New Academic Science, p.314.

Lear Corporation, (1999). *VENTILATED VEHICLE SEAT ASSEMBLY*. US 5927817.

Leu, C. (2016). *Seat ventilation meeting at the supplier*. Presentation, Sweden.

Lund Madsen, T. (1994). Thermal effects of ventilated car seats. *International Journal Of Industrial Ergonomics*, *13*(3), 253-258. http://dx.doi.org/10.1016/0169-8141(94)90072-8

media.volvocars.com. (2016). *A MILLION LIVES SAVED SINCE VOLVO INVENTED THE THREE-POINT SAFETY BELT*. [online] Available at: https://www.media.volvocars.com/uk/en-gb/media/pressreleases/20505 [Accessed 13 Feb. 2016].

media.volvocars.com. (2016). *All-new XC90 the first Volvo built on the company's new Scalable Product Architecture*. [online] Available at: https://www.media.volvocars.com/global/en-gb/media/pressreleases/148966/all-new-xc90-will-be-the-first-volvo-built-on-the-companys-new-scalable-product-architecture [Accessed 13 Feb. 2016].

media.volvocars.com. (2016). *New Scalable Product Architecture enables Volvo Car Group to move faster towards a crash-free future*. [online] Available at: https://www.media.volvocars.com/global/en-gb/media/pressreleases/136653/new-scalable-product-architecture-enables-volvo-car-group-to-move-faster-towards-a-crash-free-future [Accessed 13 Feb. 2016].

media.volvocars.com. (2016). *Volvo Cars reports best sales in its 88-year history*. [online] Available at: https://www.media.volvocars.com/global/en-gb/media/pressreleases/171102/volvo-cars-reports-best-sales-month-in-its-88-year-history-and-260-per-cent-growth [Accessed 13 Feb. 2016].

Menon, M. & Asada, H. (2006). Iterative learning control of shape memory alloy actuators with thermoelectric temperature regulation for a multifunctional car seat. *2006 American Control Conference*. http://dx.doi.org/10.1109/acc.2006.1655478

Rennels, D. and Hudson, H. (2012). *Pipe Flow*. Hoboken: John Wiley & Sons, pp.27-28.

Rutkowski, P. (2010). Thermal Comfort Modeling of Cooled Automotive Seats. *SAE International Journal of Passenger Cars - Mechanical Systems*, *3*(1), 523-532. http://dx.doi.org/10.4271/2010-01-0552

Stone, R.B., Wood, K.L. and Crawford, R.H., 2000. A heuristic method for identifying modules for product architectures. *Design studies*, *21*(1), pp.5-31.

The Regents of the University of California, (2015). *VENTILATED SEATBELT FOR EFFICIENT COOLING AND HEATING OF VEHICLE PASSENGERS*. WO 2015/061494.

Thomas, D. (2013). *Top 10 Features Drivers Don't Need*. [online] Cars.com. Available at: https://www.cars.com/articles/2013/02/top-10-features-drivers-dont-need/ [Accessed 5 Feb. 2016].

Tsai, M. (1982). Mode scattered design for fan noise suppression in two-dimensional ducts. *Journal of Sound and Vibration*, *83*(4), 501-512. http://dx.doi.org/10.1016/s0022-460x(82)80103-x

saabhistory.com (2009). *Ventilated Seats : Saab Innovation | Saab History*. [online] Available at: http://www.saabhistory.com/2007/11/17/ventilated-seats-saab-innovation/ [Accessed 4 Feb. 2016].

Ulrich, K., 1995. The role of product architecture in the manufacturing firm. *Research policy*, *24*(3), pp.419-440.

Ulrich, K. and Eppinger, S. (2012). *Product design and development*. New York: McGraw-Hill/Irwin, pp.127, 128, 297-302.

Vinoth, M. & Prema, D. (2014). Automated car safety seat cooling system using thermoelectric cooler. *2014 International Conference On Computation of Power, Energy, Information and Communication (ICCPEIC)*. http://dx.doi.org/10.1109/iccpeic.2014.6915413

volvocars.com. (2016). *Awards | Volvo Cars*. [online] Available at: http://www.volvocars.com/intl/About/Our-Stories/Made-by-Sweden/Awards [Accessed 6 Feb. 2016].

volvocars.com. (2016). *Company Information | Volvo Cars*. [online] Available at: http://www.volvocars.com/intl/about/our-company/this-is-volvo-cars [Accessed 13 Feb. 2016].

volvocars.com. (2016). *Safety Innovation in Cars | Volvo Cars*. [online] Available at: http://www.volvocars.com/intl/about/our-company/heritage/innovations [Accessed 13 Feb. 2016].

volvogroup.com. (2016). *History - Our history : Volvo Group Global*. [online] Available at: http://www.volvogroup.com/group/global/en-gb/volvo%20group/history/Pages/history.aspx [Accessed 13 Feb. 2016].

Walgama, C., Fackrell, S., Karimi, M., Fartaj, A., & Rankin, G. (2006). Passenger Thermal Comfort in Vehicles - A Review. *Proceedings of The Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *220*(5), 543-562. http://dx.doi.org/10.1243/09544070d00705

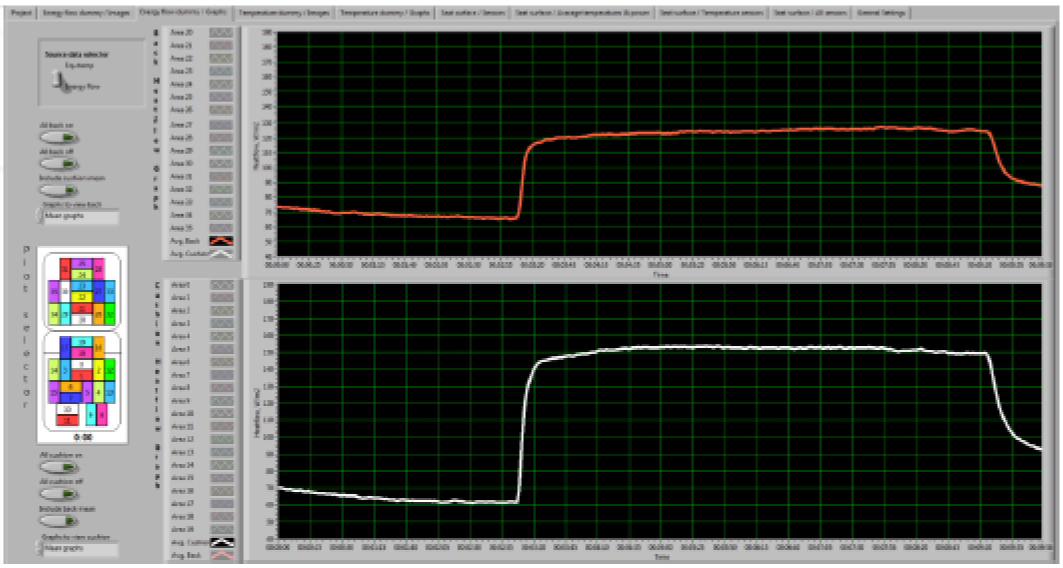
Watanabe, S., Shimomura, T., & Miyazaki, H. (2009). Thermal evaluation of a chair with fans as an individually controlled system. *Building and Environment*, *44*(7), 1392-1398. http://dx.doi.org/10.1016/j.buildenv.2008.05.016

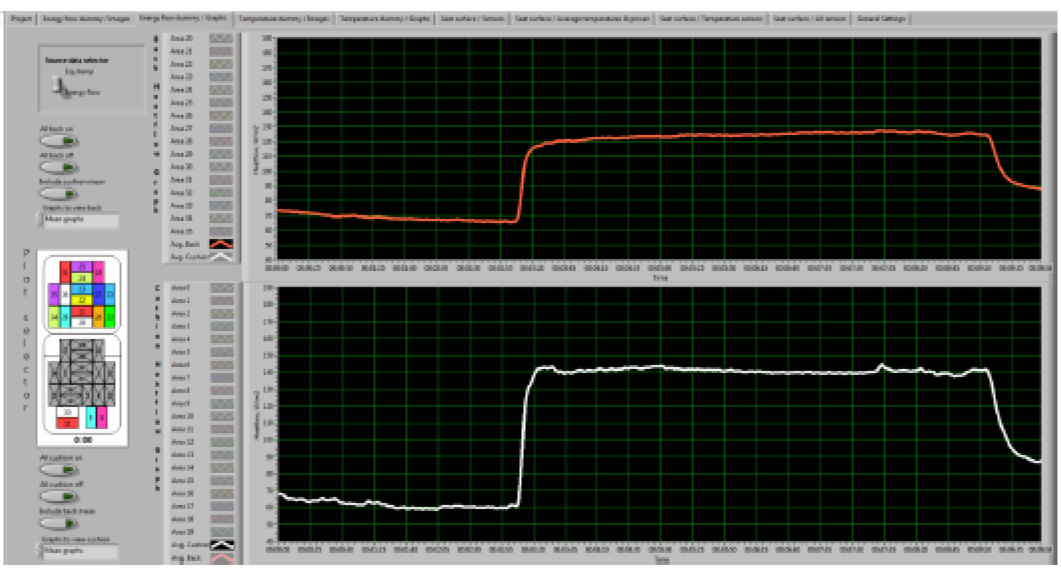
Witchie R, (2006). *ARRANGEMENT AND METHOD FOR PROVIDING AN AIR FLOW WITHIN AN UPHOLSTERED SEAT*. US 6988770.

Appendices

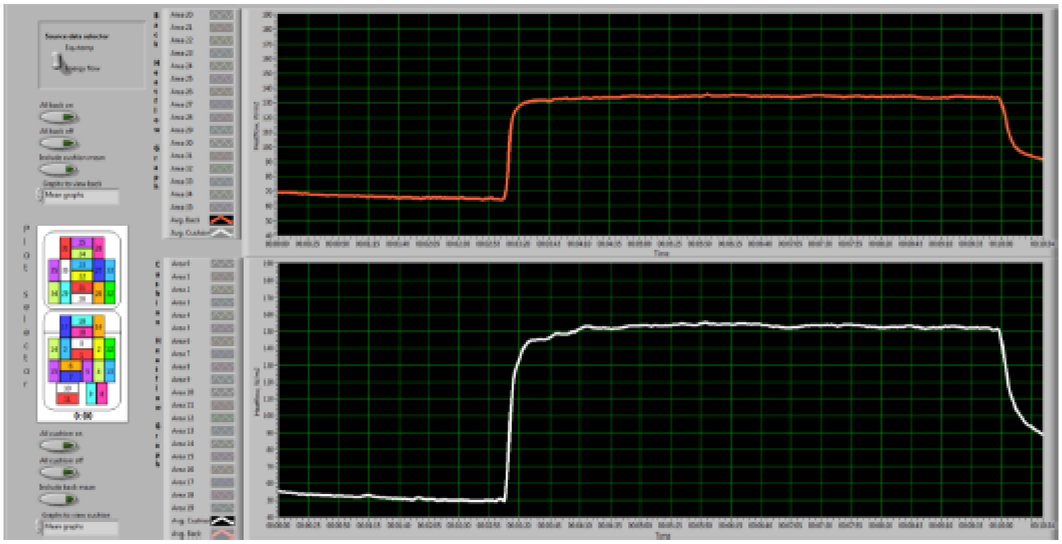
Appendix A: Results from Thermal manikin

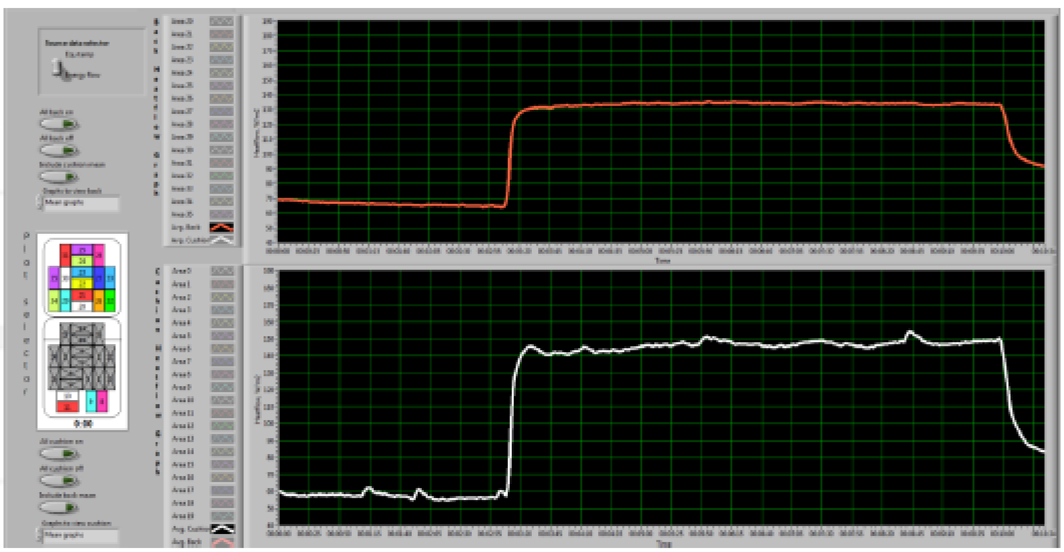
Arnold & Andrea



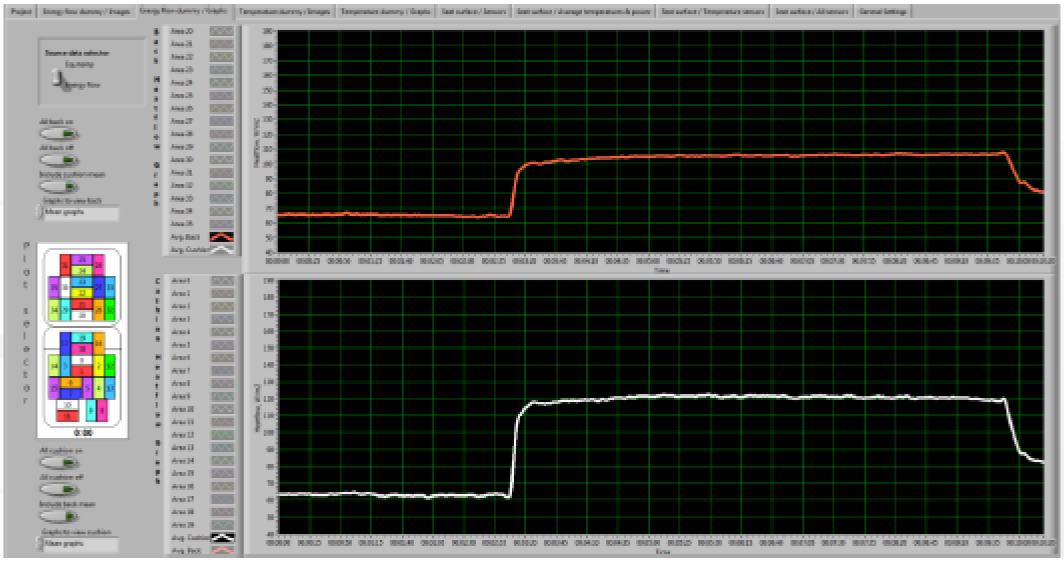


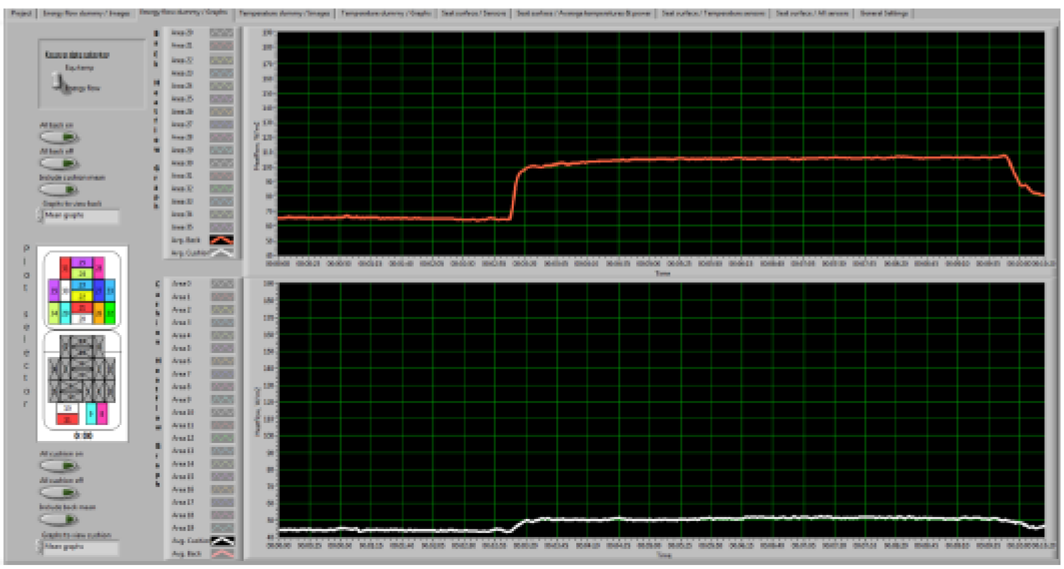
Ferdinand & Heidi





Moritz and Klara





Appendix B: Mahöle mat

Ferdinand & Heidi

0s

K1	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	41	40	41	41	41	41	41	41	41	41	41	41	41	40	41	42
2	42	41	42	42	42	42	42	42	42	42	42	42	41	41	41	42
3	42	41	42	42	42	42	42	42	42	42	42	42	41	41	42	42
4	41	41	41	41	42	42	42	42	42	41	41	42	41	42	42	43
5	41	41	41	41	41	41	41	41	41	41	41	42	41	42	42	43
6	41	41	41	41	41	41	41	41	41	41	41	42	41	42	42	44
7	41	41	42	41	41	41	41	41	41	41	41	42	41	42	42	44
8	41	41	42	42	41	41	41	41	41	41	41	42	41	42	42	43
9	41	41	42	42	41	41	41	41	41	41	41	42	41	42	42	42
10	41	41	42	42	42	42	42	42	42	42	42	42	41	41	42	42
11	41	42	42	41	41	41	41	41	41	41	42	42	41	42	42	43
12	42	41	42	41	41	41	41	41	41	41	41	42	42	42	42	43
13	42	42	42	41	41	41	41	41	41	41	41	42	42	43	43	43
14	42	42	42	42	42	42	42	42	42	41	42	42	42	43	43	43
15	41	42	42	42	42	42	42	42	42	42	42	42	42	42	43	43
16	41	41	41	41	41	41	41	41	41	42	42	42	42	42	43	43

K2	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	42	42	42	42	42	42	42	42	42	42	41	42	42	42	41	42
2	42	42	41	41	41	41	41	42	42	42	41	41	42	42	41	41
3	42	41	41	41	41	41	41	42	42	41	41	41	42	42	42	41
4	42	41	41	41	41	41	41	41	42	41	41	41	42	42	42	42
5	42	41	41	41	41	41	41	41	41	41	41	41	42	42	42	42
6	41	41	41	41	41	41	41	41	41	41	41	41	42	42	42	42
7	41	41	41	41	41	41	41	41	41	41	41	41	42	42	42	42
8	41	41	41	41	41	41	41	41	41	41	41	41	42	42	42	42
9	41	41	41	41	41	41	41	41	42	41	41	41	42	42	42	42
10	41	41	41	41	41	41	41	41	41	41	41	42	42	41	42	42
11	41	41	41	41	41	41	41	41	41	41	41	42	42	41	41	41
12	41	41	41	41	41	41	41	41	41	41	41	42	42	41	41	41
13	41	41	41	41	41	41	41	41	41	41	41	41	42	41	41	41
14	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41	41
15	41	41	41	41	41	41	41	41	41	41	41	41	41	42	42	42
16	41	41	41	41	41	41	41	41	41	40	-130	42	42	42	42	42

20s

K1	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	37	40	37	36	36	37	37	38	38	37	36	35	36	39	40	39
2	35	34	36	35	38	39	37	39	38	39	38	35	34	38	38	39
3	35	38	37	36	38	38	38	40	38	39	38	35	38	39	37	40
4	39	39	39	38	39	38	38	40	38	39	39	35	39	38	38	37
5	40	39	39	39	39	39	38	40	38	39	39	38	39	39	40	38
6	39	39	38	39	39	39	39	39	39	39	39	37	39	39	39	39
7	39	39	39	39	39	38	39	38	39	39	39	38	39	39	38	40
8	39	40	40	38	38	38	38	36	39	39	38	39	39	39	38	41
9	39	39	39	38	38	39	38	36	38	38	39	39	39	39	39	41
10	37	38	38	38	38	38	37	37	37	37	37	36	38	38	38	40
11	37	38	38	39	39	39	37	37	39	39	39	38	38	38	38	36
12	37	38	38	38	38	38	39	39	40	38	38	38	38	38	40	35
13	38	38	37	38	39	38	37	37	39	38	38	38	39	38	39	34
14	38	39	39	38	39	39	38	39	39	38	38	38	40	38	37	35
15	37	39	38	38	38	38	39	39	39	40	38	38	38	38	38	35
16	39	38	38	38	38	39	39	39	39	40	38	39	39	40	38	34

K2	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	35	36	37	37	38	38	39	39	38	38	38	38	39	39	39	39
2	35	36	37	37	37	38	38	38	38	38	38	37	38	40	39	39
3	36	38	39	37	36	37	38	38	37	37	36	36	37	40	40	39
4	37	39	38	36	35	37	35	36	36	36	36	34	36	39	39	38
5	37	38	37	36	35	37	37	38	38	37	38	33	35	37	38	36
6	37	37	37	36	34	38	37	38	38	37	38	34	34	36	35	36
7	37	38	36	35	36	37	37	38	38	38	38	37	35	36	36	36
8	37	38	37	35	36	37	38	38	38	38	38	37	35	37	38	37
9	38	38	38	37	35	36	37	38	38	38	35	35	38	38	38	38
10	37	37	38	38	37	39	39	40	40	39	39	36	38	38	38	39
11	38	38	39	39	38	39	39	40	41	38	38	37	40	38	38	39
12	39	38	38	40	38	38	39	40	40	39	38	37	39	38	39	39
13	39	38	38	39	37	37	39	41	40	38	37	37	38	37	37	39
14	40	38	38	39	38	39	39	39	40	39	37	37	37	37	37	38
15	38	39	39	39	35	35	35	36	38	39	38	38	38	37	39	38
16	37	38	38	38	38	38	38	38	39	37	-130	38	39	40	40	38

40s

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	33	39	34	30	32	35	35	35	35	34	32	31	33	38	39	38
2	30	29	30	30	35	37	35	37	36	37	36	31	30	35	36	37
3	30	34	34	32	36	36	36	39	37	37	36	31	35	37	33	38
4	37	37	36	36	37	37	37	39	37	37	37	32	36	36	35	33
5	39	37	37	37	38	38	37	39	37	37	38	35	37	37	39	35
6	38	37	37	37	38	38	37	35	38	38	38	35	37	37	38	38
7	38	38	37	37	37	37	37	35	37	37	38	36	38	38	36	38
8	38	39	38	37	37	36	36	30	37	37	37	37	38	38	37	40
9	37	38	37	37	37	37	36	31	36	37	38	37	38	38	38	39
10	36	37	37	36	36	36	32	33	33	35	35	34	36	36	37	39
11	36	37	37	38	37	37	34	34	36	36	37	36	37	37	37	33
12	36	37	37	37	37	37	38	37	39	37	37	37	37	37	38	31
13	37	36	36	37	38	37	32	34	37	37	37	37	37	37	37	30
14	35	37	38	37	38	36	32	37	38	37	37	37	38	35	34	30
15	34	38	37	37	37	33	34	37	37	39	37	37	37	37	36	30
16	38	37	37	37	37	37	37	37	38	39	37	38	38	40	33	30

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	31	31	32	34	35	35	36	36	35	36	35	35	37	37	37	37
2	31	32	33	33	33	34	36	36	35	35	34	33	36	38	38	37
3	32	35	36	33	32	33	36	36	34	34	32	31	33	38	38	38
4	33	38	36	32	30	34	32	34	32	31	33	30	31	37	37	35
5	33	36	33	31	30	35	36	36	36	36	36	29	30	34	35	31
6	33	34	32	31	32	36	36	36	37	36	36	33	30	31	30	31
7	35	37	33	31	34	36	36	36	37	36	36	35	32	33	32	32
8	36	36	35	32	34	36	36	37	37	36	36	35	32	35	36	33
9	36	36	37	36	32	34	35	36	36	35	33	32	36	36	36	37
10	35	34	37	36	35	37	37	40	39	37	37	33	36	36	37	38
11	36	36	38	38	36	37	37	40	40	36	36	34	38	36	36	38
12	37	36	37	38	36	36	38	40	40	38	36	35	37	37	37	38
13	39	36	36	38	35	35	37	39	39	36	35	35	36	35	36	37
14	39	37	36	37	36	37	38	38	39	37	35	35	35	35	35	36
15	36	37	38	37	34	35	34	36	38	37	36	36	36	35	37	36
16	34	35	37	37	36	37	37	37	38	36	-130	35	38	39	40	35

1min

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	32	39	32	28	30	33	34	34	34	33	31	29	31	37	39	37
2	28	27	28	28	34	36	34	36	35	35	35	29	28	34	35	36
3	28	32	32	31	35	35	35	38	36	35	35	30	33	35	31	36
4	35	35	35	34	36	36	36	39	36	36	35	31	35	34	34	31
5	38	36	35	35	37	37	36	38	37	37	36	33	36	36	38	34
6	38	37	36	36	37	37	36	33	37	37	37	34	36	36	37	37
7	38	37	36	36	36	36	36	32	36	36	37	34	36	37	36	38
8	38	38	37	36	36	35	35	28	36	35	36	36	37	38	36	40
9	37	37	36	36	36	36	34	28	35	36	36	36	37	37	38	39
10	36	36	36	36	36	35	30	30	30	34	35	34	36	36	36	38
11	36	37	36	37	36	35	32	32	34	34	36	36	36	36	36	31
12	36	37	37	37	37	37	37	36	38	36	37	37	36	36	37	29
13	36	36	36	37	38	37	30	33	36	36	37	37	35	36	36	28
14	34	35	37	37	37	34	29	36	37	36	37	37	37	33	32	28
15	33	37	37	37	36	30	31	36	36	38	36	37	37	37	35	28
16	38	36	37	37	37	36	36	36	37	38	37	37	37	39	31	28

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	29	30	30	32	33	33	35	34	34	34	33	32	35	35	35	35
2	30	30	31	31	31	32	35	34	32	33	32	31	34	37	36	36
3	31	34	35	31	30	30	35	34	32	32	30	29	31	37	37	36
4	32	37	35	30	29	32	31	33	30	29	31	27	29	36	36	34
5	32	35	31	29	29	34	35	35	35	35	35	28	28	32	34	30
6	32	32	31	30	32	35	35	35	36	35	35	32	29	29	29	29
7	35	36	31	30	34	35	35	36	36	36	35	34	31	32	31	30
8	36	35	34	32	33	35	35	36	36	36	35	34	31	35	36	33
9	35	35	36	35	31	33	34	35	35	35	32	32	35	36	36	37
10	34	33	36	35	34	36	36	39	39	36	36	32	35	36	36	37
11	35	35	37	37	34	36	36	39	40	36	35	33	37	36	36	38
12	36	36	36	37	35	35	37	39	40	37	35	34	36	36	37	37
13	38	35	36	37	34	34	36	38	39	35	35	34	35	35	35	37
14	38	36	35	36	35	35	36	37	39	36	34	34	34	34	34	36
15	34	35	37	36	33	34	34	36	38	36	35	35	35	34	36	34
16	32	33	37	36	35	36	36	37	37	35	-130	34	37	38	39	34

3min

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	29	35	29	26	27	31	32	32	32	31	29	26	27	33	35	33
2	26	26	26	26	30	32	32	33	33	32	31	27	26	30	30	31
3	26	29	29	28	32	32	34	35	34	33	32	27	30	31	28	32
4	31	32	32	31	33	34	35	37	35	33	32	29	32	32	30	28
5	36	33	32	32	34	35	34	35	35	36	34	30	33	34	35	29
6	36	35	33	33	35	35	34	30	35	35	35	31	34	34	35	31
7	36	35	34	33	34	33	33	28	34	34	34	32	34	35	34	33
8	36	36	34	34	34	33	33	25	33	33	34	33	34	35	35	36
9	36	35	34	34	34	33	32	25	32	33	34	34	35	35	36	35
10	35	35	35	35	34	33	26	26	27	32	33	33	35	34	35	35
11	35	36	35	34	32	31	28	28	30	30	33	35	35	35	35	28
12	35	36	36	37	37	36	32	32	35	36	36	36	35	35	35	26
13	34	34	35	37	37	36	26	29	33	36	36	36	33	34	32	26
14	31	31	35	37	36	31	25	31	33	35	36	36	35	31	29	26
15	31	35	36	37	35	27	27	31	32	35	36	37	36	36	33	25
16	35	36	36	36	35	31	32	32	33	35	36	36	36	37	29	25

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	27	27	27	28	28	29	31	31	30	30	29	28	31	31	31	31
2	27	27	28	28	28	29	32	30	28	29	28	27	29	33	32	32
3	27	30	31	27	27	28	32	32	29	29	27	26	27	33	33	33
4	28	32	30	27	27	29	29	30	29	29	28	26	26	32	32	30
5	27	30	28	27	27	33	34	33	33	33	33	27	26	30	31	27
6	28	28	28	27	29	33	34	34	34	34	34	31	27	28	28	27
7	30	32	28	27	31	33	34	34	35	34	34	32	30	31	30	29
8	30	31	29	29	30	33	34	34	34	34	34	32	31	34	35	33
9	30	30	31	30	29	31	32	33	32	33	31	31	33	35	35	35
10	29	28	32	31	30	31	34	36	36	35	33	31	33	35	35	35
11	31	30	34	33	30	32	33	35	38	34	33	31	34	35	35	36
12	33	34	34	34	31	32	34	36	37	34	33	32	33	34	35	35
13	35	34	34	34	32	33	33	35	35	33	33	32	33	34	34	35
14	35	34	33	34	32	33	33	34	35	33	32	32	33	33	33	34
15	31	32	35	34	32	33	33	34	35	34	33	32	34	33	34	32
16	29	30	35	34	33	34	34	35	34	33	-130	31	35	36	37	30

5min

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	27	33	27	25	27	30	31	31	31	30	28	26	26	31	33	31
2	25	25	26	25	29	31	32	32	32	31	30	26	25	28	28	29
3	25	29	28	27	31	32	33	34	33	32	32	27	29	29	27	30
4	30	31	31	30	32	33	34	36	35	33	32	28	31	31	28	27
5	34	33	32	31	33	35	34	34	35	35	33	30	32	33	33	28
6	35	34	33	32	34	34	33	29	34	34	33	30	33	34	34	29
7	35	34	33	32	33	33	32	28	33	33	33	31	33	34	33	30
8	35	35	33	33	34	32	32	25	32	33	34	32	33	34	34	33
9	35	35	34	34	34	33	31	24	31	33	33	33	34	34	35	33
10	35	35	35	34	33	32	26	25	27	32	33	33	35	34	35	32
11	35	36	35	32	31	30	27	27	29	30	32	35	35	35	35	27
12	35	35	35	36	37	36	30	30	34	36	36	36	34	35	33	26
13	33	34	34	37	37	35	26	27	33	36	36	36	33	33	31	27
14	30	30	35	37	36	33	25	29	32	35	36	36	34	30	28	26
15	31	34	36	37	35	30	26	29	31	35	36	36	36	35	32	25
16	34	35	36	36	35	31	30	29	31	34	36	36	36	35	27	24

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	27	27	28	28	28	29	30	30	29	29	28	28	30	30	30	30
2	27	27	28	27	27	28	30	29	28	28	27	26	29	31	31	31
3	27	30	30	27	27	28	31	31	29	29	26	26	27	31	31	31
4	27	31	29	27	27	30	30	30	30	28	29	26	26	30	30	28
5	26	28	27	26	26	32	33	32	32	32	32	27	26	28	28	26
6	26	27	26	27	29	32	33	33	33	33	33	30	28	26	26	26
7	29	31	27	27	30	33	33	33	34	34	34	32	30	30	28	27
8	29	30	30	29	30	33	34	34	34	34	34	32	30	34	34	31
9	29	31	32	31	29	30	32	32	32	32	31	31	33	35	35	34
10	29	29	32	31	28	31	33	34	35	34	33	31	33	35	35	34
11	29	30	32	32	30	31	33	33	35	34	33	31	34	34	35	35
12	31	33	34	33	30	32	33	34	35	33	33	32	33	34	34	34
13	34	33	33	33	32	32	32	33	34	33	33	32	33	34	34	34
14	33	33	33	33	32	32	33	33	33	32	32	32	33	33	33	34
15	29	31	34	33	32	33	33	33	34	33	32	32	33	33	33	32
16	28	28	34	34	32	33	33	34	33	32	-130	30	34	35	35	29

10min

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	26	30	25	25	26	29	31	30	30	30	28	25	26	29	30	28
2	25	25	26	25	28	30	31	31	31	30	30	26	25	26	26	27
3	25	28	27	27	30	31	32	33	33	31	31	26	28	27	25	27
4	28	30	30	29	31	32	34	34	34	32	31	28	30	30	26	25
5	32	32	31	30	32	34	34	33	34	34	32	29	31	32	30	25
6	33	33	32	31	33	33	32	29	33	33	33	30	32	33	31	26
7	34	33	32	31	32	32	31	28	32	32	32	30	32	33	31	26
8	33	34	32	33	33	32	31	25	31	32	33	32	32	33	32	29
9	34	34	33	33	33	32	31	25	31	33	33	33	33	34	33	29
10	35	35	34	34	33	32	25	25	28	32	32	32	34	34	32	28
11	34	35	35	31	30	29	26	26	28	29	31	34	34	34	32	25
12	34	35	35	36	36	35	29	27	34	36	36	36	34	34	30	24
13	32	34	35	36	36	35	26	26	33	36	36	36	32	32	28	25
14	28	31	35	36	35	33	24	26	31	35	36	36	34	29	27	25
15	30	34	36	36	35	30	25	26	30	34	36	36	36	33	29	24
16	30	35	36	36	35	32	26	27	29	34	36	36	35	33	24	24

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	26	26	27	28	27	28	29	29	28	28	27	27	28	28	28	28
2	26	27	28	27	27	28	31	30	29	28	27	26	27	29	29	29
3	26	28	29	26	28	29	32	32	31	31	28	27	26	29	29	29
4	26	29	28	27	30	32	32	32	32	30	31	29	27	28	28	27
5	26	27	26	28	30	33	33	33	33	33	33	30	27	28	27	25
6	26	26	26	28	30	32	33	33	33	33	33	31	29	28	28	26
7	28	29	27	29	30	32	33	33	34	34	33	32	29	29	30	28
8	28	29	31	30	30	32	33	33	34	34	33	32	30	34	34	30
9	28	30	32	31	29	30	32	32	32	33	31	30	33	34	35	32
10	27	28	32	31	28	30	33	33	34	34	32	31	33	34	34	33
11	28	28	31	31	29	31	32	32	33	33	33	31	33	34	34	33
12	29	33	33	33	30	31	32	33	33	32	33	32	33	34	34	33
13	31	33	33	33	31	32	32	33	33	32	32	32	32	33	33	33
14	31	33	33	33	31	31	32	33	32	32	32	32	32	33	33	33
15	27	29	32	32	31	32	32	32	33	32	31	31	32	33	32	31
16	26	26	32	32	30	31	32	32	32	31	-130	29	32	33	32	28

30min

K1

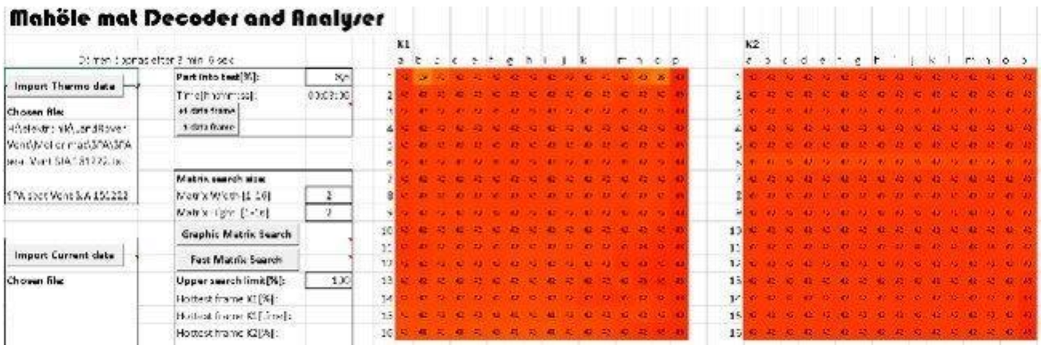
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	24	27	24	25	27	28	30	28	28	29	27	25	25	26	27	26
2	24	24	25	26	27	29	31	30	30	29	29	25	25	25	25	25
3	24	26	26	26	30	30	32	32	32	30	31	26	28	26	25	25
4	26	29	30	28	30	32	33	33	33	32	31	27	30	30	26	25
5	30	31	30	29	31	33	33	33	34	34	31	28	30	32	29	25
6	32	33	31	31	32	32	32	30	33	33	32	30	31	32	30	26
7	32	33	31	30	32	32	30	29	31	32	32	30	31	32	30	26
8	32	33	31	32	33	31	31	25	31	32	32	31	31	32	32	27
9	34	34	33	32	33	32	30	24	31	32	32	32	32	33	32	26
10	34	34	34	33	33	31	25	24	28	32	32	32	34	34	32	26
11	34	35	34	31	28	28	25	26	27	28	30	33	34	34	32	25
12	33	35	35	35	36	35	28	27	33	35	36	36	34	33	28	24
13	30	34	35	36	36	35	25	26	32	36	36	36	31	31	26	24
14	27	29	35	36	35	32	24	26	31	35	36	36	35	28	25	24
15	28	34	36	36	34	30	24	26	29	34	36	36	36	33	27	24
16	28	34	36	36	35	31	26	26	28	34	36	36	35	32	24	24

K2

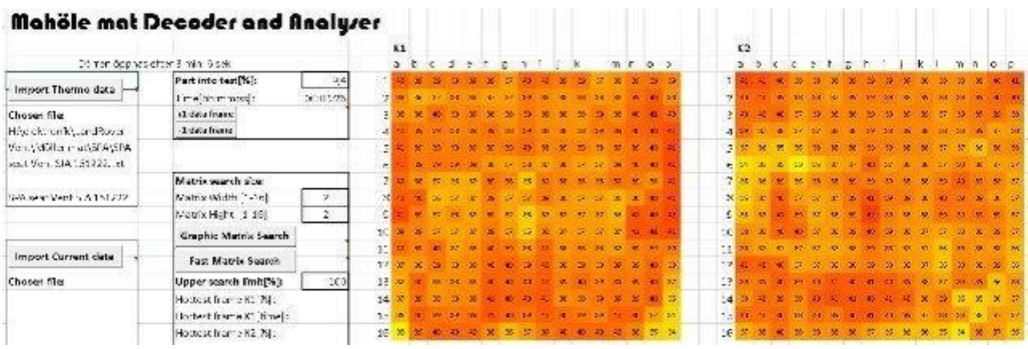
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	25	26	26	27	26	27	28	28	27	26	26	26	27	26	26	26
2	26	27	28	26	26	29	31	30	29	29	26	25	26	27	27	26
3	27	28	28	27	31	31	33	32	31	31	28	30	26	27	28	27
4	28	29	30	29	31	32	32	33	32	30	31	31	29	31	30	28
5	28	30	30	30	31	33	33	34	33	33	33	31	29	31	30	27
6	29	29	28	30	31	33	34	34	34	34	33	31	28	30	30	28
7	28	28	28	29	31	32	34	34	34	34	34	32	29	30	31	30
8	26	29	31	30	31	33	34	34	34	34	34	32	30	33	32	29
9	26	30	32	31	30	31	33	33	33	33	31	31	32	34	34	30
10	26	27	30	31	30	32	33	33	34	34	33	31	32	34	34	31
11	26	27	29	30	30	32	32	33	33	33	33	31	32	34	33	30
12	27	32	32	31	31	32	32	32	32	32	33	32	32	33	33	31
13	28	32	33	32	31	31	32	33	32	32	32	31	32	34	33	31
14	29	32	33	32	31	31	32	33	32	32	31	32	32	33	33	32
15	26	28	30	31	30	31	32	32	32	31	31	31	32	32	32	30
16	25	26	29	29	28	30	31	30	30	30	-130	28	30	31	30	27

SPA seat in Chamber

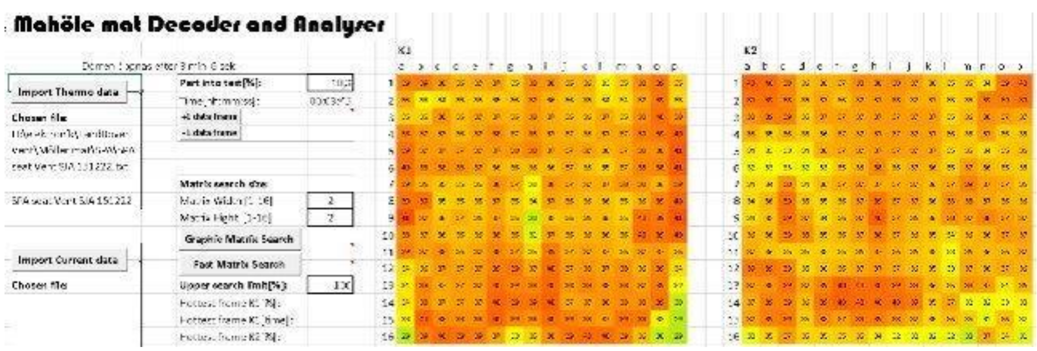
0s



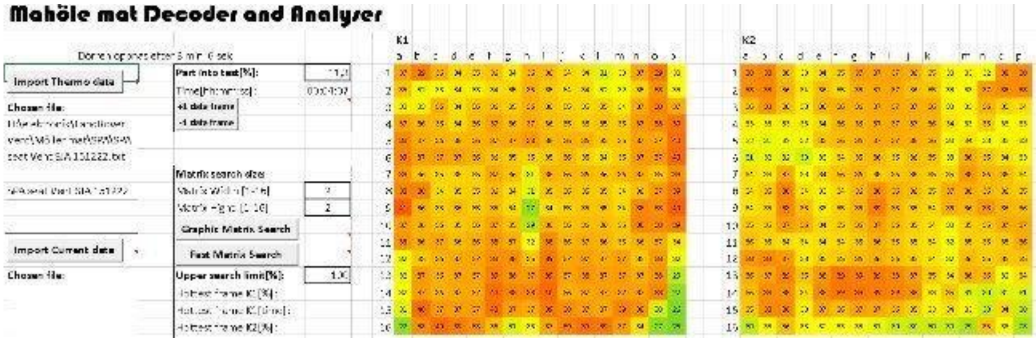
20s



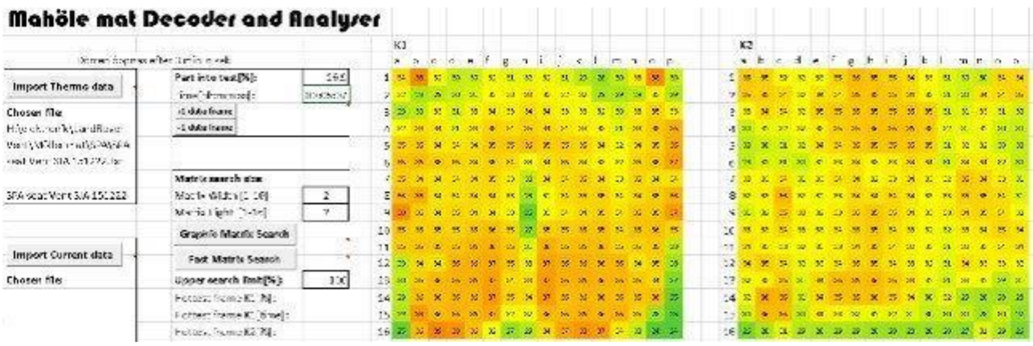
40s



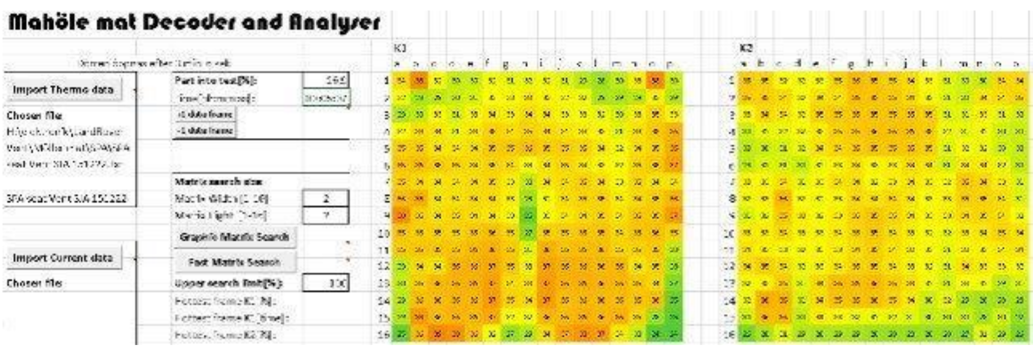
1min



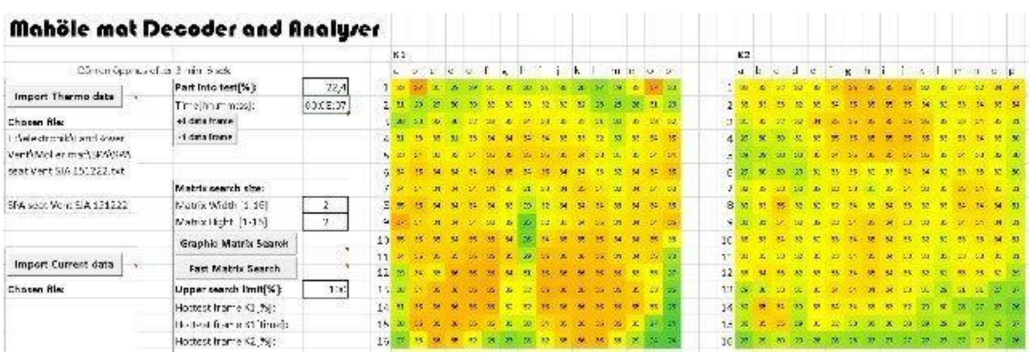
3min



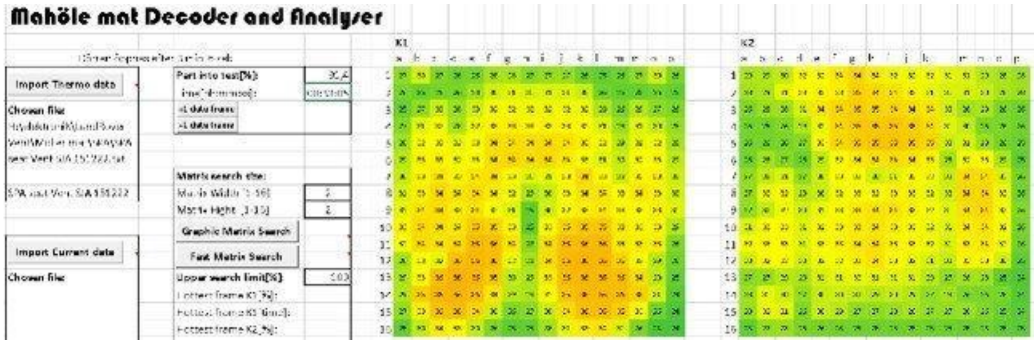
5min



10min



30min



Moritz & Klara

0s

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	42	41	41	42	42	42	42	42	42	42	42	42	42	41	41	42
2	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
3	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
4	42	42	42	42	42	42	42	42	42	42	42	42	42	42	43	43
5	42	42	42	42	42	42	42	42	42	42	42	42	42	42	43	44
6	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	43
7	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	43
8	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	43
9	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
10	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
11	42	42	42	42	42	42	42	42	42	42	42	42	42	42	43	42
12	42	42	42	41	42	42	42	42	42	42	42	42	42	43	43	43
13	42	42	42	42	42	42	42	42	42	42	42	42	43	43	43	43
14	42	42	42	42	42	42	42	42	42	42	42	42	42	43	43	43
15	41	41	42	42	42	42	42	42	42	42	42	42	42	42	43	43
16	42	42	41	41	41	42	42	42	42	42	42	42	42	42	43	43

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	43	42	42	42	43	43	43	43	43	42	42	43	43	43	43	43
2	43	42	42	42	43	43	43	43	43	42	42	43	43	43	43	43
3	43	42	42	42	43	43	43	43	43	42	42	43	43	43	43	43
4	43	42	42	42	43	43	43	43	43	43	42	43	43	43	43	43
5	43	43	42	42	42	42	43	43	43	43	43	43	43	43	43	43
6	43	43	42	42	42	42	42	43	43	43	43	43	43	43	43	43
7	43	42	42	42	42	42	42	42	43	42	42	43	43	43	43	43
8	42	42	42	42	42	42	42	42	42	42	42	43	43	43	43	42
9	42	42	42	42	42	42	42	42	42	42	43	43	43	43	43	42
10	42	42	42	42	42	42	42	42	42	42	43	43	43	43	42	42
11	42	42	42	42	42	42	42	42	42	43	43	43	43	43	42	42
12	42	42	42	42	42	42	42	42	42	42	43	43	43	42	42	42
13	42	42	42	42	42	42	42	42	42	42	43	43	42	42	42	42
14	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42
15	42	42	42	42	42	42	42	42	42	42	42	42	42	42	42	43
16	43	42	42	42	42	42	42	42	42	41	-130	42	42	42	42	43

20s

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	38	39	39	38	36	37	37	38	37	38	37	37	38	40	41	40
2	37	36	36	37	38	39	39	40	40	39	37	38	37	36	36	39
3	36	36	37	36	38	39	38	40	39	39	39	38	38	37	36	36
4	38	40	40	37	39	39	38	40	38	39	39	40	39	39	37	37
5	40	39	39	37	40	38	38	39	39	40	39	39	39	39	40	38
6	40	39	39	38	39	38	38	39	38	39	40	39	39	39	40	39
7	39	40	39	39	40	39	39	41	39	40	40	40	40	40	39	40
8	40	40	39	40	40	39	39	41	39	40	40	39	39	40	39	41
9	38	40	40	39	39	39	39	40	40	39	39	40	40	41	39	41
10	38	38	38	37	37	38	39	38	39	39	39	39	39	39	39	40
11	38	38	38	39	38	37	40	39	40	38	37	37	38	38	38	40
12	38	38	38	38	38	38	39	38	38	38	38	38	38	38	38	39
13	38	37	38	39	39	38	40	38	40	38	38	38	38	38	37	37
14	38	38	38	38	39	39	38	39	39	39	39	39	38	37	36	36
15	38	38	38	39	39	40	40	39	39	40	39	39	38	38	38	36
16	39	38	38	38	38	40	39	38	38	39	38	39	38	38	38	35

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	38	40	40	40	39	39	40	41	41	41	40	38	37	37	39	39
2	38	40	40	40	38	39	40	40	41	40	39	39	38	39	39	40
3	39	40	40	39	38	39	39	39	39	39	38	39	38	40	39	40
4	38	40	40	39	39	39	39	39	39	39	39	39	38	39	38	38
5	38	39	39	39	38	39	39	39	39	39	39	39	38	37	37	37
6	38	37	36	38	38	38	38	39	39	39	39	39	37	38	38	38
7	36	37	37	36	38	38	38	39	39	39	39	39	38	39	40	39
8	36	36	37	37	38	38	39	39	39	39	39	38	40	39	40	40
9	36	37	38	39	37	37	38	39	39	39	39	39	41	40	39	39
10	36	36	39	39	39	39	39	39	39	39	38	39	41	40	40	40
11	36	38	40	40	38	38	38	39	39	38	38	37	38	38	38	39
12	37	38	38	37	38	38	38	39	40	38	38	37	38	38	38	39
13	37	38	38	37	38	38	38	39	39	38	38	37	38	38	39	38
14	37	38	38	37	38	38	39	40	39	39	38	37	38	39	36	36
15	36	37	39	39	38	39	39	38	38	37	38	37	37	35	35	36
16	36	36	37	39	38	39	39	38	38	37	-130	37	36	35	35	36

40s

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	36	38	38	34	32	33	33	34	34	34	34	34	35	39	41	38
2	35	32	32	33	34	36	37	38	37	37	34	35	33	32	32	37
3	33	33	34	34	36	37	37	39	37	38	37	35	35	34	32	32
4	35	38	39	34	38	38	37	38	37	38	38	38	35	37	34	33
5	39	38	38	34	39	37	37	38	37	38	38	37	36	38	38	34
6	39	38	38	35	38	37	37	38	37	38	38	38	38	38	39	36
7	38	38	38	36	39	38	38	40	38	38	38	38	38	39	38	37
8	40	38	38	38	39	38	38	40	38	39	39	38	38	39	37	39
9	37	39	39	38	38	37	38	38	39	38	38	39	39	40	37	39
10	37	37	37	36	36	37	36	35	37	37	37	37	37	38	38	39
11	37	37	37	38	37	36	38	36	39	37	36	36	37	36	37	39
12	37	37	38	37	38	38	38	35	37	37	37	37	37	37	37	37
13	35	36	37	38	38	38	38	36	38	37	38	37	37	37	35	33
14	36	37	37	38	38	38	35	37	37	38	38	38	37	35	34	32
15	36	37	38	38	38	39	36	39	37	38	38	37	37	37	36	31
16	37	37	37	38	37	38	39	37	36	38	38	38	37	37	35	30

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	33	37	39	37	35	36	38	39	40	40	39	34	34	33	35	36
2	34	39	39	37	34	36	39	39	40	39	39	37	34	37	37	38
3	35	38	38	35	34	37	38	38	38	38	37	38	34	38	37	38
4	34	37	38	35	35	38	38	38	38	38	38	38	35	37	36	34
5	34	36	36	36	36	37	38	38	38	37	37	38	36	36	34	33
6	34	34	33	35	35	37	37	38	38	38	37	37	35	37	36	37
7	33	33	34	34	35	37	37	38	38	37	37	37	36	38	38	38
8	33	33	34	35	36	37	37	38	38	37	37	36	38	38	38	39
9	33	33	35	36	35	35	35	38	38	37	37	37	39	39	38	38
10	33	32	37	35	36	37	37	38	38	37	37	37	40	39	38	38
11	33	36	39	38	36	37	37	38	38	37	37	35	37	37	37	37
12	35	37	37	36	36	37	37	37	38	37	36	35	37	37	37	37
13	35	36	36	35	36	36	37	36	37	37	36	35	37	37	37	35
14	33	37	36	36	36	37	37	37	37	37	36	34	36	37	33	32
15	33	33	38	37	36	37	37	35	35	34	34	34	33	31	31	31
16	32	32	34	36	34	36	36	35	35	33	-130	33	32	31	31	32

1min

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	35	38	37	32	30	30	31	32	32	32	31	31	33	38	40	37
2	33	30	31	31	32	34	35	36	35	35	32	33	30	30	30	36
3	32	31	32	32	34	36	36	38	36	37	36	34	34	33	30	30
4	34	37	37	32	37	36	36	37	36	36	37	36	33	35	33	32
5	38	37	37	33	38	36	36	37	36	37	37	36	35	37	37	33
6	38	37	37	34	37	36	36	37	36	37	38	37	36	37	38	34
7	38	38	37	35	38	38	37	39	37	38	38	37	37	38	37	36
8	39	38	37	37	38	37	37	39	37	38	39	37	37	38	37	38
9	37	39	39	37	37	37	37	37	38	37	37	38	38	39	37	38
10	37	36	36	36	36	36	35	33	36	36	37	36	36	37	38	38
11	37	36	37	38	37	36	37	34	37	36	35	35	36	36	36	39
12	37	37	37	37	37	37	38	33	37	37	37	37	36	36	37	35
13	32	35	37	37	37	37	38	34	38	37	37	37	36	36	34	31
14	36	36	37	37	38	38	34	37	36	38	38	37	37	35	33	29
15	35	37	37	37	37	38	35	38	37	37	38	37	37	36	36	29
16	35	36	37	37	37	38	38	37	36	37	37	37	37	36	34	27

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	31	36	38	36	33	34	38	39	39	39	39	32	32	31	33	34
2	32	38	38	36	32	35	38	38	40	39	38	36	32	36	36	36
3	33	38	37	33	33	37	38	38	38	37	37	37	33	37	37	37
4	33	36	37	34	35	37	37	37	38	37	37	37	33	36	35	32
5	32	34	34	35	35	37	37	37	37	37	37	37	35	35	32	32
6	32	32	31	33	34	36	36	37	37	37	37	37	35	36	36	36
7	32	31	32	33	35	36	36	37	37	37	37	36	35	37	37	38
8	32	31	32	34	35	36	36	37	37	37	37	35	37	37	37	38
9	32	31	33	34	34	34	35	37	37	37	37	36	38	38	37	38
10	31	31	35	33	34	36	36	37	37	36	36	36	40	38	37	37
11	33	34	38	37	34	36	36	37	37	36	36	35	37	36	36	36
12	33	36	36	35	35	36	36	35	37	36	35	35	36	36	36	36
13	32	36	36	35	35	36	36	34	35	36	36	34	36	36	36	33
14	31	36	36	35	35	36	36	35	35	35	35	33	35	36	32	29
15	31	30	36	35	35	36	34	33	33	32	32	32	31	30	29	29
16	30	29	31	35	32	34	34	33	33	31	-130	31	30	29	30	30

3min

K1

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	32	36	34	29	28	28	28	29	29	28	28	27	29	34	37	31
2	31	28	28	28	29	30	32	31	31	31	29	29	27	27	27	31
3	30	29	30	31	31	33	34	34	33	34	33	30	30	29	27	27
4	30	34	33	30	33	34	34	35	34	34	33	32	30	32	31	28
5	35	35	34	31	35	35	35	35	35	35	35	34	31	34	35	29
6	36	36	35	32	35	35	36	36	36	36	35	34	34	35	35	30
7	37	36	35	33	36	36	36	37	36	36	36	34	34	35	35	32
8	38	36	35	34	36	36	36	36	36	37	37	35	35	35	36	35
9	36	37	36	35	35	35	35	34	36	36	36	35	35	37	36	35
10	36	35	35	34	34	33	32	30	33	34	34	34	34	35	36	35
11	36	35	36	36	36	35	35	30	35	35	34	33	35	35	36	35
12	36	35	36	37	37	36	36	29	36	36	36	36	35	35	36	31
13	28	33	36	37	37	37	36	31	36	36	37	37	36	35	33	28
14	33	36	36	37	37	37	31	35	35	37	37	37	36	34	31	26
15	33	36	36	37	37	36	31	36	35	36	37	37	37	36	34	25
16	31	36	36	37	37	36	34	34	34	36	37	36	36	36	31	25

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	27	32	33	32	29	30	37	38	39	38	37	30	30	33	32	31
2	28	34	34	31	29	33	37	37	37	37	37	35	32	36	34	33
3	28	33	33	28	30	35	37	37	37	37	36	35	32	36	34	34
4	28	31	30	29	32	36	36	36	37	36	36	36	32	35	33	29
5	27	28	28	31	33	35	36	36	36	36	36	35	33	34	32	30
6	27	28	27	32	32	34	35	36	36	36	36	35	34	35	35	34
7	27	27	29	31	33	34	35	36	36	36	36	35	34	36	36	36
8	27	28	32	31	33	34	35	36	36	36	36	34	34	36	36	36
9	28	28	32	32	32	32	33	33	34	36	35	34	36	36	36	36
10	27	28	31	31	32	34	35	35	36	35	35	33	37	36	36	36
11	29	30	34	33	32	34	34	34	35	35	34	33	35	35	35	34
12	31	35	35	34	33	34	34	30	33	34	34	33	35	35	35	33
13	31	35	34	34	33	34	33	30	31	33	34	32	34	35	34	29
14	28	34	34	33	33	34	31	30	30	30	33	31	33	33	29	27
15	28	28	33	31	31	33	30	29	30	28	29	28	28	28	27	27
16	27	27	28	30	28	29	30	29	29	28	-130	28	28	27	27	27

5min

K1	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	31	34	32	28	27	27	27	27	27	27	27	27	28	32	35	30
2	30	27	27	27	28	29	30	30	30	30	28	28	26	26	26	29
3	29	28	29	30	31	32	33	34	33	33	32	29	29	28	26	26
4	29	32	32	29	32	33	33	34	34	33	32	31	29	31	30	27
5	33	34	33	30	34	34	34	35	35	34	34	33	30	34	33	27
6	35	35	34	31	34	35	35	36	35	35	35	33	33	34	34	28
7	36	35	34	32	35	36	36	37	36	36	35	34	34	34	34	30
8	37	35	34	33	35	35	35	35	35	36	36	34	34	35	35	32
9	36	36	35	34	35	35	34	32	35	35	35	34	34	36	36	33
10	36	35	34	33	33	32	31	28	33	34	33	33	34	35	36	33
11	36	35	35	35	35	34	34	29	34	34	34	33	34	35	35	33
12	35	35	35	36	37	36	36	28	35	36	36	36	34	35	35	30
13	28	33	35	37	37	36	35	30	35	36	36	37	35	34	33	27
14	33	35	36	37	37	37	29	34	32	37	37	37	36	34	30	25
15	34	36	36	37	37	36	31	35	33	36	37	37	36	36	34	25
16	31	36	36	37	37	35	31	29	28	35	37	36	36	36	31	24

K2	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	28	31	32	31	29	32	37	38	38	37	36	29	29	29	29	30
2	28	32	32	31	29	33	37	37	37	37	36	34	31	32	32	31
3	29	32	32	30	32	34	37	37	37	36	35	34	30	35	34	32
4	28	31	31	31	33	35	36	36	36	36	36	35	32	35	33	29
5	28	29	30	33	33	35	35	35	36	36	35	35	33	34	32	29
6	27	28	29	32	32	34	35	35	36	36	35	35	33	35	35	33
7	28	29	30	31	32	34	35	36	36	36	35	34	34	35	35	35
8	28	29	32	32	33	34	34	35	35	35	35	33	34	35	35	35
9	28	29	32	32	32	32	33	33	34	35	35	33	35	36	35	34
10	28	28	30	30	31	33	34	34	35	35	34	32	36	35	35	33
11	29	29	32	32	31	33	34	33	34	34	34	32	35	35	35	33
12	29	34	34	33	32	33	33	31	32	34	33	32	35	35	34	32
13	29	34	34	33	32	33	33	28	30	33	33	32	34	34	32	28
14	27	33	34	32	32	33	30	29	29	29	32	29	32	32	28	27
15	26	26	30	28	29	31	28	28	28	27	28	27	27	27	27	27
16	26	26	27	27	27	27	28	28	28	27	-130	27	27	27	26	26

10min

K1	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	28	31	30	27	26	26	26	26	26	26	26	25	26	29	32	28
2	28	26	26	26	27	28	30	28	29	29	26	28	26	25	25	27
3	27	27	28	29	30	31	32	32	32	32	31	28	28	27	26	25
4	28	31	31	28	31	32	33	34	33	32	32	30	28	30	29	26
5	31	33	32	30	33	34	34	34	34	33	33	32	30	33	31	26
6	34	34	33	30	33	34	35	35	35	35	34	33	32	33	32	27
7	35	34	33	31	34	35	35	36	35	35	34	33	33	34	33	28
8	35	35	33	32	34	35	35	34	35	35	35	33	33	34	34	30
9	35	35	34	33	34	34	33	31	34	34	34	33	33	35	35	30
10	35	34	34	33	33	32	31	28	32	33	33	32	33	34	35	31
11	35	34	35	34	34	34	33	28	33	33	33	32	33	34	35	30
12	34	34	35	36	36	36	35	28	35	35	36	36	34	34	35	29
13	27	32	35	36	36	36	34	29	35	36	36	36	35	34	31	26
14	32	35	36	36	36	36	29	33	31	36	37	37	36	33	29	25
15	33	36	36	36	36	35	30	34	31	36	37	36	36	36	33	24
16	29	35	36	36	36	35	29	26	26	35	36	36	36	36	30	24

K2	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	28	30	30	29	28	31	35	36	35	35	34	29	30	32	31	30
2	28	31	31	30	29	33	36	37	36	36	36	33	31	34	33	31
3	29	32	32	30	32	34	36	37	37	36	35	34	31	34	34	31
4	29	32	32	32	33	35	35	36	36	35	35	35	32	34	32	28
5	28	31	31	33	33	34	35	35	35	35	35	34	33	33	30	29
6	28	29	29	32	32	34	35	35	35	35	35	34	33	34	34	31
7	28	29	30	30	32	34	34	35	35	35	34	34	33	35	34	33
8	27	30	32	31	32	33	34	34	34	35	34	32	33	35	34	32
9	27	30	32	31	31	32	33	33	34	34	34	32	34	34	34	32
10	27	28	29	29	31	33	33	33	34	34	33	31	34	34	33	31
11	27	27	30	31	30	33	33	32	33	33	33	32	34	34	34	31
12	28	33	34	33	31	32	33	31	32	33	33	31	34	34	34	30
13	29	33	34	33	31	32	32	28	29	32	32	31	33	34	32	26
14	27	32	33	31	31	32	30	28	28	28	31	29	31	31	26	26
15	26	26	30	28	29	30	27	27	27	27	27	26	26	26	26	26
16	26	26	26	26	26	26	27	27	27	26	-130	26	26	26	25	25

30min

K1

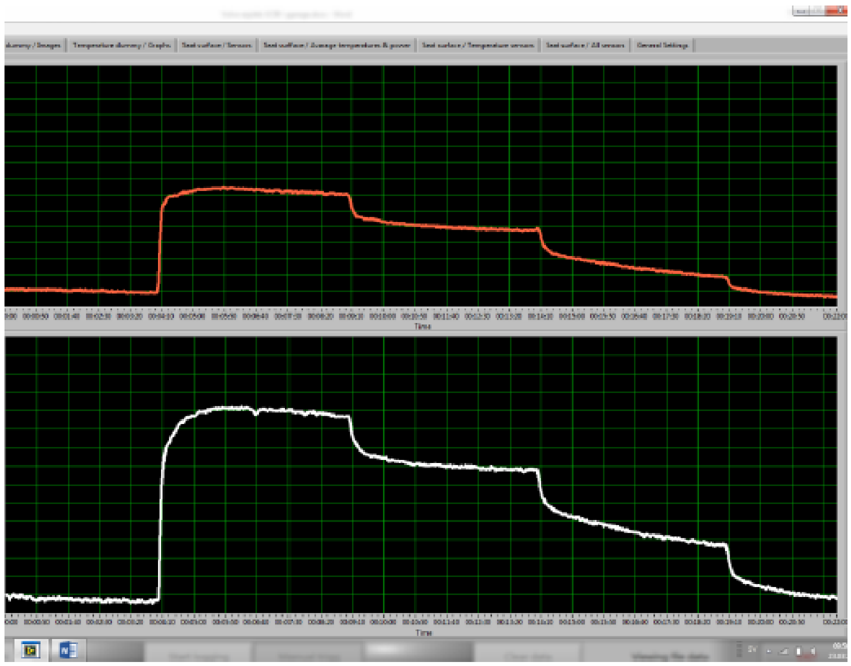
	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	26	26	26	25	24	25	25	25	25	25	25	25	25	26	27	26
2	25	24	25	25	26	27	29	27	29	29	26	27	25	25	24	25
3	25	25	27	28	29	31	32	31	31	31	30	27	27	26	25	25
4	26	30	30	27	30	31	32	33	33	32	31	29	27	29	28	25
5	28	33	32	29	32	33	33	34	34	33	33	31	29	32	30	25
6	32	33	33	29	32	34	34	34	34	34	33	32	31	33	31	26
7	33	34	32	31	34	35	35	35	35	35	34	32	32	33	33	27
8	34	34	32	32	34	34	35	34	35	35	34	33	32	33	34	28
9	35	34	33	33	34	34	33	32	33	34	34	32	32	34	34	28
10	34	34	34	32	32	32	31	28	32	32	32	31	32	34	34	29
11	34	34	34	33	33	33	33	28	32	33	32	30	33	34	34	28
12	32	34	35	36	36	36	35	27	34	35	35	35	33	34	33	26
13	26	32	35	36	36	36	34	28	35	35	36	36	35	34	30	25
14	30	35	36	36	36	36	28	32	31	36	36	36	36	33	28	24
15	32	36	36	36	36	35	28	32	30	35	36	36	36	36	32	24
16	28	35	36	36	36	34	29	27	27	35	36	36	36	36	29	24

K2

	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
1	26	27	28	28	27	29	35	36	35	35	34	29	28	29	30	27
2	26	28	29	28	29	32	35	36	36	36	35	33	30	34	33	28
3	26	29	30	29	31	34	36	36	36	36	35	34	31	35	33	28
4	26	29	31	31	32	35	35	36	36	35	35	34	31	34	32	26
5	26	27	29	32	33	34	35	35	35	35	35	34	32	32	29	27
6	26	27	28	31	32	34	35	35	36	35	35	35	32	34	33	28
7	26	28	28	29	32	34	35	35	35	35	35	34	33	34	34	31
8	26	29	32	31	32	34	34	35	35	35	34	32	33	34	34	30
9	26	30	32	32	31	32	33	33	34	34	34	32	33	34	34	30
10	26	28	30	29	30	33	33	34	34	34	34	31	33	33	34	29
11	27	27	29	30	30	33	33	33	33	33	33	31	33	34	33	29
12	27	32	33	32	31	32	32	31	32	32	32	31	33	34	33	28
13	28	33	33	32	31	31	32	26	29	32	32	30	32	33	31	26
14	26	32	33	30	31	31	30	26	26	27	31	28	30	30	26	25
15	25	26	30	27	28	30	26	26	26	25	26	26	26	25	25	25
16	25	25	25	25	25	25	25	26	25	24	-130	25	25	25	24	24

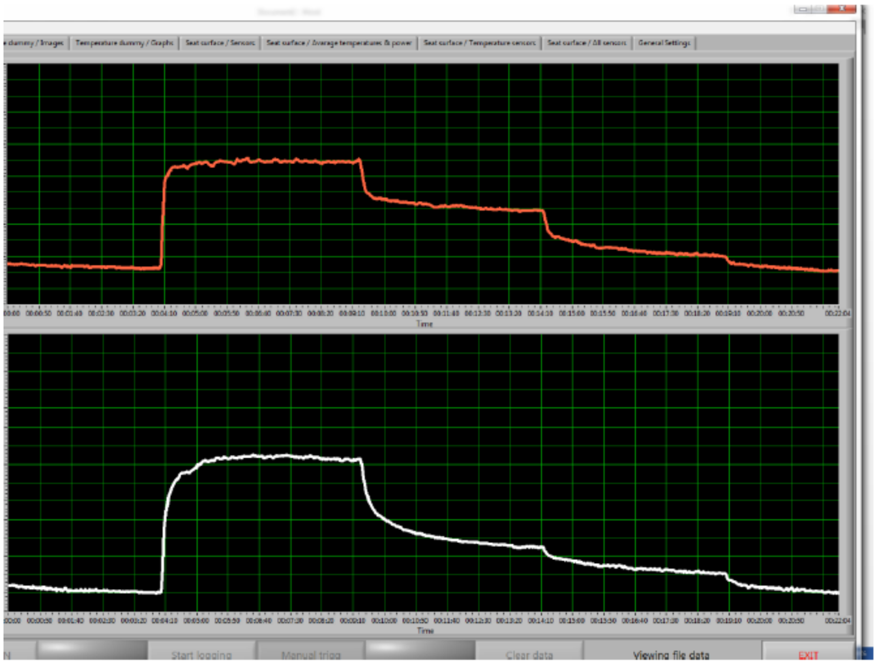
Appendix C: Benchmarking Manikin

XC90 without non-ventilated area

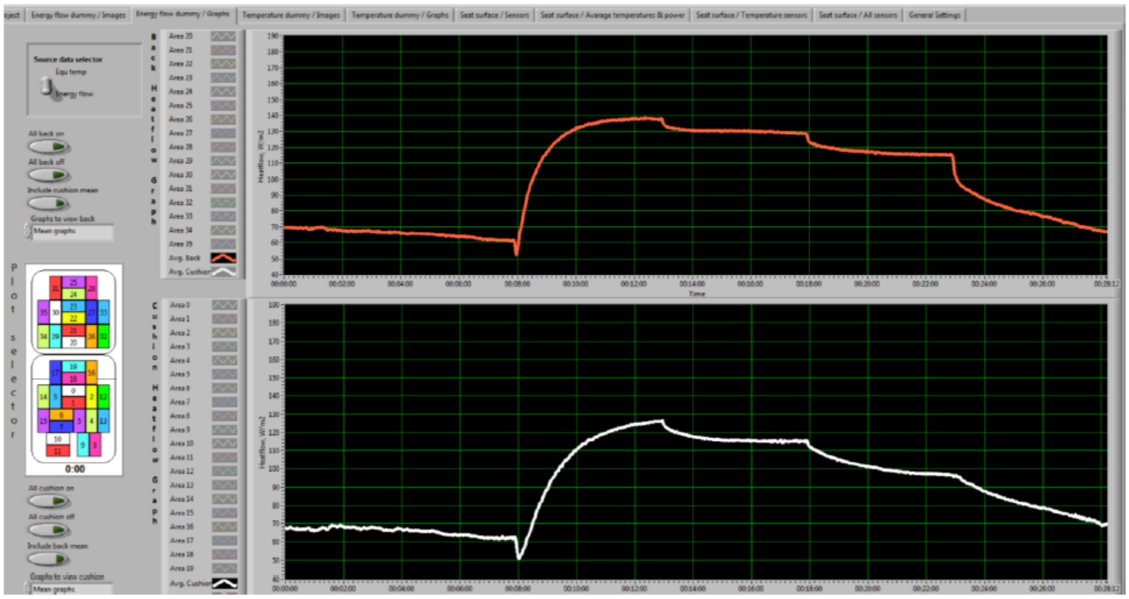


XC90 with all sensors

Volvo V70

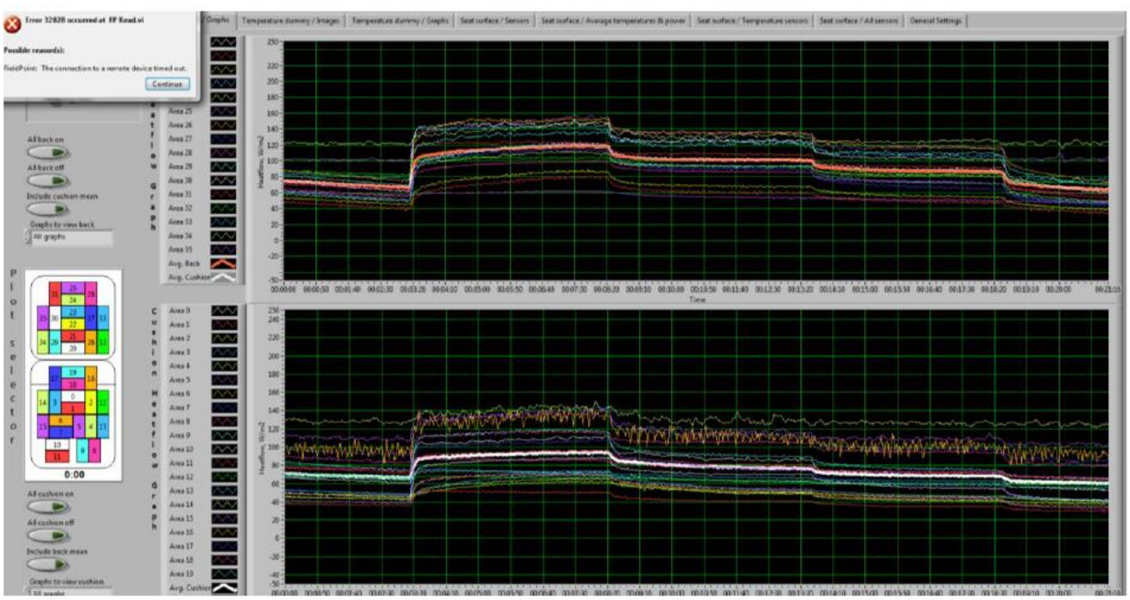

Temperature dummy / Graphs
Seat surface / Sensors
Seat surface / Average temperatures & power
Seat surface / Temperature sensors
Seat surface / All sensors
General Settings
Time
Time
Start logging
Clear data
Viewing file data
EXIT

Competitor 1



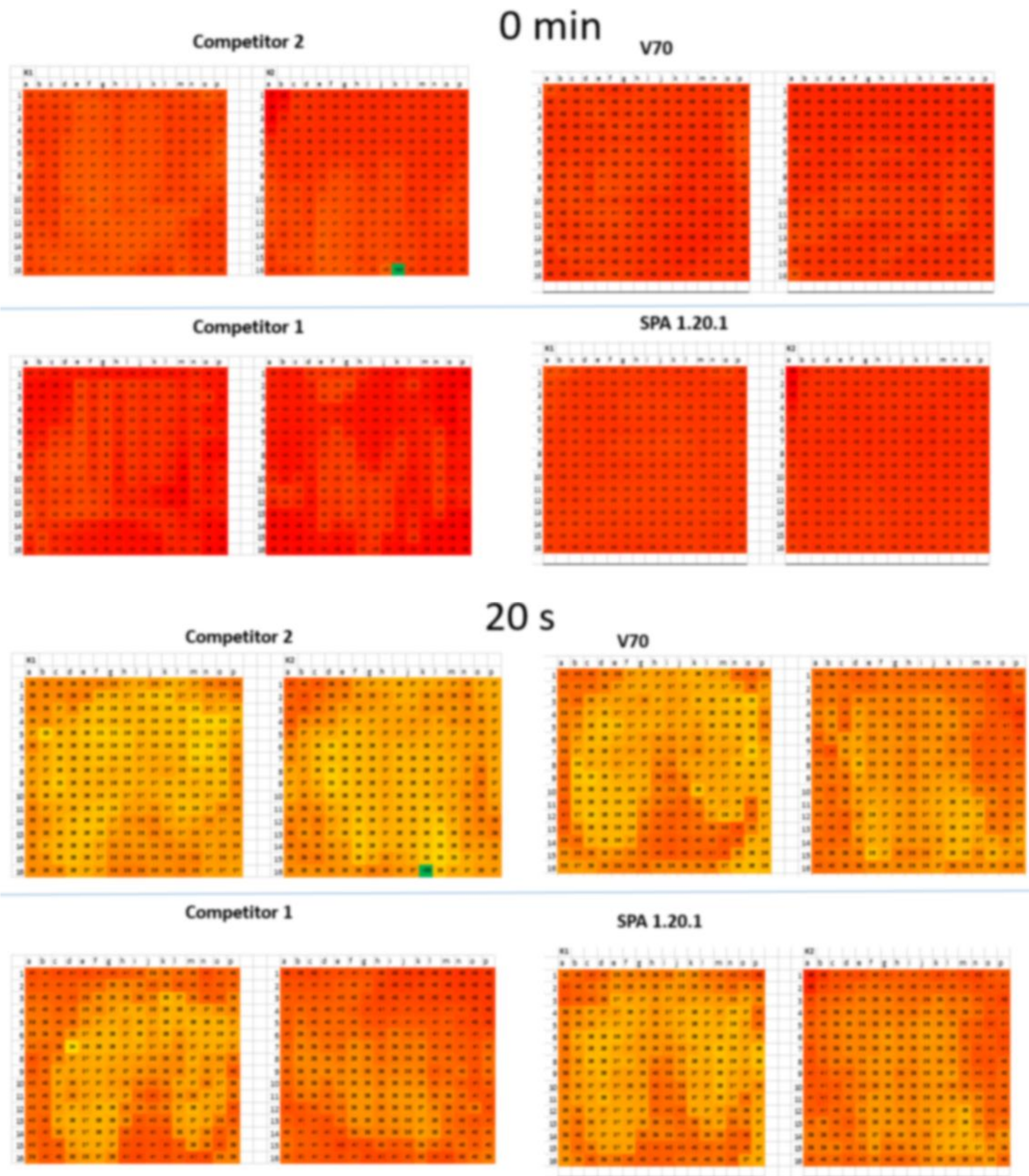
	Level 3	Level 2	Level 1
Back average	75	68	53
Cushion average	64	53	35

Competitor 2



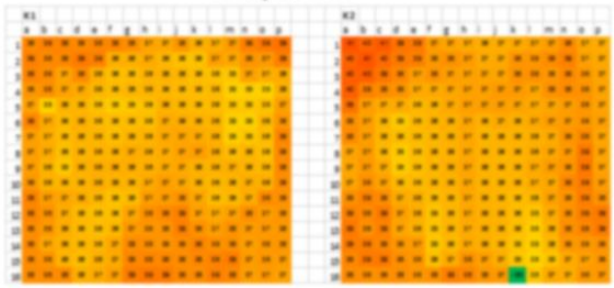
	Level 3	Level 2	Level 1
Back average	52	32	19
Cushion average	31	18	10

Appendix D: Benchmarking Mahöle mat

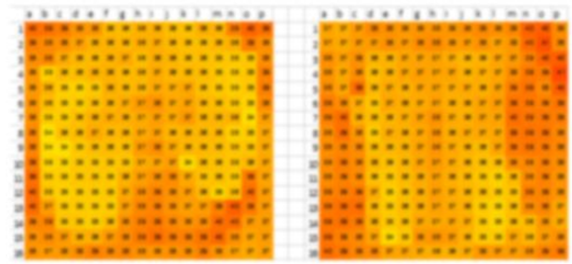


40 s

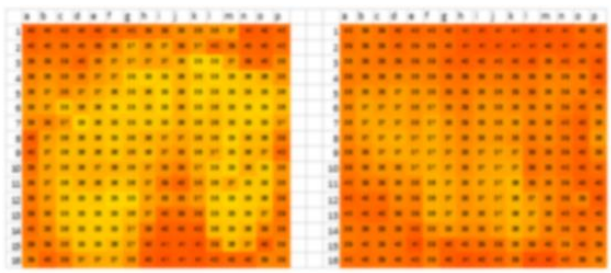
Competitor 2



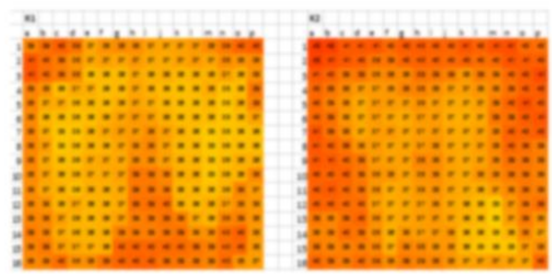
V70



Competitor 1

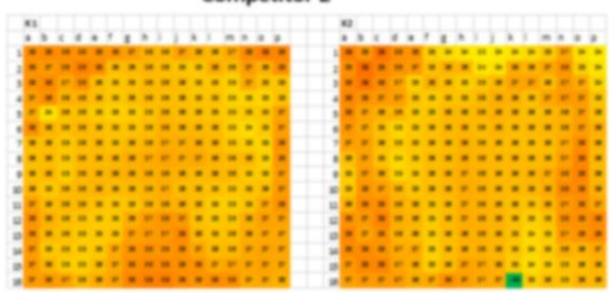


SPA1.20.1

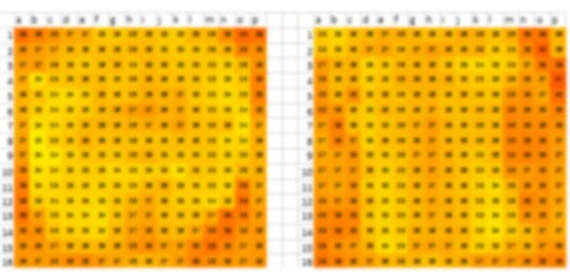


1 min

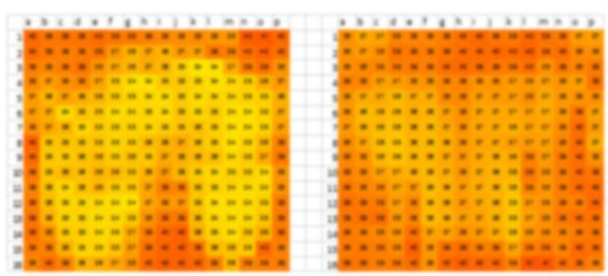
Competitor 2



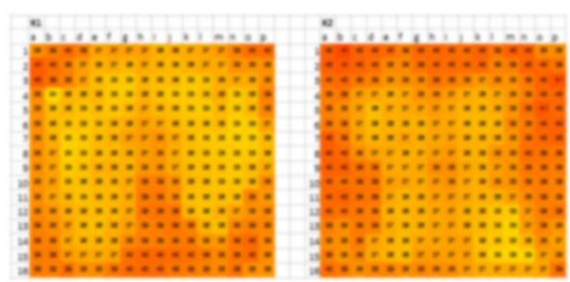
V70



Competitor 1

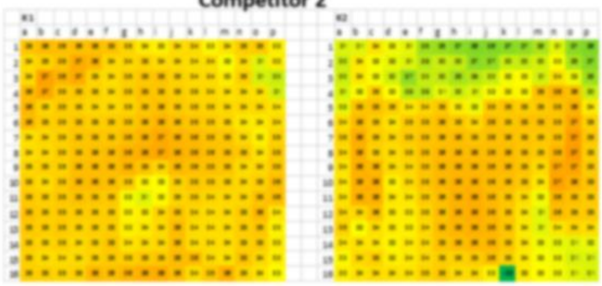


SPA 1.20.1

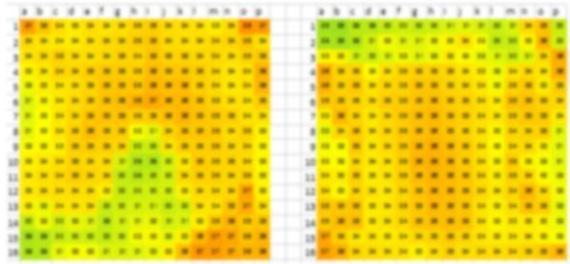


3 min

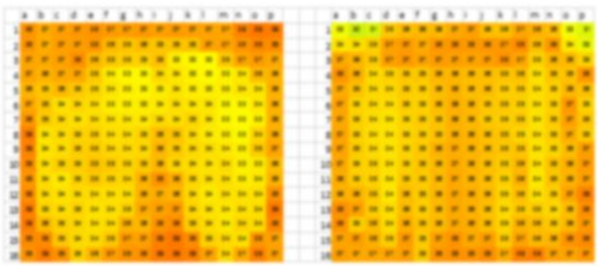
Competitor 2



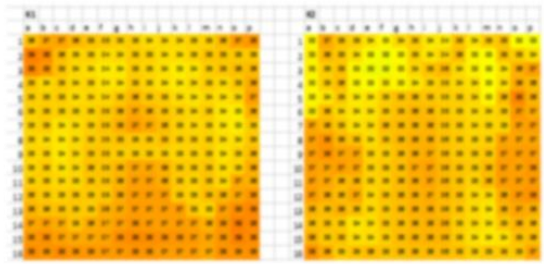
V70



Competitor 1

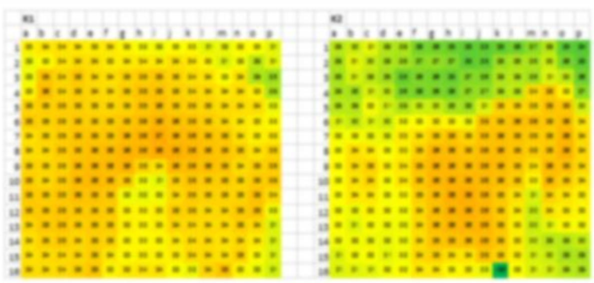


SPA 1.20.1

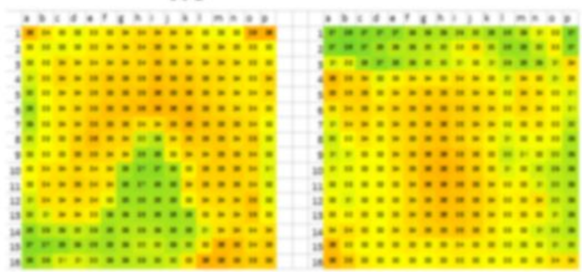


5 min

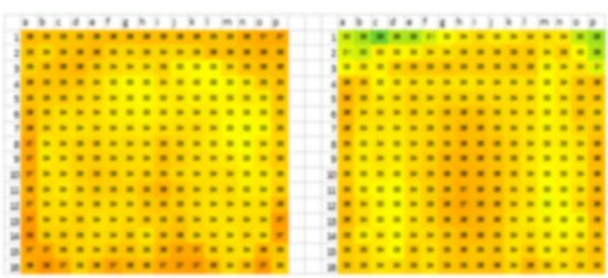
Competitor 2



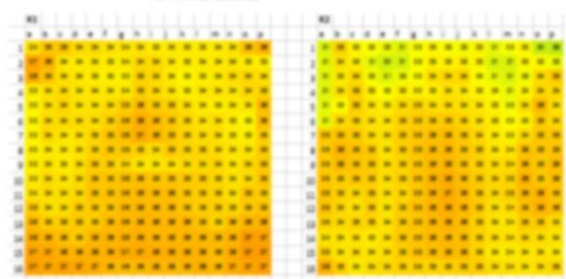
V70



Competitor 1

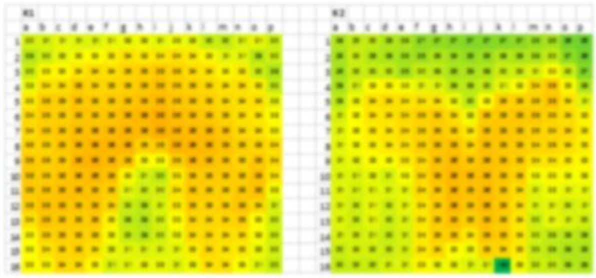


SPA 1.20.1

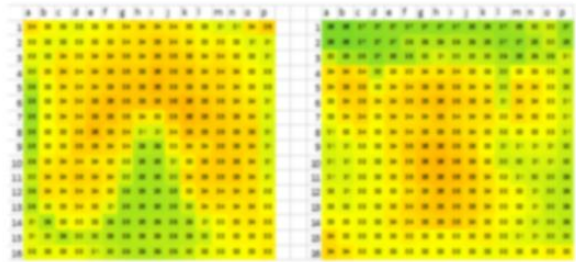


10 min

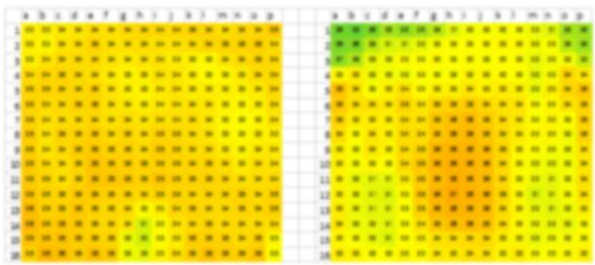
Competitor 2



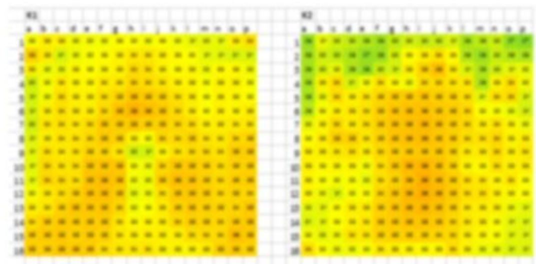
V70



Competitor 1

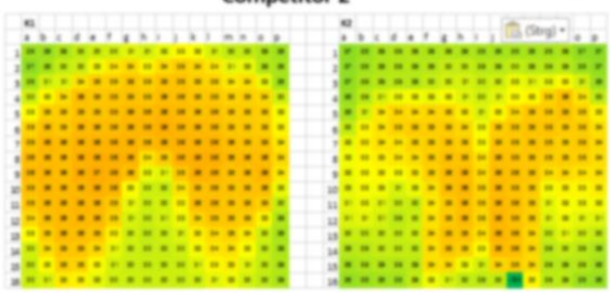


SPA 1.20.1

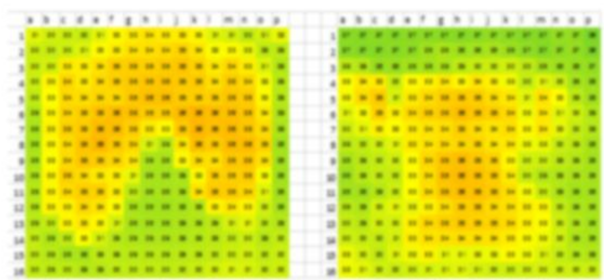


30 min

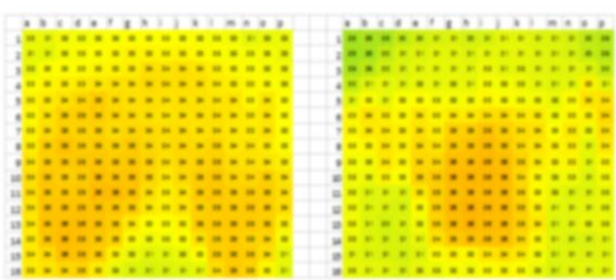
Competitor 2



V70



Competitor 1



SPA 1.20.1