CHALMERS

Energy efficient car compartment

Investigation of possibilities to reduce the energy consumption of non-propulsion systems in passenger cars

Master of Science Thesis in Product Development

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Gothenburg, Sweden, 2013

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Cover:

[The new Volvo V40 CC driving on a coast road, displaying Volvo Car Corporations devotion to nature (Volvo Car Corporation, 2013 C)]

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ABSTRACT

This master thesis was carried out in the Department of Product and Production Development at Chalmers University of Technology in Gothenburg. The work was conducted in cooperation with the unit Body and Trim at Volvo Car Corporation in Gothenburg.

The purpose of this master thesis was to investigate if there exist any opportunities to reduce the carbon dioxide emissions and extend the range for a car by making changes to the non-propulsion systems. The found opportunities would then be presented both in the form of this report and by building a demo car to visualize the changes. To be able to do this, knowledge about how the different systems in a car work and are connected was needed and required both internal and external searches.

To find innovative ideas for this purpose, brainstorming sessions were held which resulted in many different ideas. Benchmarking was also performed to see what the competitors were doing and what other industries have done in the field of energy efficiency. To sort and evaluate all the ideas that came up from these events matrices were used. One problem that occurred when trying to grasp such a wide subject was to find relevant and correct data to be able to make a correct evaluation.

The result of the thesis was that there exist possibilities to reduce the energy consumption, both in different driving cycles and for the users in their daily life. The biggest potential seems to be in the areas of mass, aerodynamics, harvesting energy and climate control.

Keywords: Volvo Car Corporation, Energy efficiency, Car compartment, Development, Concept, Carbon emission, Driving cycle.

Preface

This master thesis has been performed at Body and Trim, which is a unit of the division Research and Development at Volvo Cars Corporation in Gothenburg, Sweden. The thesis was performed in collaboration with the Department of Product and Production Development at Chalmers University of Technology in Gothenburg, Sweden. The report aims to reflect the progress, results and conclusions of the work.

There are many persons to thank for their help and support throughout the work that is presented in this thesis. First, we would like to thank our supervisor at Volvo Cars, Mr Magnus Lindh, for support, valuable insight, and feedback as well as his enthusiasm about the progress of the research. We would also like to thank our supervisor and likewise examiner, Dr. Göran Gustafsson, for feedback and support and his constructive and precise criticism.

There are several more persons to thank at Volvo Cars. Most of all our thanks go to Mrs Erja Olsson, who has been somewhat of an unofficial supervisor at Volvo Cars, for invaluable discussions and insights. Moreover the entire personnel of the section Concept Development and Planning at Volvo Cars have been of great help during the thesis. We also like to send a special thanks to the concept workshop that helped us with the building of the demo car Aurora.

Finally, a big thanks to anyone else who in any way has contributed to this thesis throughout the last 20 weeks. Without you, we would not have been able to achieve the same level of outcome.

Gothenburg, May 2013

Andreas Axelsson and Christian Jansson

ABBREVIATIONS

AC - Air Conditioning

BEV - Battery Electric Vehicle

DRL - Day Running Lights

FOH - Fuel Operated Heater

HVAC - Heating, Ventilation and Air Conditioning

IAM - Infotainment Monitor

LCD - Liquid-Crystal Display

LED - Light Emitting Diode

NEDC - New European Driving Cycle

PHEV - Plug in Hybrid Electric Vehicle

PTC - Positive Temperature Coefficient

VCC - Volvo Car Corporation

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1. INTRODUCTION

In this introduction the background to the subject of this thesis is presented. It also includes a short presentation of Volvo Car Corporation (VCC). The purpose, the research questions, the delimitations and the report outline of this thesis are also included in this chapter.

1.1 BACKGROUND

Today the climate threat is growing bigger and bigger, and the average temperature on earth is rising faster than ever before. The climate threat is arising from the increase of greenhouse gases in the atmosphere. The most aggressive greenhouse gas is water vapour, which is on a steady level but uncontrollable by man. Next comes the carbon dioxide which mankind is emitting at an alarming rate. These emissions occur mainly through combustion of fossil fuels, (Utbildningsgruppen, 2013). Of the total carbon emissions the transport sector stands for 27%, (Världsnaturfonden, 2013). With increasing environmental regulations, higher taxes on carbon emissions and an increase in demand for oil make the oil price increase. This makes the society want to reduce its need of oil. This would in turn lead to demands for a more fuel efficient transportation sector. The car business, including Volvo Car Corporation, is under especially hard pressure since the competition is high. Therefore it is a must for the car manufacturers to develop cars with less fuel consumption through higher energy efficiency and/or change to other forms of energy carriers such as electricity. The propulsion has been in focus for energy efficiency for years and now, when the most effortless improvements have been made, the focus is directed towards other areas as well as replacing the traditional combustion engines with new technologies. Something that is getting more common in the business is to, fully or partially, electrify the propulsion to increase the energy efficiency of the car. With electric propulsion there are no big emissions or fuel costs to save by making other systems more efficient. However, any electricity saved from being used by other systems can directly result in additional range of the vehicle.

VCC now wants to investigate the possibility to reduce the energy consumption of additional systems apart from the propulsion, both for fossil fuel driven and electricity powered vehicles. This is why this master thesis has been created, to see where these possibilities can be found.

The Volvo Car Corporation is a car manufacturing company that is owned, from 2010, by Geely Holding Group. It was founded in Gothenburg, Sweden, by Gustaf Larson and Assar Gabrielsson, and the first car left the factory on 14th April 1927. Volvo Car Corporation designs, develops, manufactures and markets cars all over the world. Its research and development mostly takes place in Gothenburg, Sweden. The main production currently takes place in Belgium and Sweden. But there are major production sites under construction in China. The number of employees is approximately 20 000. Volvo cars sell eleven different models in more than 100 countries around the world. The VCC has had an environmental focus for a long time. Already in 1972, Volvo stated at a UN global environmental conference in Stockholm that “Volvo is responsible not just for ensuring that its products are modes of transport that work well but also that they work in a broader context in our environment” (Volvo Car Corporation, 2013 A). This resulted in Volvo launching the three way catalytic converter and oxygen sensor (Lambda sond) four years later. This is still an integral part of modern petrol-engine cars. Today it is the V60 Plug-In Hybrid that shows Volvo Cars commitment to innovate with respect for the environment.

1.2 PURPOSE

This thesis is a first step to find out if there are any opportunities to lower the emissions from a car by redesigning or changing parts that not are included in the propulsion system. The changes will be made to components that contribute to the consumption of fuel/electricity. To show these changes a demo car will be built, but only shown internally at VCC because of confidentiality. This thesis will also inform Volvo Cars on some ideas and areas that may be worth focusing on. Another aim is to contribute some thoughts on how to handle the new regulations that will come in the future regarding carbon emissions. The purpose will also be to see if these changes can increase the range for an electrical vehicle.

1.3 RESEARCH QUESTIONS

In this section, the research questions for this master thesis are presented. The thesis is however not restricted to these questions alone, but can cover adjacent subjects as well.

1. Are there any opportunities to lower the emissions from a car by redesigning or changing the parts of the interior that contribute to the consumption of fuel/electricity?

2. Which of these opportunities should Volvo Cars look further into?

3. Can these energy savings be a selling point for the future customer?

1.4 Delimitations

The aim of the improvements is that they should be implementable at 2020 and beyond. Due to this the ideas do not need to be realizable today. However, they need to meet the legal requirements regarding that time. Future customers' requirements on cars 2020 and beyond would also be included in the development of ideas. Another delimitation is that the ideas should be on the concept level and that they do not need to be fully working products. Due to the fact that this thesis work is done at the department Body and Trim neither the driveline nor the chassis should be considered. The time for the thesis work is 20 weeks and that will also put some limitations. Because of this time limit, and that the investigation should cover so many areas that can affect the energy efficiency, the depth of the search will suffer. Besides of these limitations, there are limits due to confidentiality. Internal data and material from VCC that has been used in the thesis for learning more about the products, the concepts and other facts are confidential and could therefore not be revealed.

1.5 Report outline

The following report is structured in seven main parts:

Introduction: The first part of the report is the introduction. In it the background and purpose of the thesis are presented. The research questions and delimitations to the work is also described in this part.

Theoretical background: In this part the theory, on which thoughts and discussions in the rest of the report is built on, is presented.

Methodology: Here the approach for the thesis will be presented and when and how different methods and tools were used. In this part the development of the demo car is also described.

Results: The fourth part contains the results of the tools and methods presented. In other words, which ideas and concepts that were found most promising.

Discussion: The results are discussed and analysed. What do these results mean? Are they reasonable? What could have been done differently?

Conclusion: In this part all findings during the thesis work are concluded.

Recommendations for future work: In the final part of the report recommendations for future work is presented. It is based on the discussions and findings in the previous section.

Please note that some of the information and results are considered to be part of Volvo's intellectual property, and they are therefore left out. One example of such information is how VCC values environmental performance.

2. Theoretical background

In this chapter some theoretical facts about driving habits, driving cycles and the world climate are presented. These facts will be helpful later on in the project when it is time to determine which ideas that should be developed further.

2.1 Driving habits

From an investigation (Lindhagen, 2011), about driving patterns and condition, that VCC have performed it is shown that 75 % of all driving is done during daytime, (7am - 7pm). During all journeys the number of persons in the cars is approximately 1,25 in average (Transek AB, 2006) (Wihlborg, et al., 2010).

That 75 % of the journeys are performed during daytime shows that the solar energy is present and could be utilized. In the investigation it is stated that the solar irradiation during driving varies between 200 and 700 W/m^2. This number can be compared with the yearly average number of 120 W/m^2 for solar irradiation in Europe (European Commission, 2011). This shows that the numbers from the investigation from VCC about solar irradiation during day time can be relevant.

From an article (Clarke & Mayhew, 1994), that discusses car thefts, facts about how people parked their cars was found. It showed that more than 50% park outside and then also expose the car to the sunlight. From VCC's investigation, facts about how long driving distance that is covered daily is presented. VCC uses a rule of thumb which says that a Volvo vehicle yearly driving distance is 25000 km or 68,5 km/day. Most drives are however short, only 22 % of the trips last for longer periods than 23 minutes, which makes the start-up phase important. For example the transient heating or cooling phase for the climate system in the beginning of a trip is therefore critical. From the same report the average speed when rolling has been investigated. It was found that the average speed was between 75 and 80 km/h and that half of the driving distance was above 80 km/h.

2.2 Cycles

How eco-friendly a car is today is usually presented through the amount of carbon dioxide the it emits. These numbers exists in every folder/sheet that belongs to the car. But where does it come from? Today car manufacturers use specific driving cycles that are designed by legislators, to determine how much fuel their cars consume when driven and thereby the amount of gCO_2/km that is emitted. How the driving cycles are designed depends on which market the car should be sold on. There exist two driving cycles for the US, one for Europe and one for Japan, which are the most common ones. The problems with these are that it in some cases is very hard for the customer to be close to the measured value that the retailer is telling them. This is because some of the driving cycles are designed in a way so that they do not correspond so well with the real driving pattern of a typical user.

One example of this design fault is that when the car is driven in the test cycles none of the comfort functions or entertainment systems, such as climate system and radio, need to be turned on. The legislation does not require that, and of course the car manufactures are trying to use the legislation in their favour to get as low number as possible. Fact from the European Commission (2011) that proves this is that a car tested in the NEDC consumes 350 W, while a car driven on a road by a user will consume 750 W. However it is possible to get extra points in the NEDC if the car is equipped with something that is called eco-innovation, such as solar cells, and through that be credited for its improvements (European Commission, 2011).

The driving cycle that is used in Europe is called the New European Driving Cycle, NEDC, (Dieselnet, 2013) and (Jacobsson, 2010). It is built up by two different driving cycles. They are called the urban cycle and the extra urban cycle, respectively. The urban cycle is supposed to remind of city driving and the extra urban cycle is designed to remind of highway driving. The city part with low speed driving is performed four times and the motorway driving with high speed driving is performed one time. The whole driving cycle is performed on a chassis dynamometer that takes 20 minutes to perform, which matches good with the time for a drive according to VCC's investigation (Lindhagen, 2011). See figure 1 (Burgdorf, 2012) for more detailed information.

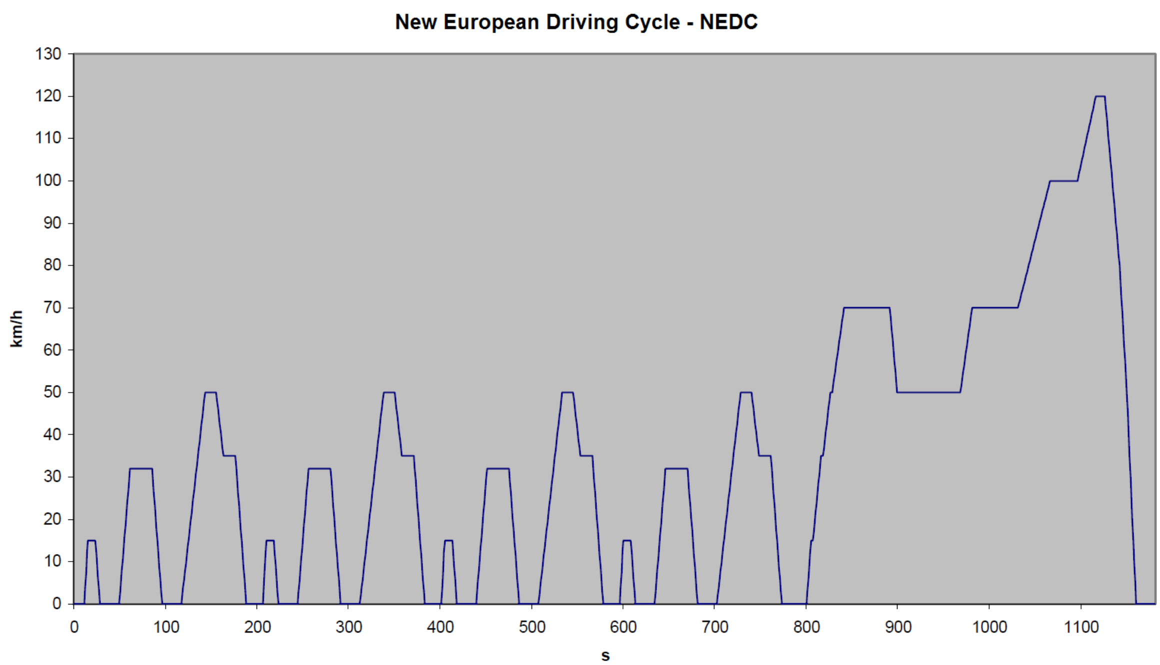

Figure 1: Plot of the NEDC driving cycle (Burgdorf, 2012)

As mentioned before none of the comfort systems or the entertainment systems like seat heat, radio, navigation and likewise are turned on. But that is not everything that deviates from the reality in NEDC. The average speed in NEDC is much lower compared to the average speed in the investigation done by VCC. The average speed from NEDC is 33,6 km/h compared with 75-80 km/h from Lindhagen (2011). These three, comfort systems, entertainment systems and average speed, are all sources to why customers get higher fuel consumption compared to the official certification figures.

Due to this problem with misguiding fuel consumption, VCC has tried to develop their own driving cycle to know how much the real consumption is for the customers. This is done so the cars not only get optimized for NEDC. It will also help to keep the difference between NEDC consumption and real consumption at a reason level. Volvo is calling their own driving cycle Real World Fuel Consumption, RWFC. The RWFC is based on NEDC and use it as a foundation. Volvo is modifying the NEDC by driving the high speed phase twice to make it more significant. This is because the average speed is higher as mentioned before. Another change is that Volvo has one warm and one cold cycle instead of one at a steady temperature. The RWFC also helps to create a more realistic number of the fuel consumption since the climate system is taken into account by putting it in automatic mode with a target temperature at 22 °C. The entertainment system is also included by letting the radio be turned on but without any volume. Both these settings are set as they are to make the RWFC repeatable.

2.3 Outside climate

Building global cars that will be sold on many different markets comes with some problems. One of them is that the cars must work in all the different climates that exist on the different markets. This forces the car manufacturers to build cars that work in a wide range of temperature from approximately -20 °C to 50 °C. By designing for this range of temperature the climate system in the car is over dimensioned in many of the real driving cases that exist on the different markets. The system is over dimensioned because the requirement for the compartment climate system is set to be able to reach a comfortable temperature level within a defined short time period (Landelius & Nielsen, 2013), regardless of the temperature of the environment.

This heating and cooling period to get to this comfortable temperature level is referred to as the “transient phase”. When the climate system has managed to reach the comfort temperature and is keeping the temperature at a steady level it has reached the “stability phase”. Because of the short time for reaching the comfort temperature and the independence between the comfort temperature and the outside temperature, the transient phase of the heating and cooling in the extreme markets forces the climate systems to be so good. Of course these extreme temperatures can occur in almost all markets but it is not an everyday event. When VCC is designing a car they test it for a certain very cold temperature to simulate a cold climate and a certain very warm temperature with sunshine for the hot climate (Bäckelie, 2012). They are doing this because they want to fulfil the comfort requirements that they have put up for the climate system. Seen to the driving habits above, that user’s usually only drive for about 20 minutes, it applies really good to have a powerful climate system so the users can get their wanted temperature during their journey. However, with the environment in mind this is not desirable, because the rapid transient phase require a lot of energy. And usually when it is cold outside the customer wears warmer clothes that will make the comfort temperature level lower. The same situation will appear when it is warm outside, that the comfort temperature level appears cold in comparison with 40 °C. So maybe it is the difference between the starting temperature and a satisfying temperature after a certain time that the requirements should cover instead of a pre-decided comfort temperature. This argument seems even more correct when looking at numbers from an investigation that has been done on how the climate looks at VCC markets around the globe. In the investigation it is found that the average temperature for Volvo's markets goes from 0 °C to 25 °C, see figure 2 (Burgdorf, 2011). But of course the temperature inside the compartment can be much higher than 25 °C if it is sunny. It can be up to 85 °C (Svenska Kennelklubben, 2009) under the right circumstances, and when this happens it will be good to have a well functioning AC-system. So it can be hard to argue against the dimensions of the system when it is about cooling. But heating is another story. The diagram in figure 2, shows that the coldest average temperature is around 0 °C. This means that the car can produce far too much heat in most cases. It gets even more interesting if the problem with less heat loss from more efficient engines is taken into consideration. Now when more cars also become electrified in some way this heat loss will be even less and make the heating an even bigger problem if it must be able to handle the requirements that are set today.

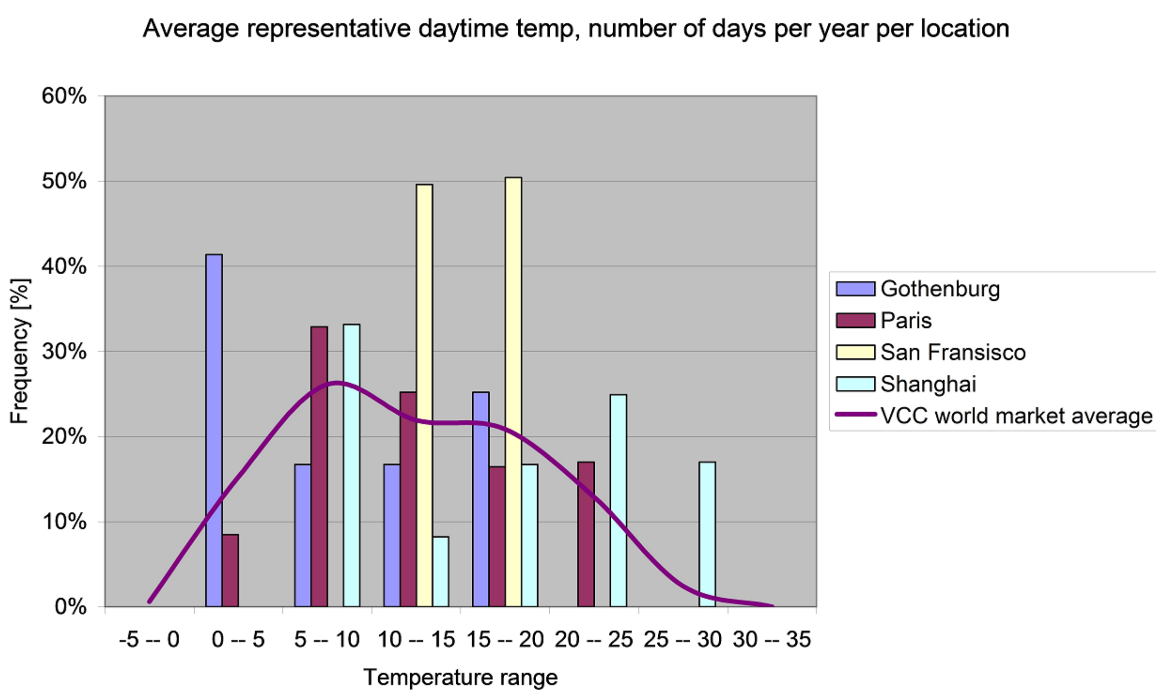

Figure 2: Daytime temperature for Volvo vehicles (Burgdorf, 2011)

3. METHODOLOGY

In this chapter the different methods that have been used throughout the thesis work will be presented. The sequence will follow the same order as the work progressed. The chapter will start with the initial phase of the work and continue with the concept generation and concept evaluation phase. Finally, the methods for how the demo car was developed are presented.

3.1 TIME PLAN

In the initial phase of the thesis work a time plan, as a Gantt-scheme, was created, see appendix A. This was done to get a good overview of what was possible to fit into the thesis work time schedule of 20 weeks. The time plan was updated during the whole thesis work. During the ramp up phase, time was spent on meeting all the different people at Volvo Car Corporation and Chalmers that would be involved and affected by the work. When the work was started up the first thing to do was to gather information about the subject. This was done through examining cars and performing interviews with people who had knowledge about the subject. After that the concept generation and the concept evaluation was planned. In the end of the thesis work, time was set aside for more intense writing.

3.2 REQUIREMENTS SPECIFICATION

Early in the master thesis a preliminary requirements specification was produced, see appendix B, a cut out can be seen in figure 3. The focus was on energy efficiency but important Volvo values were also included since the concepts were not allowed to interfere with the brands core values. Both requirements and wishes were set. The requirements were seen as demands that must be fulfilled if the concept would be carried on with and the wishes were later taken into the evaluation matrices to decide which concepts to focus on. The values and the weights for the different demands and wishes in the requirements specification were improved and developed as the thesis progressed. This was done since the knowledge about the subject increased all the time and therefore the values and the weights were needed to be changed so that the best ideas/concepts were developed in the end.

Requirement specification

#	Requirements		Value	Unit	Verification
R:1	Net energy usage compared to reference		Δ<0	W	Calculation
R:2	Cannot compromise safety features		-	-	Control of safety systems
R:3	Cannot diminish luxury feeling		-	Subjective	Subjective test
R:4	Customer value compared to reference		Same or Better	Subjective	Subjective test
R:5			Δ≤0	l/100km	Calculation
					Calculation

#	Wishes	Importance	Value	Unit	
W:1/2	Net energy usage(Gross energy usage taken into consideration)	6	-100	W	Calculation
W:3	Electrical load	4	Δ<0	W	Calculation
W:4/5	Fuel consumption/Carbon emission	5	Δ<-0,05	l/100km	Calculation
W:6	Electrical range	5	Δ>1	km	Calculation
W:7	Range	2	Δ>10	km	Calculation
W:8	Harvest "free" energy	2	>0	W	Calculation
W:9	Mass	4	Δ<0	kg	Weighing
W:10	Thermal mass	3	Δ<0	J/K	Weighing + material data
W:11	Able to build into the car (Aurora)	3	Yes	Yes/No	Checking with FU-workshop
W:12		1	<5	Year	Checking with Volvo engineer
					Checking with Volvo engineer

Figure 3: A cut out from the requirements specification

3.3 Function analysis

To get a good overview of the different functions in a car and how they are connected, a function analysis was carried out. This was a way to get the car's different functions broken down into a more manageable size and also show in which functions that there could exist potential to save energy. The method that was chosen to be used was a variant of the black box method that is mentioned in Ulrich & Eppinger (2012). This method is a way of decomposing the functions in a problem or in an object. When the first functions is decomposed the next step is to divide the functions from the first black box into subfunctions and through this visualize the smallest building blocks.

In order to better fit the desired outcome, some changes were made to the method that is stated in Ulrich & Eppinger (2012). These changes were that instead of using the three inputs, energy, material, and information into the black box only energy was chosen. Since the scope of the thesis was to look at the energy consumption and how to make it more efficient. This was also a choice that made it easier to use the method and save some time.

The first black box, figure 4, was created with a holistic view in mind. By having a holistic view, all the different functions that in some way use or harvest energy were included in the box. The inputs into the first black box were fuel and electric energy. The outputs were both positive and negative. The positive, which is coloured green, were propulsion, safety and interior/climate. These outputs where stated positive because they are things that a customer wants from a car. The negative outputs, which are coloured red, are heat loss and resistance. Between the inputs and outputs these functions were found:

1. Transform chemical/electrical energy to kinetic energy

2. Propel

3. Transform kinetic energy to electric energy

4. Store electrical energy

5. Non propulsion energy use

6. Collect used energy/Harvest energy

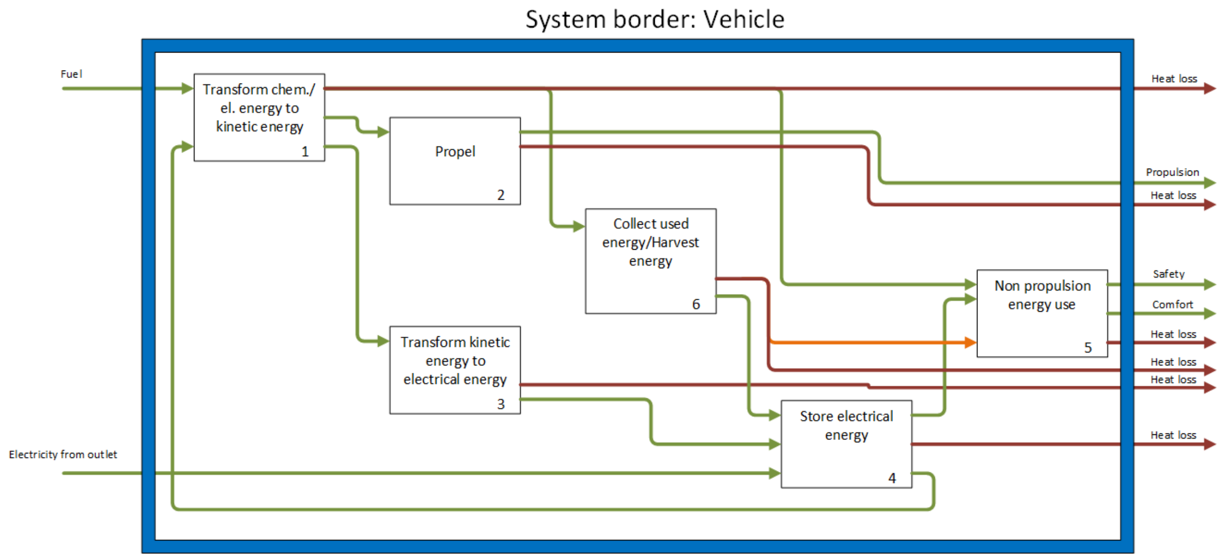

Figure 4: Main system function analysis

With this first black box as a foundation new black boxes, based on the sub-functions that were inside the scope were created. So numbers 1 to 4 were cancelled and the time was spent on numbers 5 and 6. When starting to break down “Non propulsion energy use” and “Collect used energy/Harvest energy” it appeared that one level of break down of sub-functions was not enough in “Non propulsion energy use”. This was due to that one level of break down was not enough to find the root cause of the function that was creating the consumption of energy and where the changes needed to be made. All these black boxes that were created from the first box can be seen in appendix C. For “Collect used energy/Harvest energy” it was enough with one level of sub functions to get a good overview and to be able to find where it was possible to collect energy.

When all black boxes were made, a good picture of all consumers in the car had been created. It was also a good method since it created discussions around the different functions and sub functions. Through this discussion knowledge gaps were found that needed to be closed. With this in mind it was easier to know which areas that could be worth looking at and what kind of people/specialists that could be worthwhile to contact. The function analysis also helps to show how the different functions and sub functions were connected to each other. Through these connections, ideas on how changes to the functions or sub functions could create synergies were found.

3.4 Interviews

As mentioned before, the performed interviews were done to gain knowledge about areas where there existed a knowledge gap. Some examples of these knowledge gaps were solar cells, what VCC had done before and how different components work inside the car. To be able to find the wanted knowledge, interviews were performed both internally at VCC and externally with specialists in different areas. The overall approach to the interviews were to let the first meeting with the interviewees be quite unstructured, just to get a grasp of the context and what kind of knowledge the interviewees possessed. Further into the thesis work some of the interviewees were contacted again and then with more structured and precise questions due to the knowledge gained during the work.

3.4.1 Internal interviews

An important part in the beginning of the thesis was to find out what had been done and what was going on at VCC within the subject for the thesis work. To find this out, an interview was performed with two persons that have good knowledge about where VCC stands regarding energy efficiency. This gave a good starting point and an overall picture of what fields VCC have looked at and are looking into right now. To capture further knowledge more interviews were held with more specialized personnel. Areas where it was considered that more knowledge was needed and interview with specialists internally at VCC were required were: Aerodynamics, Electricity consumption and the Climate system. These interviews were still quite open, but with some specific questions. In other areas such as smart windows, exterior lighting, glazing and A-pillars minor interviews were performed to investigate certain ideas further.

In a meeting with Lennert Sterken (2013) regarding aerodynamics, he informed about the difficulty to predict what effects aerodynamic changes will have on the total drag before making simulations or tests. He also enlightened us on how much the wake behind the car affects the drag and overall aerodynamics. Alma Ciric (2013) was interviewed to get knowledge about the electricity consumption of the car. She informed about general consumption issues and what was going on in her division before telling where information about electricity consumption figures for all components could be found. When meeting Filip Nielsen and Thomas Landelius (2013) from Climate Control System, information was provided regarding how the climate system works, challenges with new legislation and what Volvo Cars are developing in that area.

3.4.2 External Interviews

As mentioned before some external interviews were performed with specialists to get another view on the subjects compared to VCC's, and to find knowledge about things that VCC has not looked so much into. Areas where it was decided to find external knowledge was in solar cells, materials engineering and hybrid propulsion research. From the interview about solar cells, with Christoph Langhammer (2013) from Chalmers, knowledge about the solar cells market and the different types of solar cells was gained. Regarding the overall market the efficiency improvements of solar cells has stagnated, and the focus has instead been shifted towards the cost of the cells. He also mentioned that there are many different things that affect the solar cell's power and what is important to have in mind when choosing which type of cells to use. Examples that can be good to have in mind is how sunny it will be in the area where they will be used and with which angle the solar irradiation hits the cell.

The interview with materials expert Mats Norell (2013) gave some general knowledge about materials that can be used in cars and also how different materials behave together. One thing that was discussed was double glazing, problems that could occur when implemented into a car and how that could be solved. The interview with Elna Holmberg (2013) from Svenskt hybridfordonscentrum gave the information that the cost of the hybrid technology in cars have gone down in the last couple of years and that hybrid cars will probably be a more common sight on the roads in the future. She also thought that it is possible to change the design of the platform when developing a new electrical car to make it more efficient and give it longer range.

3.5 Benchmarking

The next step was to perform a benchmarking regarding the problem with energy efficiency, to find solutions that other industries have used but which have not necessarily been applied in the field of cars. A benchmarking towards other car manufacturers was also performed to get a picture of in what direction the car market is heading. This was done through checking patent databases, such as Google patent and the European patents office. Searches on the internet about the competitive car manufacturers' models were also done to find out what solutions they have in their cars today. Concept cars from the different car brands have also been investigated to get a glimpse of what the others have in store for the future. An example of this is BMW´s energy efficient cars that they call i3 and i8. One idea that came from these cars is the energy efficient headlights, see figure 5. Another example is the concept car that is the result from the collaboration between Smart and the chemical company BASF, see figure 6. Ideas from this concept car were the paint job and how much it is possible to use plastics in a car to keep the mass down.

Figure 5: Prototypes of laser headlights (Motortrend, 2011)

Figure 6: Concept car from cooperation between Smart and BASF (BASF, 2013)

As mentioned before, more areas than the car industry were investigated during the benchmarking. To gain information about these, interviews and search on the internet were performed. Some example of areas that were included in the benchmarking was the construction industry and the aircraft industry, since they are facing the same challenges with energy consumption. When investigated the construction industry and how they save energy through using good insulation materials and good windows, to stop radiation from the sun, another area was found. It was home appliances that nowadays have a selling point on their products that is how low energy consumption they have. During the process more and more areas were looked into as ideas were developed and information about them was wanted. An example of this was when the drag reduction on a car was investigated. When this was done areas with objects that are moving in a fluid were investigated. The areas were different sports (golf, javelin and swimming), boats, and nature (whales). Some other areas that came up when investigating the possibility to store heating and cooling were the medical industry and outdoor activities such as hiking and hunting. The items that were looked at were heating and cooling pads and vests that are able to store heat or cold.

Two other areas that were investigated were the space and military industries. These two were interesting because they have big budgets and can try out new technology. One example from the space industry is the thermoelectric generator (TEG) that has been used in space and is now tried in other industries, such as the car industry. Information about TEG was also found in the military industry. Another field in the military industry that was looked at was how to harvest energy from shock absorbers.

3.6 Concepts/Ideas generation

After the initial investigation two brainstorming sessions were held. This was a way to use the newly gained information and knowledge to create new ideas that could open new doors to a more energy efficiency car. This was also a way to get other people involved in the work and make them help generate new energy saving ideas for the demo car. Due to the fact that the aim for this thesis work was to investigate different possible solutions that can lower the energy consumption of future cars, the ideas did not need to be applicable in the cars today. The ideas only needed to show some potential of what they could lead to. The first brainstorming session was with another group of students from Chalmers. It was a bachelor thesis group that were working with the newly started solar cell car project and their mission within the project was to come up with ideas on how to cool the interior of the car without using any electricity. This session was performed through letting the bachelor group generate ideas for the master thesis and vice versa, the master group generated ideas for the interior in the solar cell car. After the generation of ideas all the participants were discussing all the ideas. Even at this stage some new ideas were generated, just by talking about the already generated ones.

The second brainstorming session was held together with personnel from VCC. It was divided into eight different occasions, of which in the end only five took place. This reduction of the number of occasions was due to the fact that the sessions were not filled. A likely reason was that Volvo has it quite tough economically right now and that there were vacations adjacent to the occasions. To these sessions personnel were invited to participate with their thoughts and opinions about energy efficiency in general and what actions that can make non-propulsion car systems more energy efficient in particular. Having this brainstorming sessions with personnel was a way to get ideas from people that are more involved in the process of developing cars. The sessions were however not only performed to gather ideas, but also to create acceptance for the work and the coming concepts and prototypes to make the future industrialization smoother. To promote the brainstorming sessions and the upcoming "concept car" a suiting name for the project was made up and advertisement in the form of posters, which can be seen in appendix D, and PowerPoint presentations were made to create interest. The name chosen for the project and the concept car was Aurora, which refers to Aurora Borealis the Latin name for the northern light. The name was chosen to associate with energy, Scandinavia and the future. In total around 30 persons came to the five sessions and about 200 ideas were generated.

The five sessions began with a short presentation about the master thesis and the rules for the brainstorming. After this a short movie to inspire the participants was showed. The brainstorming itself started with a ten minute individual idea generation, during which the persons wrote or sketched down their idea on post-it notes and then put the notes on a whiteboard, see figures 7 and 8. After this some of the ideas that had been generated were discussed. The whole session went on for approximately 45 minutes.

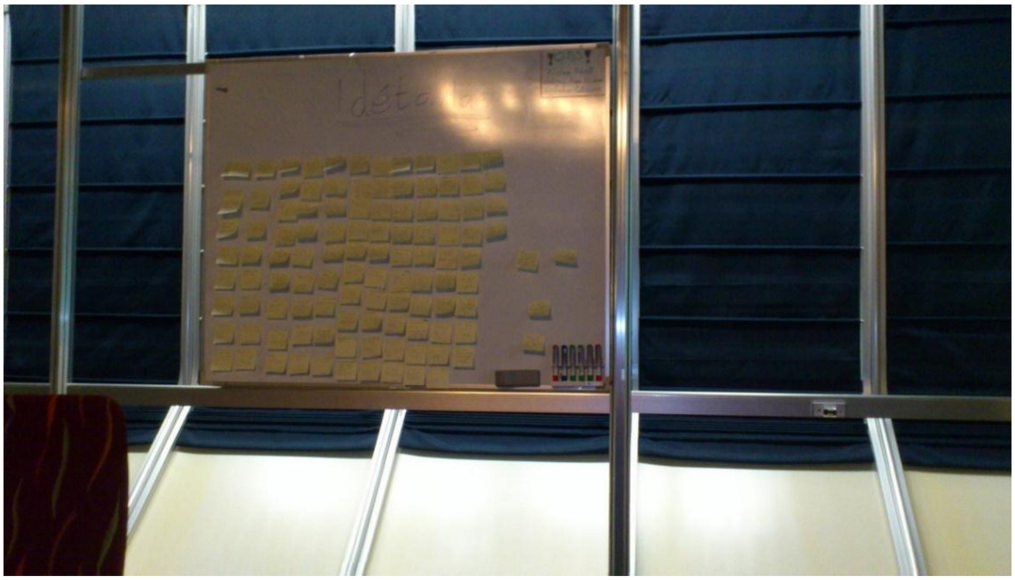

Figure 7: Picture from the individual part of the brainstorming sessions

Figure 8: The generated ideas put on the whiteboard

All the different ideas that were produced during this phase can be seen in appendix E. The brainstorming session was followed up by a session to sort the ideas. They were clustered mainly with respect to which problem they solved, but also according to physical vicinity, whichever felt most logical for the respective idea, see figure 9. In total they were divided into 21 main categories, where the larger categories in turn were divided into a few subgroups.

Figure 9: Result from the clustering of ideas

3.7 CONCEPTS EVALUATION

This section of the report describes how the screening and the selection of the 200 ideas from the brainstorming were performed. It was done using different matrices. After the first matrices it was found that more information was needed, and further investigations were therefore performed. To be sure that the chosen ideas were the right one some calculation about energy consumption and economical effect was done. The building process of the demo car Aurora is also presented in this section.

3.7.1 SET BASED DESIGN

With lack of knowledge about the different ideas and areas that were presented at the start of the project together with the fact that the project covered so many different areas of a car it was clear that a process that captured a lot of knowledge and avoided making decisions on too little facts were needed. Set based design was chosen since the process does just that, by having as principle to only eliminate the worst concepts and not picking out the ones you at the moment think are the best ones (Holmdahl, 2010). That turns the process into an iterative learning process in which between every iteration an elimination take place, where you eliminate the worst ideas. Between the iterations you need to learn more about the remaining concepts in order to with certainty figure out which one/ones that are now the worst ones. A part of set based design that was left out in this project was trade-off curves, which is used to optimize parameters for a given concept. But since the project spans over so many areas and that it doesn't stretch beyond the concept stage of product development it was regarded as unnecessary to try to optimize the concepts. Dangers when using this process is connected to the time parameter. Firstly it is hard to have a strict plan on how the development progresses since the time needed to close knowledge gaps is hard to assess, secondly some concepts might be so novel or unusual to the company that it is more or less impossible to find facts enough to conclude if the concept is a viable one or not.

3.7.2 FIRST EVALUATION

The next phase in the process was to make a comparison of all the solutions so far based on their potential to save energy. This was done to create a picture of which to focus on and which to cancel out. Since the number of ideas was so large (> 200), it was decided to start with an elimination matrix, see figure 10, which was used to get the number down to a more manageable level. The selection criteria that were chosen for the rough screening were: *Is the idea inside the scope of the thesis?*, *Is it possible to see any potential for energy savings by implementing the idea?* and *Is there any form of idea on a technical solution for the idea?.* If the answer was no on any of these three questions the idea was eliminated and not brought any further in the investigation. To eliminate in this way can be very tough and you need to be careful not to take ideas out of consideration that further into the project may prove to have great potential.

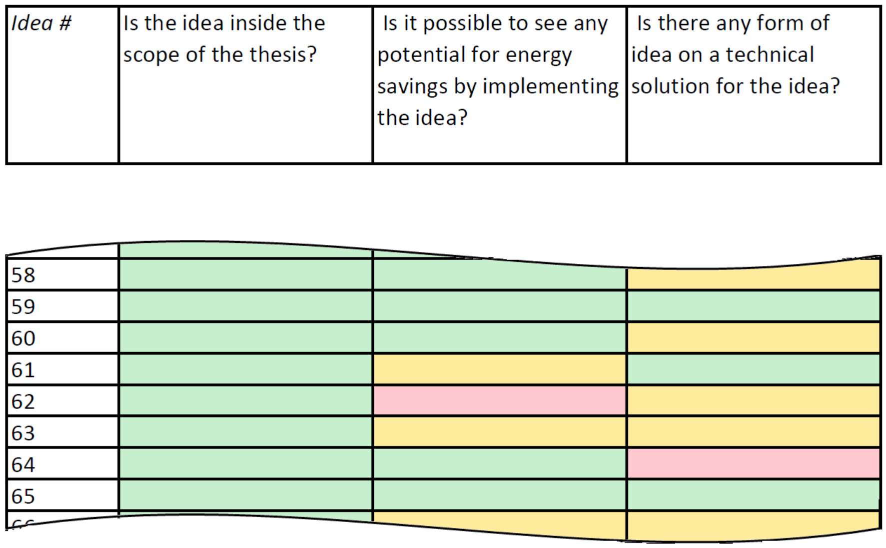

Figure 10: A cut out of the first elimination matrix for reduction of ideas

After this elimination matrix the number of ideas was still substantial. Therefore it was decided to perform a not too comprehensive screening matrix where only *Mass*, *Electricity consumption* and *Aerodynamic drag* was considered, since these metrics taken from the requirements specification together cover all energy improvements that has been encountered. These three evaluation categories were translated into *grams* CO_2 *per km* through rules of thumb established at Volvo Cars to be able to compare the ideas objectively against each other. Since some ideas/concepts gave totally different results in different conditions, the results were divided into minimum savings and maximum savings. The two result categories together with an approximation on how certain the results were for the specific idea were color coded from clear red (very bad) to clear green (very good). A cut out from this matrix can be seen in figure 11. These three colored columns made it easy to get an overall picture of which ideas that had enough potential to dig further into.

Idea #	gCO2 min	gCO2 max	Margin of error
27	0,1835	[illegible]	
28	0,1	0,28228	
29	0,1288	0,7364	
[illegible]	[illegible]	0.03	
141	4,2532	[illegible]	
142	0,3038	0,9114	
144	0,3038	0,72912	
145	0,6076	0,9114	
147	0	0,12152	
[illegible]	[illegible]	1,8228	

Figure 11: Cut out of initial screening matrix

For evaluating which ideas that should be built into the demo car Aurora or just be calculated for potential, the remaining ideas were evaluated on whether they could be visualized in a clear way or not. This was done through meetings with the involved people at VCC, such as the Concept workshop. After some discussion a building list started to get developed. This building list was a first start for the Concept workshop that let them know where to start.

3.8 Further investigation

Due to the lack of knowledge about some of the ideas more information was needed before creating a new scoring matrix to narrow down the number of ideas even more. To be able to do this some studies that VCC had performed, about driving habits and climate, were investigated. See chapter 2 in the report. Also the knowledge about the ideas needed to be improved. Therefore deeper calculations and testing were performed to fill the knowledge gaps.

3.8.1 Testing of ideas

Since there were few data for some ideas, testing of these were performed to get enough knowledge to base decisions on.

3.8.1.1 Climatise actively only where people are

A subjective test was performed to evaluate whether it was possible to divide the compartment into different climate zones by having differentiated temperature settings and thereby claim that it can be beneficial to only climatise where people sit. See section 4.1.1 for further description.

By adjusting temperature settings for a Volvo V40's dual zone climate system it was tested whether a noticeable temperature difference can be produced with existing climate system and whether it would be comfortable for the passengers. It was noted that the climate system could very well produce different temperatures at different sides of the compartment. It was very clear to the passengers and even if some "temperature leakage" occurred between the sides it still didn't feel uncomfortable in the "climatised" space. As it was now it was apparent that the two sides both actively tried to achieve the set temperature, leading to no or very little energy savings, but it seems possible to set the system so that the unoccupied side could be passive and not waste energy. A reflection is also that the temperature for the passive side should not be set too differently from the temperature of the climatised side. Both for making it comfortable and that it seems like the climate system can not create a higher temperature difference than about 4 °C between the two sides.

3.8.1.2 Passive ventilation

The idea was to let hot air dissipate through an open ventilation valve and by that reduce the temperature inside the compartment. To evaluate how effective passive ventilation could be for a car during a hot day a test were performed on a cool down scenario. By heating the compartment of a Volvo V40 to a high level, (50 °C) and then letting the car cool off in a cold outside temperature, (-1 °C), it represents a hot summers day when the air temperature inside the car compartment can reach temperatures above 80 °C even when the outside temperature is below 25 °C (Svenska Kennelklubben, 2009). The test can therefore symbolize a car that has been parked for a long time in the sun. In the reference cases all doors and windows were completely shut and in the test cases a rear window was opened about 1 cm to let the air dissipate and simulate a passive ventilation vent, see figure 12.

Figure 12: The slightly opened window to simulate a passive ventilation vent

During the tests it was observed that whether the window was opened or not had very little impact on the cooling process and virtually no difference between the reference case and the test case could be detected. Actually, it was observed that over the first tests, the cooling process went slower and slower even though the car's air temperature was brought down to normal compartment temperature between the tests (20 °C). After the third test, which was the first with the window slightly open, it was noted that even though the air temperature was down to 20 °C, the interior was hot. Therefore the compartment was exposed to the outside air and soaked until the interior had cooled down before the fourth test was performed. In this test the cooling process was, marginally, the fastest of the four and it was concluded that the interior properties and mainly the thermal mass is of far greater importance than what passive ventilation is. The results from these four tests can be seen in figure 13.

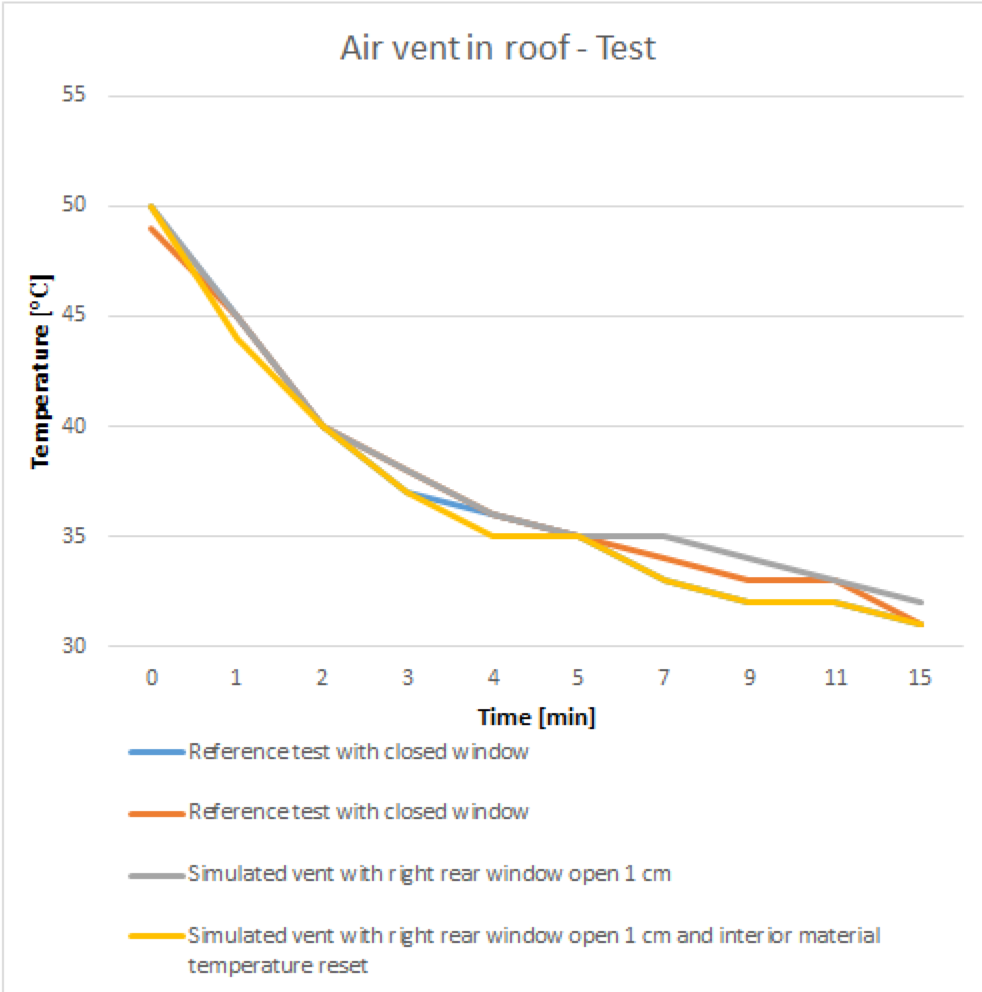

Figure 13: Test results from the test with simulated passive ventilation

3.8.1.3 Insulation

An idea that seemed to show potential was to insulate the windows. When the test for passive ventilation showed no detectable difference in the cooling scenario, it was decided to test insulated windows as well, both to see if window insulation was any better than passive ventilation and to try to establish the validity of the testing method.

To simulate double glazing or similar methods to insulate the windows aluminium insulation, usually used for engine and exhaust heat insulation, was cut to fit the windows' shapes and attached on the inside of the windows, see figures 14 and 15. All windows were covered in the test and the test procedure followed the setup for the passive ventilation above. Since the outside temperature was somewhat higher a new reference test was performed but the results were very similar to the ones of the passive ventilation tests, which can be seen if a comparison of the graphs is performed.

Figure 14: Car fitted with insulation material for simulating insulted windows (Exterior)

Figure 15: Car fitted with insulation material for simulating insulted windows (Interior)

As seen in figure 16, the test showed a significant effect of insulating the windows of a car. The temperature decreased significantly slower and it would thereby ease the load on the Heating, Ventilation and Air Conditioning (HVAC) system. As can be seen in the figure, the second test with insulated windows kept the heat the best, which was suspected to be due to the heating of the interior materials discussed in the ventilation test. The car was thoroughly vented between the tests but the results suggest that the thermal mass however affected the cooling down process. The reference test was done last and should by this logic have the slowest cool down scenario, giving confidence that the effect of insulation is of great significance.

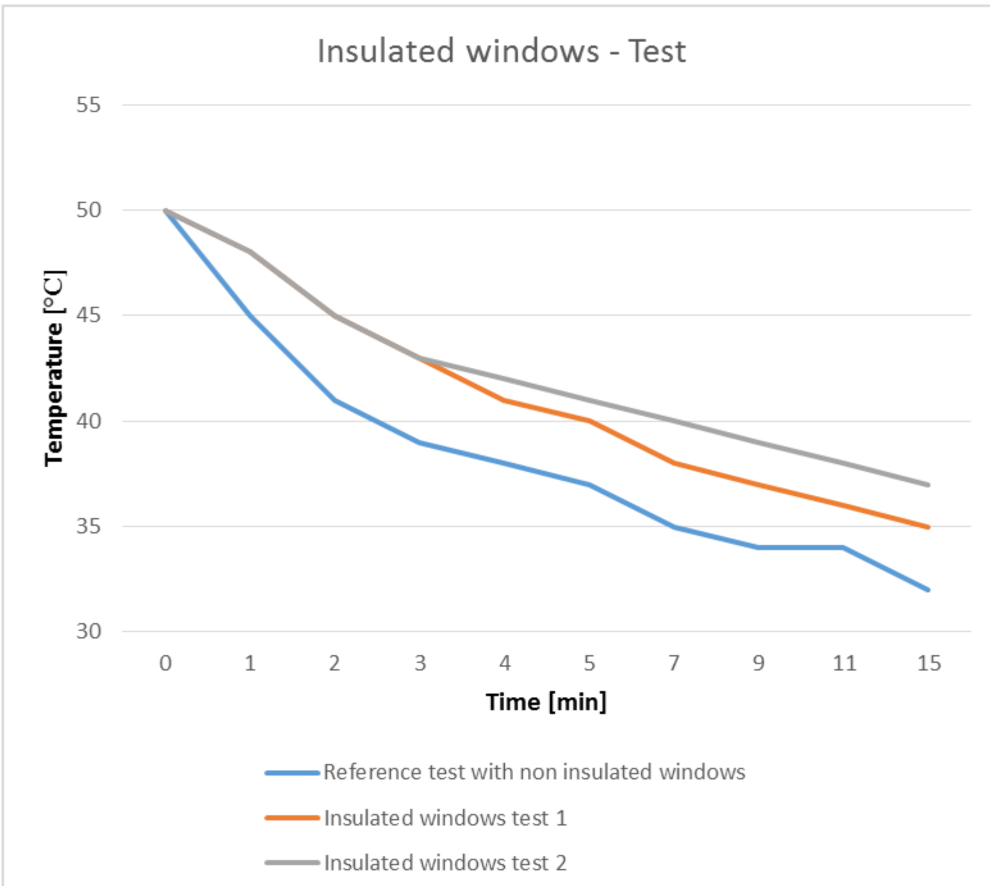

Figure 16: Test results from test with insulated windows

3.8.1.4 Sound test with personal sound

This test was performed to see if the concept “Speakers in headrest” could be realized. This idea was of interest due to the information from the internal electrical load database at VCC that showed that the audio system was consuming a constant current that could be lowered by using smaller speakers and replacing the radio and amplifier with the users own smartphone or similar device. The test was done by attaching the car’s tweeters on the side of the headrest and then play music through them, see figure 17. After listening the verdict was that the tweeters that are installed in the car today will not work due to bad sound quality. But with better speakers the concept should be realizable. With this new knowledge and the fact that people that will buy an environmentally friendly car are probably willing to sacrifice some comfort and quality of entertainment, the confidence in the concept increased.

Figure 17: Test configuration for personal sound

3.8.2 Calculations

When testing was done and the engineering judgement could not lead any further, calculations were needed to evaluate how the concepts performed against each other and to make decisions on which to keep and develop. The most important metric in the thesis is the concepts’ energy efficiency, which corresponds directly to fuel consumption and carbon emissions for a car with only an internal combustion engine. For the concepts to be industrialized the economics are also of great importance and could not be fully neglected in this thesis.

3.8.2.1 Energy

To get a grasp of how beneficial the different concepts are three main metrics were chosen: Reduced electrical load in watts (W), reduced mass in kilograms (kg) and reduced aerodynamic drag in C_d. To be able to compare the different savings against each other they were through rules of thumbs in a handbook (Burgdorf, 2012) converted to gCO_2/km savings for conventional vehicles with internal combustion engines, see figure 18. This handbook is based on the NEDC certification cycle, which makes some concepts ineffective to the reference consumption since not all systems are running during the cycle, see section 2.2. However, even these concepts that are not seen in the cycle are affecting the consumption and energy efficiency that the customer sees. To assess how the different savings affected the electrical range they were translated into electrical power in watts (W), even mass reductions and C_d improvements, and through that used to determine the extended range.

Parameter study FC_Qsim				
Change	Reduction			
	ref 116g Diesel		ref 149g Gasoline	
	gCO2/km	%	gCO2/km	%
Mass -100kg(1700->1600)	[redacted]	[redacted]	[redacted]	[redacted]
Mass -100kg(equal perfom)				
CDxA -0,1(0,64->0,54)				
RR -1N/kN(7,4->6,4)				
El load -100W				
KERS with 50% eff				
Start Stop 80% eff.				
Gearbox +1% efficiency				
Drivetrain +1% efficiency				
Transmission fully warm				
Downspeeding 100rpm				
Indicated efficiency +1%				
PMEP -0,1 bar				
Friction -0,1 bar				
Engine fully warm				

Figure 18: Rules of thumb handbook for evaluating improvements

Finding numbers for the metrics for electrical load and mass were mainly done through databases. For electrical load the Volvo internal Load Database (Volvo Car Corporation, 2013 B) and for the potential for mass savings the benchmarking site A2mac1 (A2mac1, 2013) together with engineering judgement was used. The aerodynamics were harder to evaluate, therefore experts on the subject were called in to help judge how beneficial the concepts were. For concepts connected to the interior climate in the car data from a pre-development project (Bäckelie, 2012) at VCC was very helpful as well. For a number of ideas, for which data was hard to find, calculations and approximations were made regarding similar products, for which data was easier to gather.

At first the calculations were done very roughly and for ideas without much fact they were just graded from green, potential for big savings, to red, very slim or no potential for savings. As the selection process went on the calculations became more and more refined when specific numbers were found. It should however be mentioned that all numbers presented in this thesis are approximations and should be seen more as a guide than exact figures.

3.8.2.2 Economy

When the evaluation approached finalization and the ideas that were left mainly were the ones presented in chapter 4, consideration was taken to the economy of the concepts. From the figures of energy savings the acceptable costs were calculated from a rule of thumb that is stating how much a gram of carbon dioxide per kilometer is worth in SEK, (Burgdorf, 2013). To evaluate whether the acceptable cost is achievable, now or in the future, a cost approximation was performed by checking the current cost for VCC when applicable or check similar technology on the open market and make an assumption on what the cost for VCC could be. Furthermore an evaluation was done on whether the concepts would be economically feasible. To give an overview of the economic potential for the concepts they were divided into three categories; green, yellow and red. Green representing good financial feasibility, yellow an assumed future financial feasibility and red a questioned financial feasibility even in the future. This grading is presented in the results with each idea.

3.9 Further evaluation

To get the remaining number of ideas down to a reasonable number a scoring matrix was used. The scoring matrix in Ulrich & Eppinger (2012) was used as a foundation to the scoring matrix that can be seen in appendix F, with the wishes from the requirements list. To be able to rate the concepts a rating scale that was based on relative performance was created. The ratings were 1, 2, 3, 4 and 5 where 5 was the best. The rating numbers were correlated with how the ideas perform compared to the reference car regarding the wishes in the specification list. Two points from the requirements specification list were cancelled out due to their irrelevance at this phase. The two points were regarding AURORA and how the ideas were possible to be built into the demo car. One problem that occurred when creating the matrix was that the different ideas did affect the car's consumption in different driving cases. Some of the ideas did only affect the car when it was cold and some when it was hot and sunny. This was solved by having three driving cases in the matrix. These were 43 °C with sun, 24 °C and -18 °C. By doing this the ideas that were affecting the car's energy efficiency in every driving case were shown. This was done by giving the ideas that showed performance in all driving cases, for a specific wish, an extra bonus score.

There was also a problem with scoring the solar cell ideas due to the fact that in VCC driving cycles there was no sun present in other than the hot case, which is an assumption that is too far from the reality to ignore, and solar cells were therefore not eliminated even though they gained a low score.

When working with the scoring matrix a problem with the bonus system was found. If the ideas were good in one of the top categories regarding energy efficiency they scored well, with no exceptions, in most of the top categories. These ideas were therefore automatically given a very high score compared to the rest, so high that it seemed unjustified. The evaluation criteria were too similar and therefore gave too many points. The scoring matrix was therefore updated and some criteria were combined. The four criteria that were updated were; net energy usage, gross energy usage, fuel consumption and carbon dioxide emission. These four were combined into two: net/gross energy usage and fuel consumption/carbon emission. The bonus was also corrected since ideas with only a very small benefit in all cases at first outscored ideas with very large improvements in one or two driving cases.

3.10 Building the demo car Aurora

To be able to demonstrate some the chosen concepts in a good way to the personnel at VCC an internal demo car have been built as mentioned before. It was based on a regular Volvo V40 that was modified into Aurora. By building a demo car it was easier to get feedback on the different concepts. It might even create a new mind-set, towards eco-friendliness, in the personnel at VCC when it will be shown to them. This new mind-set can help generate even more ideas/concepts that can be built into later versions of Aurora. The actual building/construction of Aurora was done by the Concept workshop. It has a lot of knowledge and experience from building demo cars which came to use many times through the building process.

As mentioned earlier in the report a building list was created. It was founded on the concepts that looked most promising. The list was created to help the workshop plan their work. This list was then developed, by adding and removing things to/from it, when the knowledge about the concepts increased. When the actual remodelling of the car started, it was with the concepts that were decided to be included in Aurora. As the modification continued the communication between the involved persons increased so no mistake regarding the design would be made. To know if the building process was on track during the master thesis, weekly meetings with the workshop staff were held. During these, the modifications that would be made to the car were discussed. Another thing that was discussed was the design of the concepts that would be built. This was done by showing quick sketches, see figures 19-22, of the main ideas and from the sketches realistic concepts that could be built were generated.

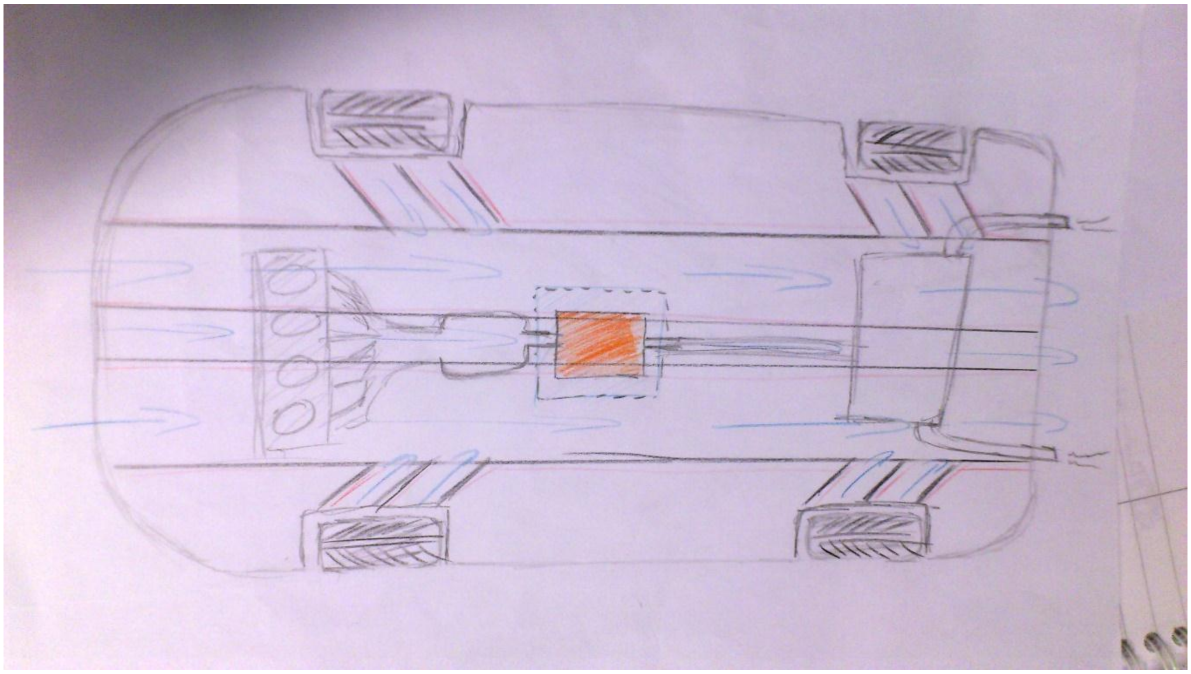

Figure 19: Sketch of flat underbody and Thermo Electric Generator

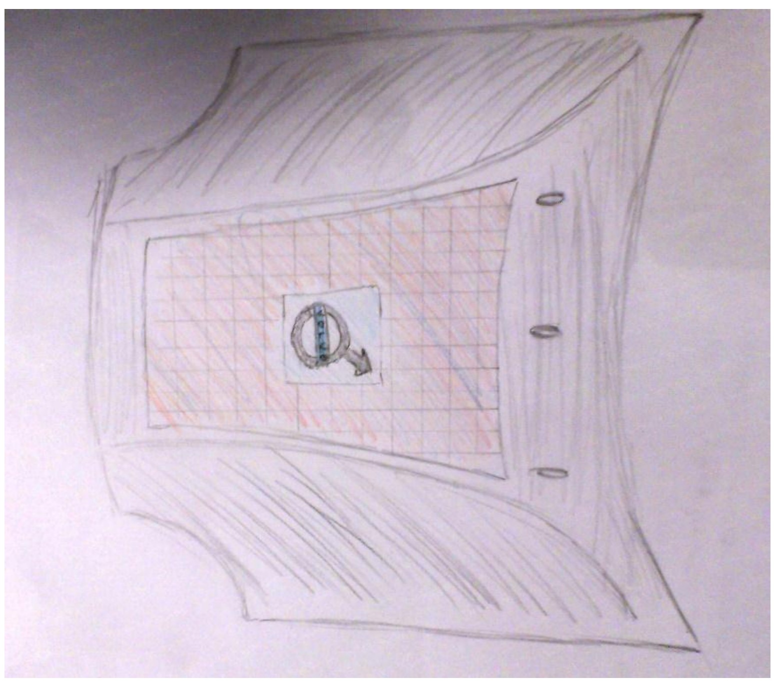

Figure 20: Sketch of Carbon fiber components and solar cells

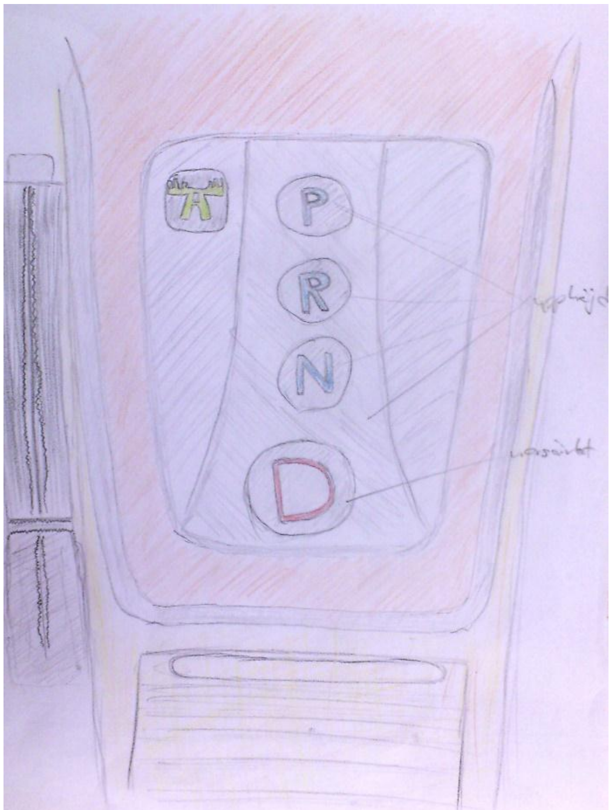

Figure 21: Sketch of the replacement for the gear lever

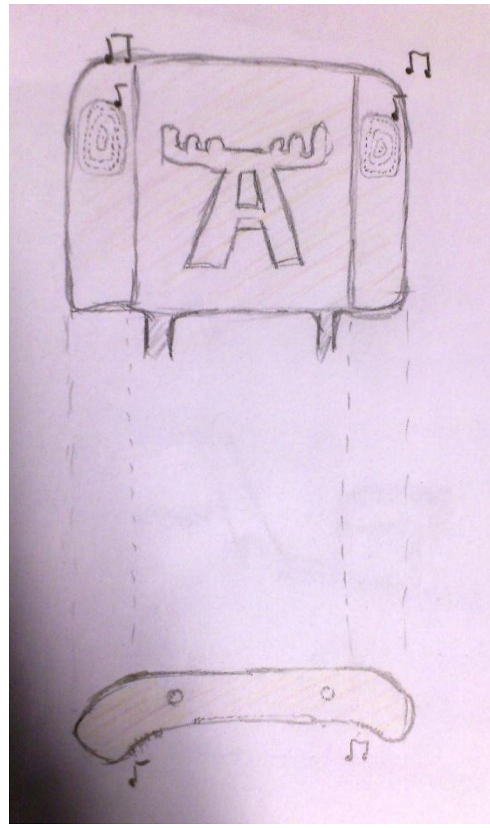

Figure 22: Sketch of the speakers in the headrest

4. RESULTS

In this chapter, the concepts that have been chosen through the matrices are presented with a short description of how they work, followed by a table that shows how much the concept saves with respect to *electrical power, mass, aerodynamic drag* and *total carbon emission. Economic potential,* based on the carbon emission savings, is also included in the table. It is also shown if the concept contributes to lower carbon emissions in the driving cycle NEDC. The final version of the demo car Aurora, with all modifications, is also presented in this chapter. Finally, a compilation of how much all concepts together can affect the consumption and the range for a car is presented. It should be noted that all figures in this chapter are approximations and should be seen more as a guide rather than explicit figures.

4.1 CLIMATE

A well-known fact is that the climate system, depending on environment, can consume a lot of energy. In the past, the heating was not a problem thanks to the heat loss from the combustion engine, but today with more efficient engines and more electrification in the car, it is not so simple any more (Landelius & Nielsen, 2013). A way of getting enough heat is to install a Positive temperature coefficient (PTC) heater that converts electric energy to heat or a Fuel Operated Heater (FOH).

The cooling of the compartment has never had the same help from any energy loss and it is therefore always consuming electrical energy when running. Another drawback with the cooling system is that it is almost always running to help drying the air that goes into the compartment. Due to this the car is always cooling the air before heating it. This drying problem is also the root cause to why a car needs to exchange so much air when it is running not to start fogging on the windscreen. Here below are some concepts that can help to solve some of the above mentioned problems. How much these different concepts will help the climate system will of course depend on the ambient temperature, but also on which type of car that the concept will be implemented in. Because a battery electric vehicle (BEV) does not have any heat loss from the engine like a traditional combustion engine has and the plug in electric vehicle (PHEV) only has it when the combustion engine is running, efficient heating becomes even more important for these cars. It should also be noted that in the climate calculations and simulations there is always an ambient temperature that creates a situation in which no heating or cooling is needed to maintain the comfort temperature. Therefore most improvement figures in this section is ranging from 0 up to a maximum, which most often is present at a very high or a very low temperature (Bäckelie, 2012).

Thermal mass is a phenomenon that is also affecting the climate system. It is the ability of an object to store heat, and it is the product of the mass and the specific heat capacity. High thermal mass helps to “smooth out” temperature fluctuations. If the compartment of a car had higher thermal mass it would therefore be harder to heat or cool. So by either reducing the mass or change materials the climate system may have to work less.

4.1.1 Climatisation only in occupied seats

This concept is about controlling the climate system so that it is only heating or cooling where people are sitting in the car. An example of this can be when the driver is alone in the car and the climate system is nowadays heating or cooling the whole compartment. With this concept, the air will be guided towards the driver and the conditioning will be shut down at all other locations of the compartment. Through this setup the climate system will not need to heat or cool the whole compartment, and it can therefore save energy. To make this concept possible the car needed to be changed in some ways. Some examples of changes are where to place multiple temperature sensors and make a software update that controls the airflow into the compartment. Below, in table 1, are the savings for the concept in numbers.

Table 1: Table of metrics for Climatisation only in occupied seats

Metric	*Value*	*Unit*
Electrical power	0-1000	W
Mass	~ 0	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0-25	gCO_2/km
Affect NEDC	No	
Economic potential	Green	

An even more radical solution will be to build sections inside the car which divide the compartment into smaller volumes of air, and to just heat/cool these. Another radical solution is to create some form of climate suit that the user puts on, makes it possible to get a very near body climate.

4.1.2 USE HEAT PUMP TO HEAT COMPARTMENT

Heat pumps are based on the principle that gas that is compressed increases in temperature and gas that expands decreases in temperature. The gas that circulates in the heat pump collects energy from the medium on one side (2), and by compressing it the temperature increases (3) and the extra energy can be transferred to the other side (4), see figure 23.

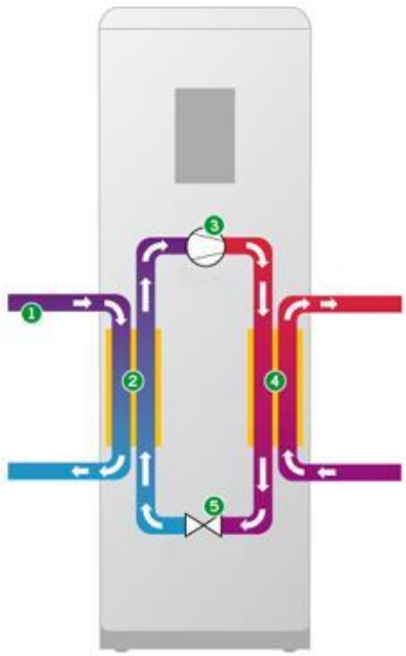

Figure 23: Schematic picture of a heat pump (Thermia, 2013)

In house installations it is possible to save 30-70 % of the energy depending on which technique that is used and the house's construction, (Energimyndigheten, 2010). Different setups can be achieved by different choices of the mediums used on the hot and the cold side. For the car, there exists several different installation opportunities. One of them is to use an air to air heat pump and just implement it in the existing system. One concept on how to do it is to make it possible to change the direction of the flow in the AC-system and through this change create a heat pump. Another variant is to use the coolant from the engine on one side to heat the air going into the compartment on the other side. Of course this idea only works for a car with a combustion engine that needs a coolant. A third idea is to try to use the outlet air from the car and take the energy from it to heat the incoming air. A problem with heat pumps is that they lose some function if it gets cold, usually somewhere between -5 and -20 °C. If the car must work in these conditions one solution can be to add a small PTC element to the system. This concept is most efficient for BEVs and PHEVs, due to their lack of excessive heat from a combustion engine, but it will also help in a traditional car. The numbers below, in table 2, are for an installation of an air to air heat pump in a BEV. The carbon emission savings are therefore not real, but are presented for comparison.

Table 2: Table of metrics for Use heat pump to heat compartment

Metric	*Value*	*Unit*
Electrical power	0-2100	W
Mass	0-? (Depends on implementation)	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0-50	gCO_2/km
Affect NEDC	No	
Economic potential	Yellow	

4.1.3 Insulate roof and doors

Another way to grasp the problem can be to investigate why the car needs to use so much energy to heat/cool the compartment. For being a relatively small volume, the compartment consumes a lot of energy. One of the big energy losses is the problem that a car lets the heat dissipate through its borders. In addition to that the cars always also has a certain cooling effect on the body due to the headwind. A concept that will reduce this conduction and by that decrease the energy consumption for the climate system is to insulate with new and better material. This will of course increase the mass of the car, but the calculations show that the gain is bigger than the losses (Bäckelie, 2012). In the case of the calculations a 15 mm thermal wrap was integrated into the vehicle door and roof. To get even better results an aerogel, which today exists as a commercial insulation material in the building industry, can be used. The numbers below, in table 3, show what can be saved through insulating the roof and doors with thermal wrap.

Table 3: Table of metrics for Insulate roof and doors

Metric	*Value*	*Unit*
Electrical power	0-200	W
Mass	~ 0	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0-5	gCO_2/km
Affect NEDC	No	
Economic potential	Green	

4.2 Windows

Another area of the car that also affects the climate system is the windows. They have the same problem with conduction as the rest of the car but, as the test with insulating the window showed, probably an even bigger problem. Then there also is the headwind that makes the conduction even higher for the windows. Another problem that occurs, and which affects the window design, is the radiation from the sun and at which angle it hits the car. It is especially the IR-radiation that will affect the climate system, but also the UV-radiation should be kept in mind due to the problem with faded interior. The problem with the IR-radiation is that it is heating up the car both when it is parked and when it is driven. This forces the climate system to work harder when it needs to cool the compartment at start and when it needs to maintain a chosen temperature. The problem with keeping the temperature at a steady level is the inflow of radiation through the windscreen that forces the system to always cool the air above the dashboard. A radical solution to this problem would be to change the angle on the windows so that they create shadow over the interior. A problem with this will of course be the increased drag. Some more realistic concepts that do not interfere so much on the design are presented below.

4.2.1 Double glazing

This concept uses the same principle that has been used for insulating windows in buildings for a long time. By using two layers of glass with a small space between them which contains stationary air, see figure 24, the conduction between the outside and the inside can be reduced. When adding an extra layer of glass the mass of the car increases. One way to counteract this is to use plastic in one of the layers. That the insulation properties for double glazing are present in a car as well as in a house can be seen in the test that have been performed that showed that the temperature declined much slower with insulation on the windows in cold weather. More about this test can be found in section 3.8.1. How big savings that can be accomplished by changing to a new window design depends on the environment climate and if calculated on the transient phase or stability phase. Below, in table 4, are the figures for the biggest and lowest savings for a type with two layers of glass.

Table 4: Table of metrics for Double glazing

Metric	*Value*	*Unit*
Electrical power	10-430	W
Mass	+20	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	+1-10	gCO_2/km
Affect NEDC	Yes, mass	
Economic potential	Yellow	

Figure 24: Schematic figure of double glazing (Alanni, 2013)

4.2.2 POLYCARBONATE GLAZING

This solution is based on the idea of replacing all the glass windows except the windscreen with plastic windows. The windscreen is not replaced for safety reasons. The gain by replacing glass with plastic is that the conductivity is lower for plastic than for glass. This reduces the conduction, so that the climate system does not have to work as hard to maintain a certain temperature. Another benefit with usage of plastic is the mass reduction, which can be as high as 50 % (Clawson, 2009), (Abrahamsson, 2013). A drawback with plastic windows are that they can easily get scratched. A possible solution to this problem is to put some kind of clear varnish on the plastic windows that protect it against scratches. Another problem with plastic windows is that even if they insulate good against heat transfer they do not insulate as good as glass does towards noise. Crazing and tarnish are also well-known problems that affect plastic which gets old. This could be solved by UV-protection of the plastic. Then there also exists a problem that is related to safety. Polycarbonate is almost unbreakable, which can make it difficult to get people out of a crashed car. This can on the other hand be a good feature, since it also makes it hard for a burglar to get into the car. Something that also is hard to know is how plastic windows will react to icing. But despite these problems some car manufacturers have started tests to change their rear window into plastic. Why they have not tried to change more windows is because road safety authorities do not have approved plastic windows for front and side windows (Abrahamsson, 2013). One last thing is that polycarbonate windows are more expensive than glass windows. However, if the car manufacturers use plastic instead of glass they can integrate the windows more into the design of the car and through that decrease other manufacturing costs, (Abrahamsson, 2013). Below, in table 5, are the savings that can be made from changing to polycarbonate windows.

Table 5: Table of metrics for Polycarbonate glazing

Metric	*Value*	*Unit*
Electrical power	0-190	W
Mass	10	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0,5-5	gCO_2/km
Affect NEDC	Yes, mass	
Economic potential	Yellow	

4.2.3 Hydrophobic surface on windscreen

By using nanoscale technology on the windscreen it is possible to make it water repellent, see figure 25, and thereby reduce the wipers workload when raining. In the future, if the nanoscale technology can be developed even further, it might be possible to remove wipers and thereby remove the electric motors, linkage and more. If this becomes possible it will mass and electricity consumption. Even with today's solutions, which is a 2 composite liquid that is mixed and then applied to the windscreen, (Auto motor & sport, 2005), (Selins Glas, 2013) , the wipers and motors can be designed with a lower performance level and by this save mass and electrical energy. Another benefit with this concept is that it keeps dirt, insects and ice/frost away from the windscreen which creates a better view for the driver and through that also a safer drive. The table below, table 6, shows the numbers for savings that can be made with a future solution that removes wipers and motors.

Table 6: Table of metrics for Hydrophobic surface on windscreen

Metric	*Value*	*Unit*
Electrical power	0-10	W
Mass	4	kg
Aerodynamic drag coefficient	0-0,003	C_d
Carbon emission	0,5-1	gCO_2/km
Affect NEDC	Yes, mass and aerodynamic	
Economic potential	Green	

Figure 25: Oakley glasses demonstrating hydrophobic surface on the left side (Oakley, 2013)

4.2.4 IR-REFLECTING GLAZING

IR-reflecting windscreens already exist in today's cars as an option for the customer to choose. But when creating an energy efficient car all windows should have IR-reflecting ability. This is because by using IR-reflecting windows the climate system's workload can be reduced. This concept is of course most efficient when the sun is shining, but it also helps somewhat when it is cloudy. By stopping the infrared radiation from entering the compartment the concept saves energy both in the transient and in the stability phase. Another concept that could handle the transient problem, which come from that the interior gets hot when the car is parked in the sun, is smart glass. This also have another benefit compared to IR-reflecting glass, namely that when you park the car you get an inbuilt cargo cover since the window becomes opaque. Today this technique is much more expensive than IR-reflecting glass and only works when the windows are opaque and therefore IR-reflecting windows seems to be a better solution at present. The table below, table 7, shows the numbers for how much an installation of IR-reflecting windows can save.

Table 7: Table of metrics for IR-reflective glazing

Metric	*Value*	*Unit*
Electrical power	0-475	W
Mass	+0,5	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0-12	gCO_2/km
Affect NEDC	No	
Economic potential	Green	

4.3 Electricity consumption

For a long time there has been no focus on the electricity consumption of passenger cars, even though it affects the fuel consumption quite heavily since the electricity is produced from the car's combustion engine. This is a fairly inefficient process, although it has been significantly improved in later years. Below are some areas where there are potential to save electricity and thereby fuel.

4.3.1 Speakers in headrest

The audio system in a car can consume a lot of energy, but the exact rate is very depending upon the system's performance level and the listening volume. However, even at a low volume there is potential for energy savings. According to Volvo Car Corporation (2013 B) the electricity consumption of the sound system at normal listening is 45 W.

One concept for reducing the energy consumption of the sound system is to bring the sound source closer to the listener, i.e. to move the speakers to the headrest, see figure 26. By using smaller speakers in the headrest it is possible to reduce the power which the speakers need and make it possible to only play sound/music in the seats where passengers sit. Further all present speakers as well as the amplifier can be removed, which also reduces the mass of the vehicle and saves even more energy. For figures see table 8.

Table 8: Table of metrics for Speakers in headrest

Metric	*Value*	*Unit*
Electrical power	40	W
Mass	5	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	1	gCO_2/km
Affect NEDC	Yes, mass	
Economic potential	Green	

Figure 26: Picture of Bose's speakers in headrest for a convertible (Automotive addicts, 2010)

A not as drastic measure to reduce the energy consumption of the audio system is to only make use of the speakers next to the occupied seats. This of course does not have the same energy savings potential as having the speakers in the head rest and gives no mass reduction. But this can be an option that is easier to adopt as no or little alterations is needed to the physical components and the system can be used at full power if wanted. The energy savings for this option is about half of what can be achieved by taking away the speakers and putting small ones in the headrest.

4.3.2 Seat heat only in occupied seats

The heating of the seat is a convenience that cannot be taken away, on cold markets, even though it can consume large amounts of energy. It also contributes to the impression that the compartment is warm, which makes it possible to reduce the power that is needed from the climate system. The function is thereby needed in cold climates, but energy efficiency can be improved.

By making the seat heat functional only when the seat is occupied, energy waste can be minimized for example when passengers are dropped off or when not the same seats are occupied from one trip to another. For figures see table 9.

Table 9: Table of metrics for Seat heat only in occupied seats

Metric	*Value*	*Unit*
Electrical power	0-150	W
Mass	~ 0	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0-4	gCO_2/km
Affect NEDC	No	
Economic potential	Green	

Making the seat heat more efficient is another way to go, which can be accomplished by putting the heating element closer to the passenger. An idea is to weave heat conducting material into the seat fabric. If Peltier elements are used they can also cool the passenger, which helps to lower the needed AC power.

4.3.3 LED HEADLIGHTS

Another contributor to the electricity consumption of a car is the lighting, and in particular the exterior lighting since it runs more often and at higher power than the interior lighting. Of course, the exterior lighting is a necessity and a safety feature, which with Volvo's image cannot be compromised with. But if technologies can give the same light performance as current solution with lower electricity consumption there are energy savings to gain.

A technology which can produce as good lighting qualities as the present halogen solution is Light Emitting Diodes (LED). Replacement of the halogen lights with LED can save around 80% (Wörman, 2013) of the power needed. The present, Day Running Lights (DRL), technology that Volvo has implementing, where the high and low beam is turned off in daylight and only energy efficient LED position lights running instead, does not give as high savings as they can seem when you reduce the power consumption of the headlights. According to Lindhagen (2011) 75% of the total driving is done during daytime, which is taken into consideration in the calculations for the concept. At first, the LED headlights seemed to imply a mass saving considering their small size relative to the halogen lights. However they need further components like cooling and controls that neutralize the mass saving (Wörman, 2013). For figures see table 10.

Table 10: Table of metrics for LED headlights

Metric	*Value*	*Unit*
Electrical power	16	W
Mass	~ 0	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0,5	gCO_2/km
Affect NEDC	No	
Economic potential	Yellow	

A further improvement from the LED technology is laser, which a few competitors are looking into. This should only consume half of the energy that LED does and be much brighter (Parker, 2011), (Ackerman, 2011). However, with DRL and the already low energy consumption of LED headlights there are not much energy to save.

4.3.4 Screen in power saving mode as standard

A source of energy consumption is the screens of the infotainment system. Because of the strict quality and safety requirements in the auto industry, the well-established Liquid-Crystal Display (LCD) technology is used. Energy can however be saved since during most of the time these screens are not used.

The easiest way to improve energy efficiency of the infotainment monitor (IAM) is to set it to screensaver mode, and have that as the standard option for the car. With this modification replacing the LCD screen by LED and other changes becomes uninteresting since the equipment is so seldom used. The drawback of this idea is that it may be annoying to the customer to have to touch controls to light up an otherwise black screen. For savings see table 11.

Table 11: Table of metrics for Screen in power saving mode as standard

Metric	*Value*	*Unit*
Electrical power	10	W
Mass	~ 0	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0,3	gCO_2/km
Affect NEDC	No	
Economic potential	Green	

An extra function to the screensaver mode is to implement a function so the screen is not put in screensaver mode while looked at, like the technology used in for example Samsung phones. Or even better, wake up when looked at using an eye tracker system.

4.3.5 Charge battery when parked

The car needs electrical energy to operate, both to make the car go and to power systems like e.g. climate and lighting. To produce this electrical energy most cars use an alternator that take power from the engine and convert it to electrical energy. Thereby the fuel consumption and carbon emissions are highly affected by how much power the alternator needs to deliver to the battery.

By avoid using the alternator for producing electricity it is possible to save fuel, in NEDC and even more in real world conditions. Use of the connection for the engine pre-heater to also recharge the battery, and program the car not to use the alternator until the state of charge is down to a certain level, could save energy. According to Lindhagen (2011) most trips are just short distances, which can make this method of recharging the battery when parked save a lot of fuel and carbon emissions.

The challenge is to create an intelligent system to control when and how much the alternator should be engaged in the electricity production, and how to encourage the user to plug in the car to the engine pre-heater preferably all year round. For savings see table 12.

Table 12: Table of metrics for Charge battery when parked

Metric	*Value*	*Unit*
Electrical power	0-750	W
Mass	~ 0	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0-20	gCO_2/km
Affect NEDC	No	
Economic potential	Green	

4.4 Harvest energy

Traditionally the energy that has been used for both the propulsion and other systems has come from the fuel tank, either directly or via conversion into electrical energy. When looking for even higher energy efficiency, there are available energy sources around the car. Today it is already very close to being more profitable to try tapping these than to just make the engine more efficient. For electric cars it would be beneficial as well, as it can extend the range and/or make it less necessary to plug in the car to recharge.

4.4.1 Solar cells

During daytime cars that are driven or parked outdoor are exposed to the sun, which often just results in undesired heating of the compartment. If the sun radiation could be utilized to produce energy it would ease the need for energy from the engine.

Solar cells on the roof of the car, see figure 27, can charge the battery as long the sun is shining. Depending on the type, for example a dye-sensitized solar cell can generate energy in cloudy weather and when shaded as well (Langhammer, 2013). On a car roof it is reasonable to cover up to about two m^2 with solar cells. When the sun is at zenith the solar irradiation in Europe is about 1000 W/m^2, and with dye-sensitized solar cells with efficiency of about 10%, power of 200 W can be produced. The solar cells can harvest energy all the time to recharges the battery and reduce the need for using the alternator, which saves additional energy. Over a year this sums up to about 200 kWh, which can be utilized to 90 % in a car with an internal combustion engine if a battery of the size of VCCs start & stop batteries is used (European Commission, 2011), (Volvo Car Corporation, 2012). The customer can then save around 1000 SEK a year (European commission (2011) and based on a fuel price of 14 SEK/l). Beside this benefit of solar cells it does inflict a mass increase, which also is at the top of the vehicle, affecting the car's performance and handling. The energy savings also depend on how large part of the daytime the car is parked outdoor compared to indoor. In the calculations it has been assumed that a user with solar cells on the roof of their car always park outside. For savings see table 13.

Table 13: Table of metrics for Solar cells

Metric	*Value*	*Unit*
Electrical power	0-200, but generates also when parked	W
Mass	+5	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	+0,2-5, without charging when parked	gCO_2/km
Affect NEDC	No, but can be credited	
Economic potential	Green	

Figure 27: Solar cells on the roof of a concept car from Pininfarina (Green-blog, 2009)

If the battery is fully charged or if there is no possibility to charge it, a way to take care of the energy generated when parked is to ventilate the compartment, which reduces the need for the HVAC system at start-up.

4.4.2 Thermoelectric generation from exhaust heat

An engine should in the ideal case transform all energy into kinetic energy, but a lot of the energy is lost in excess heat, both from the engine itself and through the hot exhaust gases evacuated. The heat from the engine has for a long time been used for heating the compartment of the car, but only studies and prototypes have been done on how to use the heat energy from the exhaust.

A way to recover the heat energy from the exhaust is to use a thermoelectric generator, see figure 28, which consists of a material that produces a current if heated on one side. It is a commercially available material which has been tested for different applications, among them the automotive industry, but no one has yet brought it to mass production. Research is being done to improve the efficiency further. Different sources (Energy Harvesting Journal, 2010), (Zervos, 2011) say that it can deliver 200-600 W in electric power and in all conditions, apart from the first minutes in very cold temperatures since the exhaust gases is not hot enough. This makes it a very promising concept, but the cost is high and it is only viable for cars with an internal combustion engine, so BEVs are disqualified and the potential for PHEVs is reduced. The cost can however be expected to fall significantly when the technology starts being used on a large scale. For figures see table 14.

Table 14: Table of metrics for Thermoelectric generation from exhaust heat

Metric	*Value*	*Unit*
Electrical power	300	W
Mass	+5	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	7	gCO_2/km
Affect NEDC	No, but can be credited	
Economic potential	Yellow	

Figure 28: Schematic picture of a thermoelectric generator adopted from (The car connection, 2013)

There are also other ways to recover some of the energy in the hot exhaust gases. One is to use an organic Rankine cycle and another to let the exhaust heat power a sterling engine, both to produce electricity. One concept in which the heat is not converted to electricity is to use it to heat the compartment, either through a heat exchanger, a liquid heating system or some other device.

4.4.3 Harvesting energy from vibrations in shock absorbers

A form of energy that is always present, to a smaller or larger extent, is the vibrations from the roughness of the road. This is today dissipated as heat in the shock absorbers.

MIT students (Chandler, 2009) have shown that there is quite a potential for using the vibrations. In an extreme case for an off-road car in rough terrain, savings comparable with up to a 10% reduction of the fuel consumption is possible, but for more normal use savings of 1-6% is realistic by using the student's technique with a turbine uses the oil flow in the shock absorber. The better the roads and the lighter the cars, the lower the potential for energy savings become though. Another test with coil and magnet (Li, et al., 2013) shows a potential for savings of 1-5% of the fuel consumption. For savings see table 15.

Table 15: Table of metrics for Harvesting energy from vibrations in shock absorbers

Metric	*Value*	*Unit*
Electrical power	50-250	W
Mass	~ 0	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	1-5	gCO_2/km
Affect NEDC	No, but can be credited	
Economic potential	Red	

4.5 Aerodynamics

A difficult but important area when trying to reduce the energy consumption of a car is its aerodynamics, because it induces drag on the car which slows it down. The aerodynamics is very dependent on the speed that the vehicle travels at, and with the knowledge gained on people's driving habits (Lindhagen, 2011) that the average speed is 75-80 km/h rather than in the NEDC where it is 33,6 km/h, the aerodynamics are even more important. In discussion with experts (Lennert Sterken (2013), Tim Walker (2013) and Johan Ljungberg (2013)) the improvements in C_d*A for every concept was found. C_d*A is the product of C_d, which is the coefficient of drag for the shape of the object involved, and A, which is the frontal area of the object. With the complexity that is involved in aerodynamics it is hard to find general rules on what is preferable, but as a rule of thumb all protrusions from the body is adding drag and you want to keep the surface smooth to reduce drag. However, there are exceptions from the rules with vortex generators that protrude from the body to produce vortices that steers the airflow and reduce the drag. Another exception is that a certain structure on the surface, mimicking the shark's skin, can make the drag lower (Jonsson, 2006).

In coming sections are a number of aerodynamic improving concepts presented and what they can give in terms of reduced carbon emissions and extended range.

4.5.1 Reduce drag from rear wake

A phenomenon that should be taken into account is the wake behind the car. It produces suction forces on the car which increase the drag. They are influenced by the cars overall aerodynamics, but can also be affected by measures at the rear end of the vehicle. One such thing is to put a "bottomless box", see figure 29, at the end of the vehicle, which helps reduce the suction forces (Dickison, 2012). For figures see table 16.

Table 16: Table of metrics for Reduce drag from rear wake

Metric	*Value*	*Unit*
Electrical power	-	W
Mass	~ 0	kg
Aerodynamic drag coefficient	0,005	C_d
Carbon emission	0,3	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

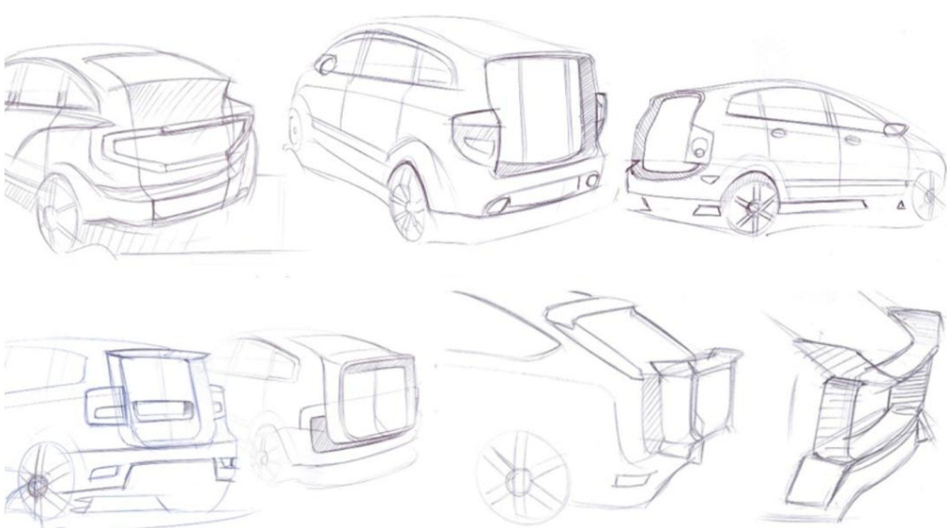

Figure 29: Sketches for rear wake reduction concepts (Dickison, 2012)

4.5.2 Remove rails

A small but nonetheless noticeable drag is produced by the rails on the car. If they were removed mass would also be saved. This idea is only valid for cars with rails. See table 17 for savings.

Table 17: Table of metrics for Remove rails

Metric	*Value*	*Unit*
Electrical power	-	W
Mass	3,5	kg
Aerodynamic drag coefficient	0-0,005	C_d
Carbon emission	0,2-0,5	gCO_2/km
Affect NEDC	Yes	
Economic potential	Green	

4.5.3 Replace door handle with sensor

Replacing door handles with sensors and some opening devices saves both mass and aerodynamic drag. See table 18 for savings.

Table 18: Table of metrics for Replace door handle with sensor

Metric	*Value*	*Unit*
Electrical power	~ 0	W
Mass	2	kg
Aerodynamic drag coefficient	0-0.003	C_d
Carbon emission	0,1-0,3	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

4.5.4 Remove rear view mirrors

If rear view mirrors should be removed, they must be replaced by cameras, see figure 30, and a screen which reduce the mass savings. There is also an issue with using screens instead of mirrors because of the electricity consumption, but this is taken into consideration in the calculations. See table 19 for savings.

Table 19: Table of metrics for Remove rear view mirrors

Metric	*Value*	*Unit*
Electrical power	+12	W
Mass	2,5	kg
Aerodynamic drag coefficient	0,005-0,015	C_d
Carbon emission	0,1-1	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

Figure 30: Side rear view camera for the concept car Volkswagen XL1 (The Telegraph, 2013)

4.5.5 CHANGE BODY SHAPE

A most drastic measure that cannot be implemented on an already launched vehicle is to change the overall body shape of the car to a more aerodynamic one. In the calculations it has been assumed that it is possible to alter the body shape for the next Volvo V40 to get the same C_d as the launched Mercedes CLA (Birch, 2013), i.e. going from a C_d of 0,29 (Walker, 2013) to a C_d of 0,22. See table 20 for savings.

Table 20: Table of metrics for Change body shape

Metric	*Value*	*Unit*
Electrical power	-	W
Mass	-	kg
Aerodynamic drag coefficient	0,07	C_d
Carbon emission	5	gCO_2/km
Affect NEDC	Yes	
Economic potential	Green	

4.5.6 Active grille shutter

Often when the car is driven, the air intake is unnecessarily large and just produces aerodynamic drag. If it could be controlled so that it was always closed when not needed the drag could be reduced. See table 21 for savings.

Table 21: Table of metrics for Active grille shutter

Metric	*Value*	*Unit*
Electrical power	~ 0	W
Mass	~ 0	kg
Aerodynamic drag coefficient	0,005-0,012	C_d
Carbon emission	0,3-0,7	gCO_2/km
Affect NEDC	Yes	
Economic potential	Green	

4.5.7 Active chassis, lowers the body with increasing speed

Ground clearance is necessary when approaching obstacles like bumps, curbs etc., but at high speeds it just infers aerodynamic drag. An active chassis which automatically reduces ground clearance at higher speed would therefore be very beneficial, or if possible a fixed low ground clearance is preferable. See table 22 for savings.

Table 22: Active chassis lowers the body with increasing speed

Metric	*Value*	*Unit*
Electrical power	~ 0	W
Mass	~ 0	kg
Aerodynamic drag coefficient	0,01-0,015	C_d
Carbon emission	0,5-1	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

4.5.8 Flat underbody

During later years some work has been done on improving the aerodynamics under the car, for example on the underbody panels of the new Volvo V40. Further improvement is possible. The calculations compare the Volvo V40 with the preferred design of a flat underbody. See table 23 for savings.

Table 23: Table of metrics for Flat underbody

Metric	*Value*	*Unit*
Electrical power	~ 0	W
Mass	~ 0	kg
Aerodynamic drag coefficient	0,01-0,03	C_d
Carbon emission	0,5-2	gCO_2/km
Affect NEDC	Yes	
Economic potential	Green	

4.5.9 Aerodynamic rims

By making the rims more aerodynamic, mainly by making them smooth and solid, it is possible to reduce the airflow and thereby aerodynamic drag induced by the wheels. One problem that can occur with a rim design like this is that the cooling of the brakes can be disturbed and therefore jeopardise the braking performance. But an eco-friendly vehicle should not be driven so hard that the temperature of the brakes reaches this critical level. See table 24 for savings.

Table 24: Table of metrics for Aerodynamic rims

Metric	*Value*	*Unit*
Electrical power	~ 0	W
Mass	~ 0	kg
Aerodynamic drag coefficient	0,005-0,015	C_d
Carbon emission	0,3-1	gCO_2/km
Affect NEDC	Yes	
Economic potential	Green	

4.5.10 Cover up wheel arches

Like the above this is a measure to reduce the drag induced by the rotation of the wheels, but instead of improving the rim design covering up the wheel arch so that the rotation of the wheel impacts the airflow as little as possible, see figure 31. There have been attempts to incorporate this for all four wheels, but covering the front wheels impacts the steering of the car. It was therefore decided to here just study covering of the rear wheels. The biggest potential for energy savings is when the rear wheels are adjusted inward, so that a completely flat surface can be created. See table 25 for savings.

Table 25: Table of metrics for Cover up wheel arches

Metric	*Value*	*Unit*
Electrical power	~ 0	W
Mass	~ 0	kg
Aerodynamic drag coefficient	0,002-0,02	C_d
Carbon emission	0,1-1	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

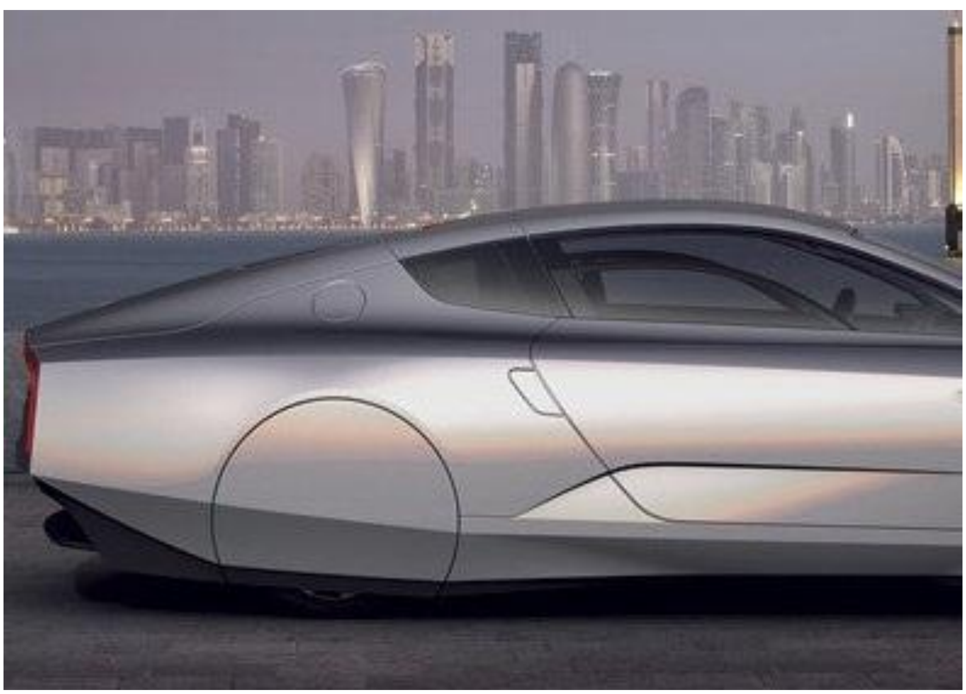

Figure 31: Covered up wheel arches on the concept car Volkswagen XL1 (Car and Driver, 2013)

4.5.11 Air curtains for front wheel arches

A way to reduce the drag from the front wheels without impact the steering of the car is to use air curtains, a method employed by other car manufacturers (BMW, 2013). Air is let into a slot in the front bumper and out just in front of the wheels, see figure 32. By making the cross-sectional area smaller in the outlet than in the inlet, the airflow passes the front wheels at an increased speed and helps create better aerodynamics. See table 26 for savings.

Table 26: Table of metrics for Air curtains for front wheel arches

Metric	*Value*	*Unit*
Electrical power	~ 0	W
Mass	~ 0	kg
Aerodynamic drag coefficient	0-0,01	C_d
Carbon emission	0-0,5	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

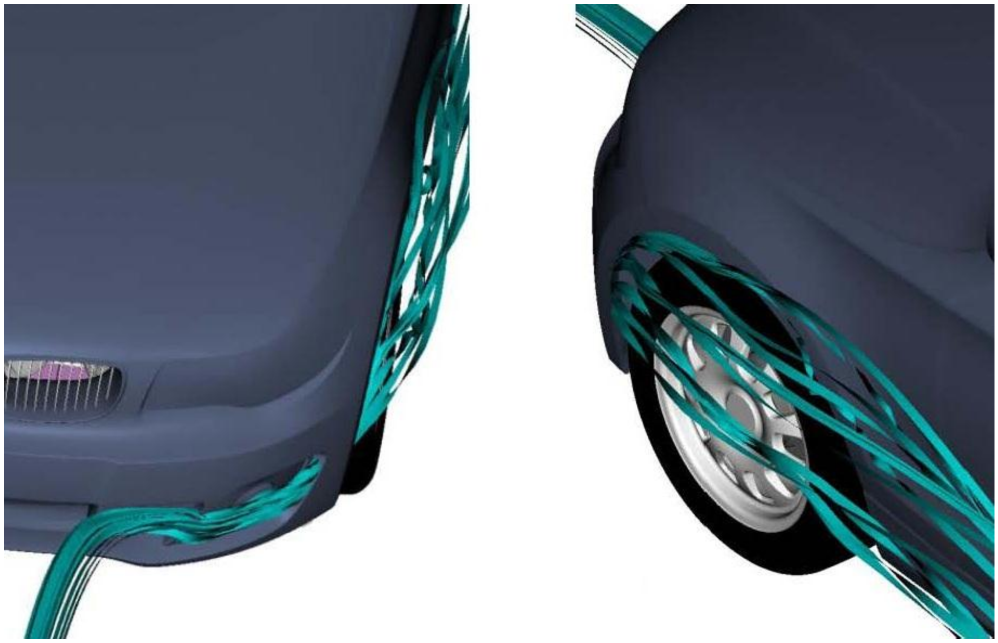

Figure 32: Schematic picture of the airflow with air curtains (The smoking tire, 2010)

4.6 Support driver to act more eco-friendly

During the brainstorming and development phase it was found that some ideas that should support the driver to act more eco-friendly were hard to find a good estimation on energy savings. It was hard to know how big the energy savings could be through implementing the support system. Because it is always the driver of the car who makes the choices if he/she wants to follow the tips and guidance or drive as usual, so it also depends on the driver's eco driving skills. Three concepts that could help the driver are presented below.

4.6.1 Eco-friendly GPS

This idea is about making the GPS system, which is in the car today, more eco-friendly. It can be done by connecting it to the traffic system and in that way making it avoids traffic jams. Another possible update is to let the GPS advice on which road to choose to reduce the fuel consumption for a trip. It can try to find ways around cities so that the driver does not need to stop at any traffic lights. It can also try to avoid motorways to keep the speed down to a more fuel efficient level. One more function that could be a good selling point for the new GPS is if it could be synchronized with the users to do list in their smartphones and with the information from the phone and the traffic system creates the most eco-friendly route.

4.6.2 Display that shows the energy consumptions of non-propulsion systems

The basic idea with this concept is to make the driver aware of what the different systems that are used in the car are consuming. This can be accomplished by visualising them on a display, where the sum of the energy consumption from seat heat, radio, defroster, lights, climate system etc. can be shown. By making the driver aware of what the different comfort and entertainment systems are consuming at the moment the driver can more easily understand that there are more things that affect the fuel consumption. This can make the driver change his/her habits when it comes to using different systems, such as how long time the seat heat is on. A meter that works like this is used in the Volvo C30 Electric but should be clarified and implemented in all cars.

4.6.3 Online game through Volvo on call

This concept will try to make eco-friendly driving a competition between different Volvo drivers. The idea is for the drivers to compete in who can drive a certain route using as little fuel as possible. The drivers will see in their app “Volvo on call” if the trip they are going to make is in the competition. A good example for a trip that can be in a competition is the road between Gothenburg and Stockholm which many people are traveling. The competitions can run for a certain time periods, for example a week, and the most energy efficient driver during that period can win a small prize. This concept is a step to make people want to drive more eco-friendly.

4.7 Mass reduction

A trend in the automotive industry is to lower the mass of the cars. During the last couple of decades the cars have become heavier with every model released. However, today car producers are trying to cut grams to every component. Below are some concepts that lower the mass of the car. The two biggest mass savings are presented in more detail, while the smaller ones are included in the section about secondary weight reduction as a list that sums up all the savings.

4.7.1 Opening system in carbon fiber

This concept is about changing the material in the opening system of the car from steel to carbon fiber. The parts that are included in the opening system are hood, doors and tailgate. Another component that also where changed into carbon fiber in the calculation were the front fenders. By changing the material a mass reduction of 100 kg can be attained, for savings see table 27. The cost of the car will increase due to the more expensive manufacturing process, but just as big a factor for the high price is that the supply is still just coping with the increasing demand on the market. Large resources are put into increasing the capacity, which over time will bring the price of carbon fiber down (Black, 2012).

Another problem with carbon fiber is that the manufacturing process time is longer than for the corresponding steel component. One cost benefit that comes with carbon fiber is that the cost for changing a part is lower due to the lower cost of the plastic model that is covered with fiber and put into the oven compared to a big change in a press, which is needed for the steel. Components that do not need to possess any rigid properties or take any substantial force can be made from regular plastic and thus become cheaper. Another benefit that comes with this concept is that the car will get a higher potential for better driving characteristics. If even further mass reductions are desired it is possible to look into the possibility of constructing the whole body in carbon fiber. This should lead to higher costs though, and focus has to be on safety characteristics if this concept is chosen.

Table 27: Table of metrics for Opening systems in carbon fiber

Metric	*Value*	*Unit*
Electrical power	-	W
Mass	100	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	5	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

4.7.2 LIGHTWEIGHT SEATS

A component that contributes quite a lot to the mass of the interior is the seats in a car. This concept addresses the problem in the form of redesigning the two front seats. The calculations for the seat have been done on a lightweight seat with comfort functions kept as intact as possible. This mass reduction is possible today, as the concept has been developed by a supplier, see figure 33 (Johnson controls, 2013). The supplier claims that it is very comfortable and functional, but with the high standards of Volvo seats it should be evaluated thoroughly. However, the concept displays the potential of making the seats lighter. Also if the backseat is included as well, larger savings would be accomplished. A more radical solution that shows how much mass can be saved by changing the seats is to put in “real” racing seats that only weigh a fraction of the standard seats. A change like this could save around 35 kg, (A2mac1, 2013), (Recaro Automotive, 2013) . But of course this would be hard to realize due to the requirements on comfort of a car in this segment, so the figures are for the less radical seat, see table 28.

Table 28: Table of metrics for Lightweight seats

Metric	*Value*	*Unit*
Electrical power	0-40	W
Mass	10	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	0,5-1,5	gCO_2/km
Affect NEDC	Yes, mass	
Economic potential	Yellow	

Figure 33: Lightweight seat from Johnson Controls (Johnson Controls, 2013)

4.7.3 Secondary weight reduction

Beside the concepts presented, which themselves contribute significant to lowering the energy consumption in the vehicle, a general type of concept which can easily be benefitted by each other is mass savings. According to Eckstein, et al. (2011) a single mass saving contributes to the possibility of reducing the mass on other components by having lowered the load. Due to this a mass saving of 100 kg can in secondary weight reduction reduce the total mass by another 30 kg. This secondary weight reduction in turn gives opportunity for even further mass reductions, with these iterations included a mass saving of 100 kg has the potential to save 45 kg extra, summing up to a total of 145 kg. With this in mind it is important to look into even small mass savings and add them together. Two big savings which have been investigated earlier in the report is the carbon fiber opening systems and a lightweight seat. But apart from them, a number of smaller mass savings has been investigated in the project.

Summarized mass reductions:

Lighter insulation material between engine and compartment	1,5 kg
Change material in booth and tailgate to carbon fiber sandwich	1,5 kg
Use more foam plastic, applied on inner non-touching panels	3 kg
Use lighter materials in IP, non-structure material	1,5 kg
Replace door handle with sensor	2 kg
Remove rear view mirrors	2,5 kg
Remove a door, having only right door in rear seat	10 kg
Remove gear lever, replace with gear buttons	1 kg
Fixed hood/Workshop hood	4 kg
Replace wipers with hydrophobic surface on windscreen	4 kg
Change to tilted windows in rear seat	2 kg
Take away canned spare tire and develop better on call service	2 kg
Carbon fiber rims instead of aluminium	35 kg
Speakers in headrest	5 kg
Polycarbonate glazing	10 kg
Opening systems in carbon fiber	100 kg
Lightweight seats	10 kg
--	
Total weight reduction	195 kg
Secondary weight reduction	90 kg
--	
Total weight reduction after Secondary weight reduction	285 kg

This total weight reduction can thereby together with secondary weight saving loops give a final total of 285 kg weight reduction on the whole vehicle, see table 29 for savings. In an energy saving perspective this also means that the engine can be tuned down or replaced by a smaller version, making the energy savings even higher. Also all interior mass savings makes the thermal mass less, which in turn reduce the stress on the HVAC system.

Table 29: Table of metrics for Secondary weight reduction

Metric	*Value*	*Unit*
Electrical power	-	W
Mass	285	kg
Aerodynamic drag coefficient	-	C_d
Carbon emission	19	gCO_2/km
Affect NEDC	Yes	
Economic potential	Yellow	

4.8 THE DEMO CAR AURORA

The concepts that have been built into Aurora are, as mentioned before, only at a conceptual level due to the limited time and budget for the thesis work. This puts the quality and functionality of the concepts at varying levels. The main idea with this demo car was nevertheless to show VCC the concepts and create something to talk about there. The choices were made with this in mind. That the concepts could be visualized and were distributed across the car, both interior and exterior, means that there will always be something to look at during the presentation of Aurora.

The interior of the car has been modified with concepts that help the driver to lower the electricity consumption by making systems more effective and by showing what the different system consume, decrease the workload on the climate system and lower the mass of the interior. A concept that has been chosen to visualize the electricity consumption is to install a small display. To symbolize the efficiency of systems the seat heat optimization has been visualized by connecting a small light to the sensor in the seats. It will light up when someone is sitting in the seat and symbolize that it possible to turn on the seat heat. Speakers in headrest and that the IAM-screen is set to screensaver mode are also concepts that will lower the electricity consumption. The modification that will help to lower the workload on the climate system was chosen to be double glazing which was constructed by combining a regular glass window with a polycarbonate window to show two concepts at once. Two other concepts that will visualize a more direct heating/cooling, and through that lower the workload, were “Climatisation only in occupied seat” and red seams in the seat to visualize some form of Peltier element. The third area of change of the interior was, as mentioned, to lower the mass. This was shown by removing the gear lever and replacing it by gear selection buttons and a redesigned front seat with lower mass than the standard seat. Some of these different changes to the interior can be seen in figure 34.

Figure 34: A collage with pictures of the interior of Aurora.

Regarding the outside of the car the main goal was to create a body which was as smooth as possible. Simultaneously the changes to the exterior should be easily seen when looking at the car. To create a body as smooth as possible all protruding components were removed. The side mirrors were replaced by small cameras and the door handles by sensors. Even the shark fin on the roof was removed to create a better impression. Some other concepts that also were added to Aurora and which affect the drag were to cover the wheel arches, air curtains for front wheel arches, change to thinner wheels, totally flat underbody, lower the car and move out the rear lights to reduce the drag from the rear wake. All these changes will be marked with a thin green line on the car to make it easier to see them. There also exist some changes to the exterior that will lower the electricity consumption. These changes are LED-headlights and the TEG on the exhaust pipe that will generate electrical energy from the heat loss. To visualize the concepts that are about changing material in opening systems and harvest energy from the sun a new hood was designed. It has a piece that is from transparent plastic with printed fake solar cells underneath. In the center of the plastic part the engine block is shown with the Aurora badge. All these modification and changes to the exterior can be seen in figure 35.

Figure 35: A collage with pictures of the exterior in Aurora.

4.9 Summarized improvements

To summarize the savings possible by implementing the concepts described above the saving figures were grouped into categories. Among these categories there are some which affect the official fuel consumption in NEDC while others do not. The numbers in gCO_2/km are from a car with an internal combustion engine, and extra km is for BEV.

Savings seen in NEDC	gCO_2/km min	gCO_2/km max	km extra min	km extra max
Aero modifications	2	8	2,5	10
Aero body change (CLA)	6	6	7	7
Mass	15	15	19	19
Savings not seen in NEDC*				
Electrical	1,5	1,5	1%	1%
Harvested	8	18	6%	13%
Climate cold	0	45	0%	35%
Climate hot	0	45	0%	35%

The figures should only be regarded as rough approximations and there are a lot of factors that they dependent on, for example the powertrain and its configuration, the outside climate, the driving habit/driving cycle and other customer behaviour. It should also be said that not all concepts can be combined in a good way, or the benefits are less for the combination than the sum of the two concepts separately. For example, a few aero improvements that are counted in aero modifications are included in the design of the CLA which means that if one should try to do both (the aero modifications and the body change) the sum would be lower than 14 gCO_2/km saved and under 17 km extra for the BEV.

*The savings that are not seen in NEDC is from a higher consumption level and cannot be subtracted from the official fuel consumptions/carbon emissions. It is not either possible to evaluate the extended range in km, since there are no official data on how long the range is when all systems are running.

5. DISCUSSION

5.1 DIFFERENTIATED CARS

During the thesis work it was found that there is a potential for energy savings, in different areas and settings. Some concepts save energy in all settings while others do not, so it would be beneficial to differentiate and implement different concepts in different cars or markets. Which concepts that should be combined in a car and the focus of the car is no trivial question, but nonetheless an attempt to put together four different cars is made. First a car in a cold environment and a car in a hot environment are discussed, since all concepts that affect the climate system are temperature dependent. Further an electric car is especially sensitive to electricity consumption, has no heat from the engine to use for heating the compartment and the range is very critical, making it necessary to differentiate the concepts used in an electric car. Finally a global car is presented, with concepts that could fit into the whole fleet of cars.

5.1.1 COLD CLIMATE CAR

The heating of the compartment is especially important for cars used in cold climates. With the reduced heat from the engines that comes with improved efficiency either additional heating or some insulation of the compartment, or both in some cases, is needed. The present solution with PTC-heater is energy inefficient but quick and convenient. By insulating the windows, where the most of the heat seems to disappear, see section 3.8.1, it is possible to reduce the needed heating for the compartment. The insulation can be done through double glazing or replacing the regular windows by polycarbonate windows. However, the double glazing has a mass issue and polycarbonate windows other problems like low sound insulation. A suggestion for this is to use polycarbonate for the inner glass of the double glazing. This gives good sound and heat insulating properties and a minimum of extra mass, which is very helpful for the stability phase but does affect the transient phase less. To improve the efficiency of the heating process, compared to the PTC-heater a heat pump can be used, see section 4.1.2. It is especially helpful for the electric car which lacks excess heat. A lower cost solution is to only climatise actively where people are that neither affects mass nor sound insulation in a noticeable way. If the climate system can be controlled in a way so that each nozzle can be controlled individually it saves energy, since on average 1,25 persons are travelling in a car (Transek AB, (2006), Wihlborg, et al., (2010)). For a non-electric car it is recommended to use the concept climatisation only in occupied seats to start with together with the double glazing with inner glass in polycarbonate.

5.1.2 Warm climate car

For a car used in hot environments cooling of the compartment is of considerable importance. The AC-cycle has already a good efficiency and the improvements possible are both expensive and technically difficult, so the authors of this thesis have chosen to focus on other opportunities. The solar irradiance is a big factor in the heating of the compartment, which can be counteracted with IR-reflective glazing. This is a technology that is already used as an option in the windscreen of the VCC cars, but should be implemented in all windows and preferably included in base car. By preventing a large part of the solar energy from entering the compartment the load on the climate system is decreased. These together with the concept of climatising only in occupied seats, which are used in the cold environment as well, represents efficient and relatively low-cost solutions to the problem of cooling the compartment. Another concept that works very well in warm, or rather sunny, climate is the solar cells. With 2 m^2 of solar cells it is possible in optimal conditions to generate half of the electrical power need in NEDC and a quarter of the real world driving electrical power need (European Commission, 2011). Even more interesting is the yearly harvesting of 200 kWh electricity or 1000 SEK fuel (see section 4.4.1). It is surprising, since it means that it is more profitable for a customer of a car with combustion engine to install solar cells than it is for a customer with an electric car. The electric car has the benefit of getting a slightly longer range with solar cells but in money terms the payback is faster for petrol or diesel cars. It can however be argued that owners of electric cars can pay extra for the image of an environmentalist that solar cells conveys.

5.1.3 Electric car

As mentioned earlier, the electricity consumption is critical for an electric car. There are a number of systems that run on electricity, apart from the propulsion, but the heating of the compartment is a substantial part since there is no excess heat from the engine in an electric car. Therefore it is important to make the heating as energy efficient as possible, which is done by using a heat pump combined with the concept of climatising only in occupied seats. This also improves the energy efficiency of the cooling process. Apart from the climatisation there are a few other concepts that could help lower the electrical load. By implementing speakers in the headrest instead of the regular speakers and amplifier it is not only possible to save electrical load, but also mass and cost making it a very good concept, except for the risk of reducing the customer value since it is difficult to get a sound quality equal to that of the regular speakers. Nonetheless it is considered a concept of great potential, since customers who buy electric cars are already sacrificing performance for environmental awareness. Another concept that has a sacrifice connected to the increased environmental friendliness is the LED-lighting, high and low beam. This is not connected to performance, which is equal to or even better than for both the standard halogen solution and the xenon option, but to cost. It is much more expensive than other technologies on the market right now, even though it will probably become less expensive as the technology gets used more widely. This again is something that is believed to be acceptable because of the eagerness to be environmental.

5.1.4 Global car

Apart from the specific cars discussed above there is quite a big number of concepts that can or should go into all cars that are produced and delivered from a manufacturer that has the environment as one of its' core values. To start with, there are three low cost solutions that should be implemented quite soon. Firstly the seat heat should be programmed so that it cannot run when no one is sitting in the seat. Further, the IAM should be set to screensaver mode as default, which reduces its electricity consumption considerably. The third low cost solution that should be implemented short term is to inform the driver of how much the non-propulsion electrical systems are consuming, so that he/she can control what they think are worth having switched on. And not only in electric cars, but in all cars.

There are two categories of improvements that have a big influence on fuel consumption and range and that are not only visible to the user but also in official emissions tests, namely mass reductions and aerodynamic improvements. These should be investigated thoroughly beyond this thesis work because even though many opportunities for improvement has been discovered and presented many of them present difficulties in terms of how expensive the implementation seems to be. Large mass savings seem to be the hardest to accomplish without getting substantial cost increases, such as the carbon fiber opening systems. It is however rewarding if it is possible to reduce mass, thanks to the secondary weight reduction and, if the reduction is interior, thermal mass as well. Therefore mass reduction should be at the focus when designing all components and it is important that design groups communicate with each other. Concepts presented in the report should be further investigated with regards to cost per unit mass ratio, SEK/kg, and should be first implemented on the most environmental cars, the electric, hybrids and the model which has the lowest CO_2 emissions and then spread to the rest of the fleet. The same strategy should apply to the aerodynamic improvements, but here the costs are not as high so implementation should be looked into right away. Therefore the implementations of the concepts should possibly come sooner than the mass reductions. Active grille shutter is already being planned. Aerodynamic rims should be offered for all low emission vehicles. For upcoming electric or extra low emission cars covered up wheel arches, active chassis and cameras instead of rear view mirrors should all be aimed at being implemented.

An area that has come into focus lately by the car manufacturers is the possibility not only to reduce the energy consumption but to harvest energy from the surrounding environment or energy that until now has gone to waste. There are a number of possibilities in this area, where two seem especially interesting. Solar cells have, as discussed in section 5.1.2, a great potential, not only for electrical cars but equally or even more for cars with combustion engines. Because of this, and the fact that the solar irradiation is substantial even in northern countries like Sweden, it should not be aimed at being implemented in just electrical cars or cars in warm climates, but in all cars. An area where experiments have been carried out for some time but no production model has been presented is in making use of the heat from hot exhaust gases from internal combustion engines. A number of different technologies have been experimented with, of which the most promising seem to be the TEG. It is of course useless for an electric car, but for all other cars it produces a steady amount of power as long as the engine is running. It is expensive at the moment, but it is considered that it would still be worth implementing, if not only for the fuel savings, but for the marketing potential. The cost will also go down considerably if the technology becomes common and with increasing fuel prices a breaking point will be reached.

A concept that could be difficult to implement due to user behaviour is to charge the battery when the car is parked. This means that the user need to connect the car to a power outlet when parked, something that is done by some in winter to preheat the engine and/or precondition the compartment. If this behaviour could be encouraged all year around it would in itself save a lot of energy since the engine would always work at the right temperature from the start and the transient heating/cooling phase should be performed by electricity from the outlet. If you could also charge the battery during this time it would be possible to cancel the need for using the alternator for quite some time of the drive. This means that no electricity consumption would do any impact on the fuel consumption or emissions.

5.2 General discussion

With the thoughts on the concepts presented it should be said that it is possible that some concepts have been missed or evaluated improperly, since even if a set based design approach was pursued there were knowledge gaps that could not be completely closed within the timeframe and therefore some decisions were made even though some data was lacking. It can therefore not be guaranteed that further investigations in this area will come to the same results. Another factor for increased deviation is that fuel consumption and energy savings mainly are determined by how the car is used. It is therefore very difficult to evaluate exactly how much that can be saved for concepts that lay outside official driving cycles like the NEDC.

Concepts which affect the climate system are an example of this. VCC has made climate simulations, which the figures in this report are to a large extent based on, and these climate considerations are included in the RWFC driving cycle. But even then it does not completely agree with reality. For one thing the temperature that the climate system is set to reach in the simulations is static even though many people would experience the same temperature as too warm in the winter and too cold in the summer. Even the driving patterns of users deviate from the driving cycles, and from user to user as well, which makes it very hard to predict consumption or range figures with good accuracy. In order to get an accurate prediction of the user’s figures an individual driving cycle would need to be simulated, with all the right loads, outside temperatures and driving patterns. This would actually make it easier to charge a higher price for the improvements as options since the customers could see exactly how much they would save. It is understood that it would be hard to get all the data and simulations for this, but it could be worth looking into since much data is already logged in the new Volvo cars.

When discussing the customers’ eagerness to pay for a function that improves the environmental image of the vehicle and its environmental impact it is good that VCC has set a cost target for each gCO_2/km saved, making it easier for engineers to quickly evaluate if the improvement is financially viable. It is however important not to focus too hard on the single gCO_2/km figure since other values like image, design and etc. can be important together with the earlier discussed fact that the emission figures are uncertain in their nature. Customer can also have very different views on how much it is worth for a decreased impact on the environment, a customer of a high performance car would probably not pay much but on the contrary a customer of a low-emitting car or electric car would probably happily pay some extra.

Another interesting discussion that has come up during the work with this thesis, regards the fact that electric cars do not need to be as clean or environmentally friendly as they are portrayed. Depending on the electrical mix, an electric car can have even higher CO_2 emissions than a low-emission diesel car. But still no of the emissions are visible in the official figures since they do not come from the tailpipe. This also makes it more difficult to justify costs for energy efficiency improvement since it “Does not affect the environmental impact”. Of course it does in the end since less electrical energy, which is produced from dirty coal, is needed but the only benefit seen from the customer point of view is a small increase in range. This together with the fact that bigger efficiency improvement potentials have been found for cars with internal combustion engines, which affects the fuel cost for the customer more, should open up a discussion of the focus of energy efficiency improvements. Even though everybody talks about electric cars and that they would be a solution for the environmental crisis, it is not true until the electricity production become clean, which is yet only a fact in very few countries yet. This highlights a need not to focus emission figures purely on tailpipe emissions but the whole process from well to wheel. But that is a possible topic for another thesis.

6. CONCLUSIONS

During the work with this thesis, a lot of dependencies were discovered. In the driving cycles the emissions depend heavily on the regulations, where in reality they depend on the roads, the user, the surroundings, the outside temperature, traffic situations and much more. With all these dependencies it is not surprising that the real fuel consumption and emissions for a user are far from the official NEDC figures. Much work must be done to get the numbers closer, inform the users on what the figures depend on and to what degree, and if possible also influence the authorities to use certification cycles closer to reality.

To get the energy efficiency to increase there are four areas to look into with great effort; mass and aerodynamics, which both are noticed in the official cycles, harvesting of energy, which is not but can be credited through eco-innovations, and the climatisation of the vehicle, which with present cycles and regulations can only be seen by the customers and not in any official figures.

The largest potentials for energy efficiency improvements have been found for cars with internal combustion engines, which together with the discussion of how clean electric cars really are brings light to a discussion of how far the electrification should be brought. Using a hybrid system for brake regeneration increases the energy efficiency of the vehicle, but charging the vehicle from the outlet might as well make the impact on the environment bigger than reducing it.

If one hunt for the ultimate energy savings, it is very hard not to sacrifice any performance. Both the climate system and other electrically consuming systems can reduce the energy consumption, but the biggest savings are not in new efficient technology but to control in a way that the systems are not used more than necessary, like climatising only in occupied seats and replacing the high power sound system by smaller speakers close to the listeners.

Energy harvesting is not only for electric cars and efficient hybrids, but for all cars. Solar cells on the roof and thermoelectric generator on the hot exhaust system are able to more or less neutralise the need for using the alternator to charge the battery. All of the fuel can then be used for propulsion of the car.

The authors hope that these thoughts and the recommendations below can help VCC get an overview of the energy consumption which originates from other sources than the propulsion of the vehicle. If they actively work with this, VCC will have a possibility to lower its' fleets CO_2 emissions.

7. Recommendations for future work

Here are some recommendations for further evaluation and investigation. It includes areas deliberately delimited from this project as well as predicted areas of interest.

As mentioned before the figures in this report are only for guidance and are not any explicit results. This requires the economic and energy calculations to be further developed, preferably with people from relevant groups, so that the input data can be as correct as possible. This improvement will help to decide in which direction the biggest potentials for savings exist.

The demo car Aurora can also be improved. Due to the time limit some of the ideas were not possible to be built into Aurora. So for later presentations of Aurora it can be developed with some of the ideas that not did get a chance this time. Another way to go is to let the persons that have seen the demo car suggest further improvements and through this involve the personnel at VCC.

One thing that has become clear is that a car is a complex system and that the cooperation between all sections in the company is very important. So one thought about the future is that all different sections must get an understanding of how what they do affects all the others and that many small savings can together become one big.

For more hands on recommendations on what areas to look into for reducing the energy consumption of a passenger car, the four areas presented in the conclusions; mass, aerodynamics, harvesting of energy and the climatising of the compartment. Three of these areas seem to have surfaced in the VCC organisation and gotten attention, but the harvesting of energy is in our opinion not investigated thoroughly enough. Another more explicit area that ought to attract more attention is systems that highly affect the climatisation of the compartment but lay outside the HVAC system, like insulation of the windows and possibilities to control the climate only in those parts of the compartment that are occupied.

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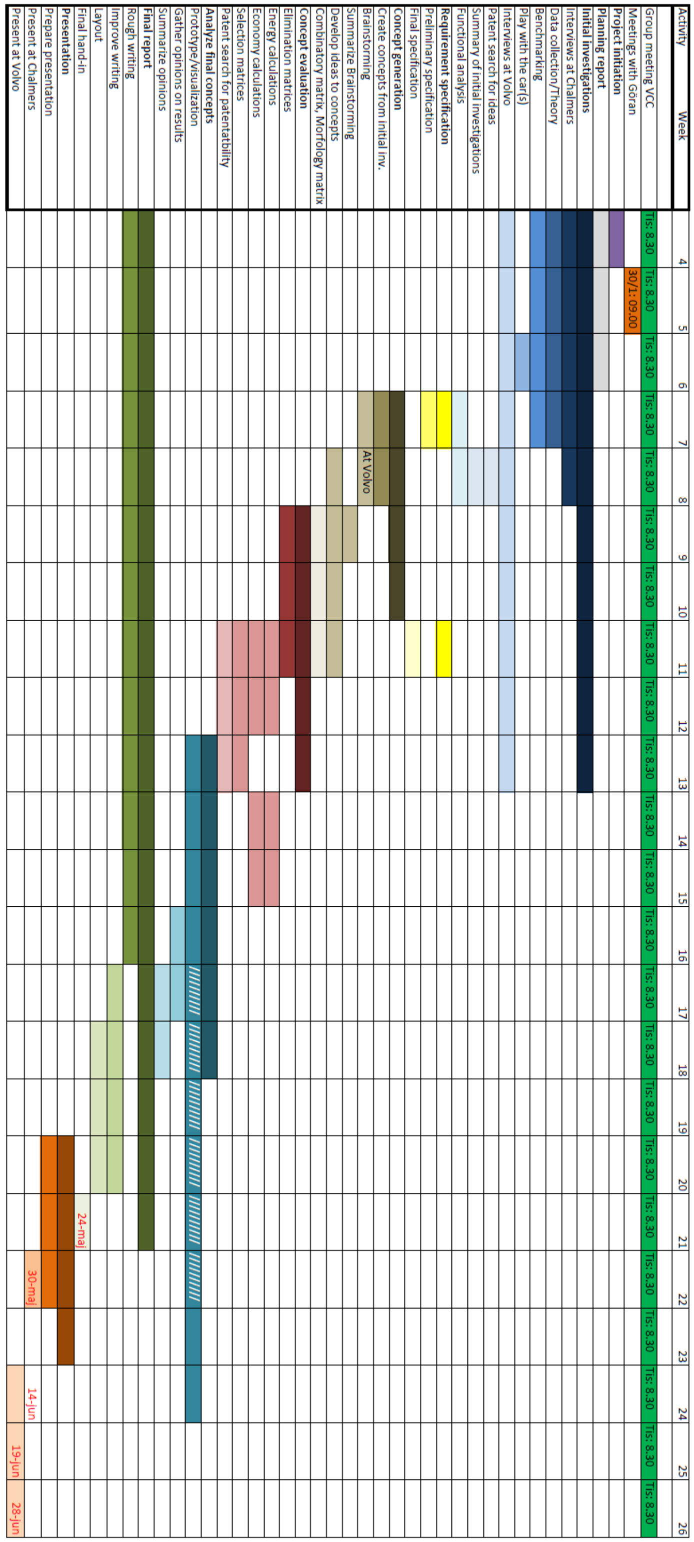
9. APPENDICES

A. TIMEPLAN



///////=Partially work
Date=Deadline

B. REQUIREMENTS SPECIFICATIONS

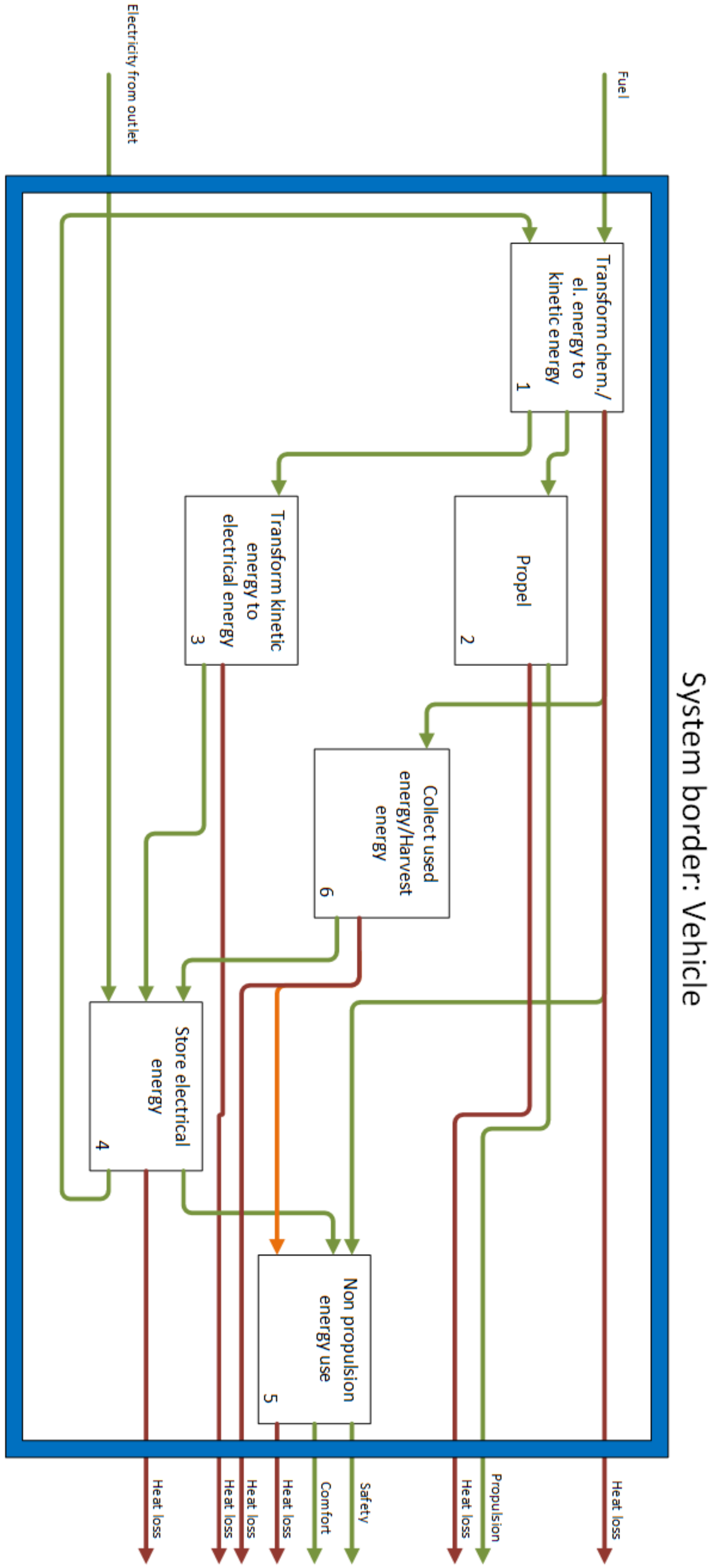
Requirement specification

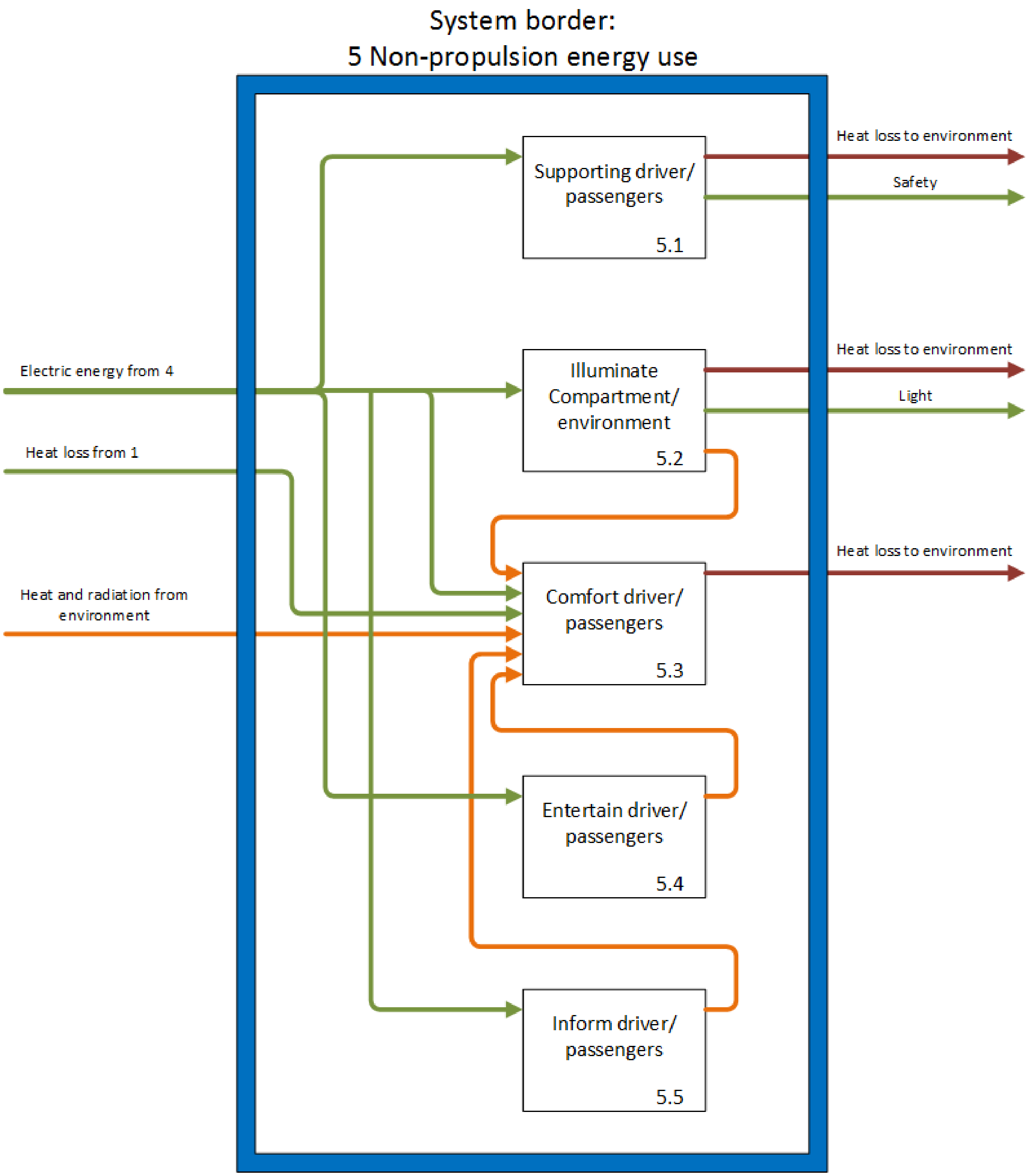
#	Requirements		Value	Unit	Verification
R:1	Net energy usage compared to reference		Δ<0	W	Calculation
R:2	Cannot compromise safety features		-	-	Control of safety systems
R:3	Cannot diminish luxury feeling		-	Subjective	Subjective test
R:4	Customer value compared to reference		Same or Better	Subjective	Subjective test
R:5	Fuel consumption		Δ≤0	l/100km	Calculation
R:6	Carbon emissions		Δ≤0	gCO2/km	Calculation
R:7	Range		Δ≥0	km	Calculation
R:8	Cannot inflict harm on human beings		None	-	FMEA/Checking with engineers/ergonomics
R:9	System area		B&T	Department	System boundary chart
#	**Wishes**	**Importance**	**Value**	**Unit**	**Verification**
W:1/2	Net energy usage(Gross energy usage taken into consideration)	6	-100	W	Calculation
W:3	Electrical load	4	Δ<0	W	Calculation
W:4/5	Fuel consumption/Carbon emission	5	Δ<-0,05	l/100km	Calculation
W:6	Electrical range	5	Δ>1	km	Calculation
W:7	Range	2	Δ>10	km	Calculation
W:8	Harvest "free" energy	2	>0	W	Calculation
W:9	Mass	4	Δ<0	kg	Weighing
W:10	Thermal mass	3	Δ<0	J/K	Weighing + material data
W:11	Able to build into the car (Aurora)	3	Yes	Yes/No	Checking with FU-workshop
W:12	Can be applied in production short-term	1	<5	Year	Checking with Volvo engineer
W:13	Can be applied in production long-term	3	<30	Year	Checking with Volvo engineer
W:14	Cost effective by emission	3	<300	kr/gCO2	Calculation
W:15	Cost effective by range	3	<XXX	kr/km range	Calculation
W:16	Compartment comfort compare reference	3	Same or Better	Subjective	Subjective test, Measurement
W:17	Cleanability compared to reference	1	Same or Better	Subjective	Subjective test, Measurement
W:18	Reflect Scandinavian Design	2	-	Subjective	Subjective test
W:19	Scalability	3	50	%	Checking with Volvo engineer
W:20	Sustainable/Environmentally friendly Life Cycle	1	Same or Better	Affect on environment	Calculation
W:21	Able to be visualized into Aurora	4	Yes	Yes/No	
W:22	News value / Innovation height	4	-	Subjective	
W:23	Functionality	3	Same or Better	Subjective	Subjective test, Measurement
W:24	Reduced aerodynamic drag	3	Δ<0	Cd*A	Table from aerodynamic division

Δ=difference between current solution and new solution

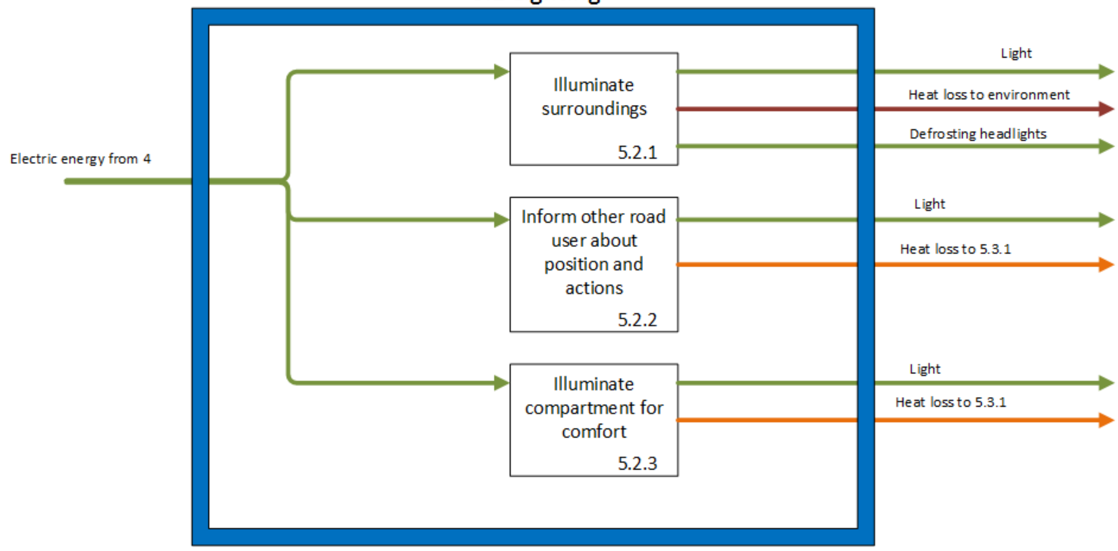
Reference car Volvo V40 and where needed Volvo C30 Electric & Volvo V60 Plug in

C. Functional analysis

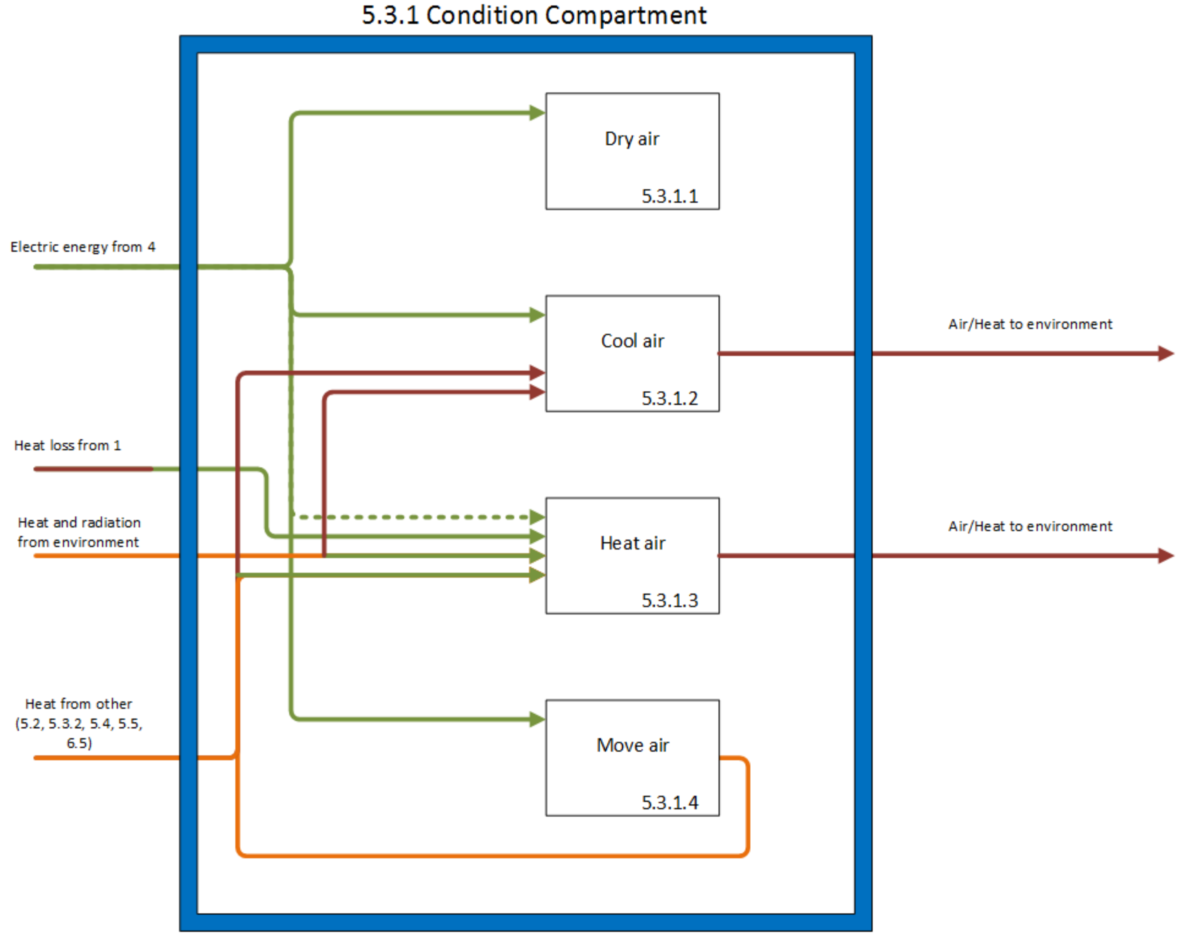


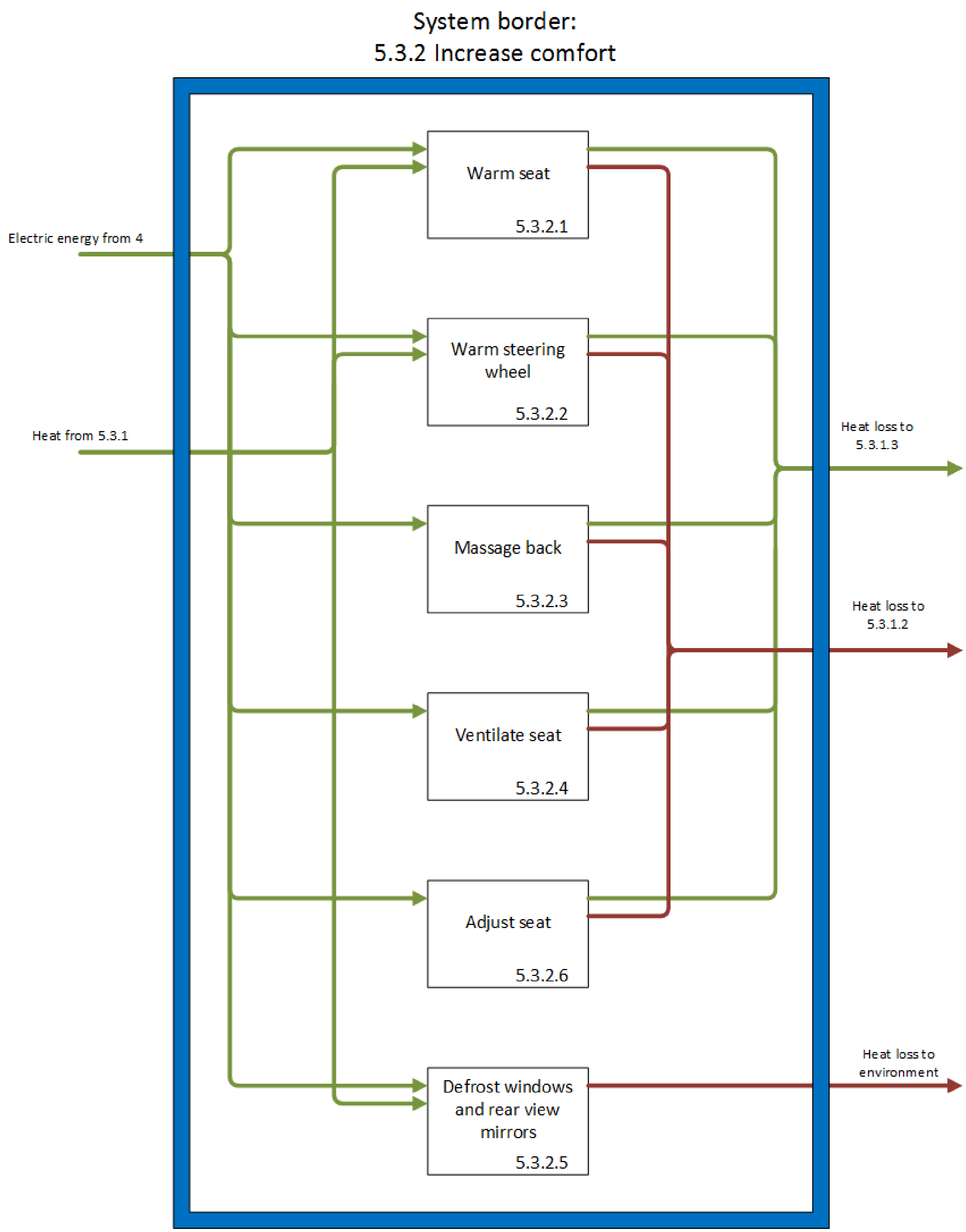

System border:
5 Non-propulsion energy use
Supporting driver/ passengers
5.1
Illuminate Compartment/ environment
5.2
Comfort driver/ passengers
5.3
Entertain driver/ passengers
5.4
Inform driver/ passengers
5.5
Electric energy from 4
Heat loss from 1
Heat and radiation from environment
Heat loss to environment
Safety
Heat loss to environment
Light
Heat loss to environment

System border:
5.2 Lighting

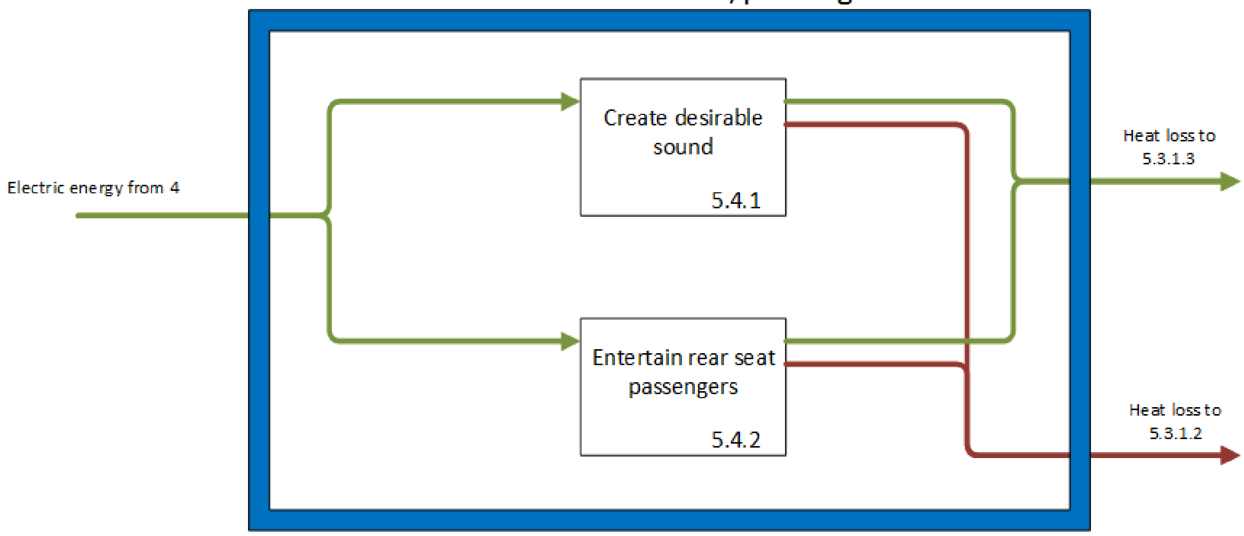


System border:
5.3.1 Condition Compartment

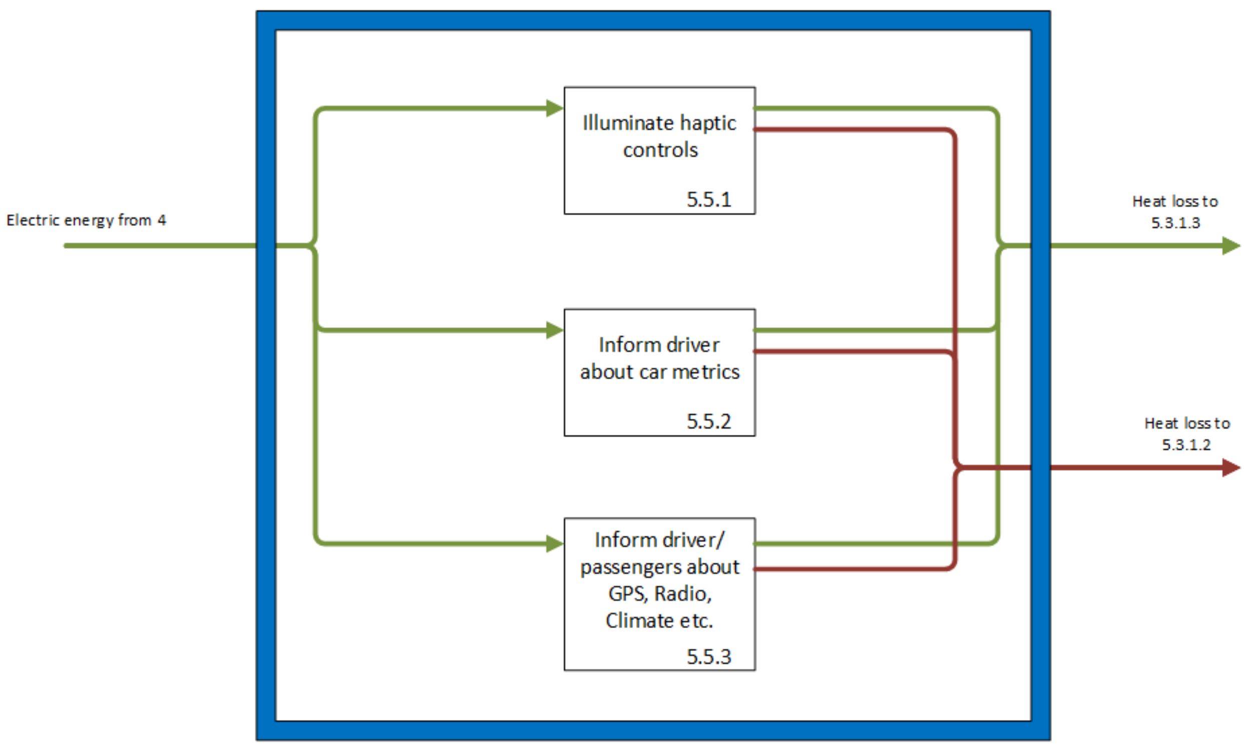


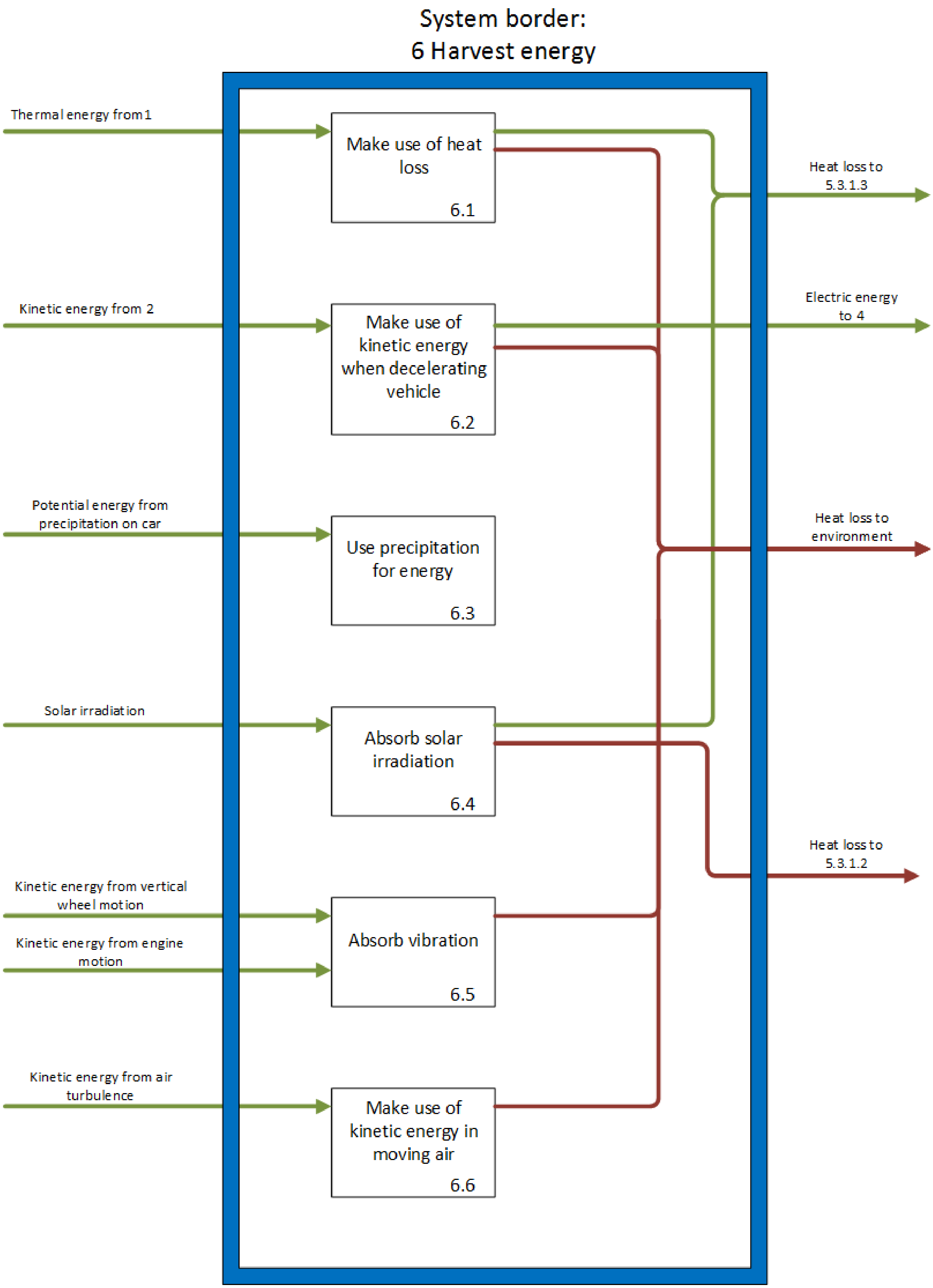

System border:
5.3.2 Increase comfort
Electric energy from 4
Heat from 5.3.1
Warm seat
5.3.2.1
Warm steering wheel
5.3.2.2
Massage back
5.3.2.3
Ventilate seat
5.3.2.4
Adjust seat
5.3.2.6
Defrost windows and rear view mirrors
5.3.2.5
Heat loss to 5.3.1.3
Heat loss to 5.3.1.2
Heat loss to environment

System border:
5.4 Entertain driver/passengers



System border:
5.5 Inform driver/passengers




System border:
6 Harvest energy
Thermal energy from 1
Kinetic energy from 2
Potential energy from precipitation on car
Solar irradiation
Kinetic energy from vertical wheel motion
Kinetic energy from engine motion
Kinetic energy from air turbulence
Make use of heat loss
6.1
Make use of kinetic energy when decelerating vehicle
6.2
Use precipitation for energy
6.3
Absorb solar irradiation
6.4
Absorb vibration
6.5
Make use of kinetic energy in moving air
6.6
Heat loss to 5.3.1.3
Electric energy to 4
Heat loss to environment
Heat loss to 5.3.1.2

D. Advertising for brainstorming event

E. ALL IDEAS GENERATED DURING THE WORK OF THE THESIS

Category nr	Category	Idea nr	Idea	Further description
1	**Weight reduction**			
1,1	*Lightweight materials*			
		1	Replace metal with plastic where possible, also glass	Roof?? Hood??
		2	Lighter insulation material	
		3	Change material in booth and tailgate	New material from supplier
		4	More composite materials, carbon fiber components	
		5	Use more foam plastic	Use on non touching surfaces
		6	Use EPP(Expanded Polypropylene) as structure	E.g. In IP and DP. Exists in luggage floor?
		7	Use lighter materials in IP	E.g. Carbon fiber
		229	Carbon fiber body	Or only opening systems
1,2	*Lightweight seats*			
		8	Reduce weight on seat fixation structure	Change fixation of seat
		9	Mesh/net seat.	Without cushions.
		10	Fixed seating positions.	Adjusted by actuators and controls after driver --> Simpler seats, lower weight
		11	Seat with air cushion	Don't need foam. Save weight.
		12	Change material in seat.	E.g. Shell seat (LWD), carbon fiber
		13	Perforated seats	Less thermal mass, breathes better
		14	Lightweight seats	Combination of all seat ideas
		15	Lightweight seat frame	E.g. Seat frame in composite material
		230	Lightweight seat for buliding into Aurora	
1,3	*Other lightweight solutions*			
		16	Steer by wire	
		17	Secondary weight reduction potential	ATZ01-2011
		18	Hydroforming	Process to save ~150 kg per car body
		19	Smaller steering wheel	
		20	SAAB/Koeniggsegg windscreen to get more vertical A-Pillars	
		21	Textile roof	
		22	Remove door sill around window to save weight	
		23	Tailgate a la Volvo Duett	Do not need reinforcements in the roof
		24	Lightweight chassi for cars with lower top speed	
		25	LWD 860 kg instead of 1600 kg	Car to investigate
		26	One brake instead of four	E.g. On flywheel
2	**Remove components**			
2,1	*Remove for weight and aero*			
		27	Remove rails	
		28	Remove door handle and replace with sensor	
		29	Remove rear view mirrors	Replace with camera
		30	Remove one windshield wiper	Old mercedes
		31	More effective wipers	Other mechanical solution
2,2	*Remove for weight*			
		32	Replace rear window with camera	
		33	Remove rear spoiler	
		34	Remove a door/ one door	
		35	Remove gear lever	Paddles or buttons instead
		36	Fixed hood/Workshop hood	Doesn't need to open, flip front
		37	Remove gas springs for hood	Reduce to one, or use old school version
2,3	*Replace wipers*			

		38	Grafen on windscreen	http://www.svt.se/nyheter/vetenskap/ny-anvandning-for-mirakelamne
		39	Nanotech on windscreen	
		40	Hydrofobic surfaces with aerodynamic effects	
3	**Window solutions**			
3,1	*New window designs*			
		41	Change to tilted windows, same as Lynx	Save weight, better ventilation
		42	Less window area	Less radiation, maybe lower weight
		43	Thinner glass	Chemical hardened? Willow glass?
		44	Film that distributes heat from the sides to center of glass	
3,2	*Radiaton reflecting windows*			
		45	Sun radiation angle	During winter, when sun is low, heat radiation is let through, otherwise not
		46	Car jalusi	Like old times 80's cars to block solar radiation on rear window but not sight
		47	IR-reflecting glazing	Block irradiation when hot and radiation when cold
		48	Reduce solar irradiation through automation	Automatically IR-blocking when needed
		49	Solar curtains	Does already exist?
3,3	*Energy efficient windows*			
		50	Double glazing	
		51	Low-emission glazing	
		52	Energy glazing	Better insulation
		53	Polycarbonate glazing	Better insulation, weight reduction
3,4	*Smart windows*			
		54	Smart glazing	Glass that can become opaque
		55	Smart windows	See through screen which can be used as solar blocker, can be combined wit solar panels
		56	Photochromatic glazing	Works as sunglasses which darkens outside. Windscreen
4	**Screens and visualization**			
		57	IP screen always set to screensaver mode	
		58	More energy efficient screens	IGZO
		59	Replace DIM/IP screens to LED if not	
		60	Replace DIM/IP screens with DLP from Texas Instruments	Can ba shaped more freely
		61	Replace buttons in IP to LED/DLP-screens	
		62	YOUM	Bendable screens
		63	Remove IP screens/DIM, use driver tablet/phone	
		64	Terminator eye	Picture reflected/projected on glasses instead of screens. Even better direct on retina
		65	Screens only active when looked at	Samsung tech
		66	Thin film, OLED film in "foder"	
5	**Lighting**			
		67	Use low energy interior lighting	E.g. LED
		68	Use LED exterior lighting, even headlights	
		69	Optimize extras	LED etc.
		70	Lights on only when dark	Interior, welcome lights etc.
		71	Light only where people is	By the opened door, in occupied seats
		72	If welcome lights on, shutdown at start up	
		73	Use innovative LED	MIT tech. 200% efficiency?

		74	One light source instead of many(Laser headlight)	Use fiberoptics/mirrors to distribute. Laser as lightsource? Headlights or interior
		75	Replace headlights with sweeping direct laser	
		76	Store light from day and use when dark	
6	**Climate**			
6,1	*Improve AC*			
		77	Carbon dioxide as cooling media	Should be able to save 5-6% of energy
		78	Isolate HVAC	
		79	Use turbine instead of throttle valve in AC cycle	
		80	Linear compressor	Home appliances is looking into it
		81	Do not let cooling fluid through heat element when not needed	Valve as in old days
		82	Increase temp diff in AC cycle to improve efficiency	Use waste heat. Investigate more. Fiat powerpoint. Nrel.gov
		83	Optimize climate with regards to driving habits	Acceleration, hills, etc. Spin-off idea from Volvo FH.
6,2	*Passive ventilation*			
		84	Autotilt sunroof	
		85	Ventilation by natural draft	Chimney effect, hatch in top of car
		86	Fresh air hatch	Like 240, 740.
6,3	*Thermal mass*			
		87	Material that absorbs heat when cold but not when warm	Improve transient heating phase
		88	Lower thermal mass	Reduce mass and thermal capacitivity
6,4	*Preconditioning with outlet connection*			
		89	Preconditioning of car	Use electric power from outlet instead of fuel/battery
		90	Use outlet connection to more systems than climate control	e.g. Seat heat, exhaust system heat up
6,5	*Preconditioning without outlet connection*			
		91	Replace interior air with exterior air on startup	Preferably on lock up, and air from beneath the car
		92	Parking ventilation through solar cell driven fans	
6,6	*Control airflow*			
		93	Optimize recirculated air vs new air	Use more recirculated already heated/cooled air?
		94	Use fan less and AC compressor more	
		95	Use different air inlets in different climates	Hot from plenum, cold from underneath?
6,7	*Individual climate*			
		96	Virtual rooms	Divide passenger space into smaller rooms which can be individually climatized
		97	Climatize actively only in occupied seats	
6,8	*Perceived climate*			
		98	Liquid cooled/heated gear lever and steering wheel	
		99	Heat/cool in seat	More actively than now. Peltier element
		100	Control humidity	
		101	Liquid cooling/heating in seat	
		102	Direct heat/cooling to sensitive areas	E.g. Neck, feet, head, hands. i.e. Floor mats and alike
		103	Heating blanket	Integrate with airbag?

		104	Climate jump suit	Connect to clothes through universal connection, airbag in suit, monitor heart frequence etc to check health and sleepiness
		105	Same temperature on entire body	Compensate for external factors like sun on one side. Warm/cold panels
		230	Infrared heating	
6,9	*Heat pump*			
		106	Use heat pump for heating	
		107	Use recirculated air for heating new air through heat pump	
		108	Replace PTC with AC as heat pump	
6,10	*Other heat sources*			
		109	Replace FOH with other heat source	
		110	Mechanical connection from engine/exhaust to seat heat	
		111	Liquid cooled/heated compartment	
		112	Use crash absorbing beams for ventilation channels	
6,11	*Climatize food*			
		113	Peltier-element to heat or cool beverage	
		114	Heat/cool beverage in cup holder	Without affecting consumption. Through heat loss or alike
		115	Heat/cool beverage in armrest	
		116	Cool groceries	Bag, EPP box or other way to keep groceries cold
7	**Battery modifcations**			
		117	Higher battery voltage	Weight savings through less need of cables
		118	Small battery for preconditioning	Charged during driving, preconditions when not connected to outlet
8	**Electricity regulation**			
		119	Centralize electrical system	Use few large systems instead of many small
		120	Use generated electricity better	E.g. Leave spare room in battery for regeneration, use the electricity directly in consumers
		121	Shut off all electronics in start/stop	
		122	Shut down all stand by systems	Allow longer start up time when possible
		123	Use regenerated electricity to other systems than propulsion	Mazda should have a car with this
		124	Charge battery when plugged in for preconditioning	
9	**Limit customer options**			
		125	Timer on seat heat	
		126	Seat heat only running when seat is occupied	
		127	Standard choice is the most energy efficient	More effect requires active choice
		128	Back to standard choice when car has been shut off	Don't start seat heat on restart, defroster shut off at start up etc.
		129	Remove function automatic defrost on rear window	
		130	Lower top speed	Can be dimensioned substantially lighter
		131	Reminder to regulate seat heat, climate	
		132	Keyless, take away remote control use RFID	Cheaper
		133	Remove electrically operated functions	Such as foldable mirrors, seat adjustment, tailgate
10	**Support driver to drive more eco-friendly**			

		134	Fuel consumption setting	Driver able to set fuel consumption, top speed acceleration etc. Is reduced
		135	Eco friendly GPS	Choose roads with low traffic, and other eco friendly attributes
		136	Smarter coasting	Help driver coast properly when approaching stops or slow moving traffic
		137	Gear shift indicator more noticable	E.g. With sound
		138	Fuel efficient interval on rpm meter	
		139	Geo-optimized settings	Dependent on for example weather, slopes, road condition
		140	Compete in fuel efficiency online	
		226	Show driver how much non-propulsion systems use	A la C30 electric
11	Aerodynamic actions			
		141	Change body shape	More aerodynamic. Drop shaped.
		142	Aerodynamic rims	Also active(covered in high speeds)(by springs?)
		143	Hide rear view mirrors in high speeds	
		144	Cover air intake(radiator)	Active Grill shutter
		145	Active chassi, lowers the body	Cameras and sensor check for obstacles and raise the body
		146	Retractable rails	
		147	Integrated headlights	No split lines
		148	Flat underbody	
		149	Le mans roof	Roof heightened only around driver/passenger. Heighten roof on entry
		150	Direct airflow away from wheel housing	Cone like device in front ov wheel
		227	Cover up wheels hubs	Active or passive
		228	Air curtains for wheels hub	A la BMW
		231	Reducing drag from rear wake	
12	Isolate			
		151	Outer panels with lower thermal conductivity	
		152	Insulate roof, floor, doors	
		153	No draft, tight cars	
		225	Box around engine	Conect the enginge box with the compartment
13	Wheels			
		154	On call pitstop	On call service, instead of spare tyre
		155	Fiber rims	Carbon fiber or other composites(plastic composite BASF Smart) in rims
		156	Reduce rolling resistance	Through better bearings etc.
		157	Thin covered up rims	Bicycles, low weight
		158	Correct tyres	Optimized tyres even after first tyre change
		159	Shape changing tyres	Catamaran in high speeds
		160	Active tyre pressure	Pressure depends on velocity, temperature, traffic situation etc.
14	Defrost solutions			
		161	Let out hot air by rear view mirrors	
		162	Frost detection	Camera/rainsensor determine if frost on windscreen. Automatic defrost starts on lock up
		163	Frost free windscreen	Surface material
		164	Fog free windows	Nanotech on window interior

		165	Less area defrosted	Only few lines on electric defroster active to defrost most important area
15	**Harvest energy from**			
15,1	*Sun*			
		166	Solar powered ventilation	
		167	Solar cells on roof	Can be on hood etc.
		168	Glass roof and windows as solar cells	
		169	Let ALL exterior surfaces be solar cells	
		170	Solar panels(for heat not electricity)	
15,2	*Humans*			
		171	Use driver steering wheel motion for energy	
		172	Through training equipment	
		173	Use body heat	Can be used with thermoelectric materials
15,3	*Shock absorbers*			
		174	Generate energy from shock absorbers	
15,4	*Exhaust system*			
		175	Thermoelectric generation	
		176	Sterling engine	Use the heat to run a sterling engine that is conected to a generator
		177	Use heat loss for heating compartment	Through liquid or air distribution, floor heating, heat exchanger
		178	Organic rankine heated by exhaust	
		179	Generate electricity from moving exhaust gases	
15,5	*Other harvesting sources*			
		180	Use kinetic energy in airflow	E.g. Around wheels, air intake radiator. Turbine. Jet streams.
		181	Store energy between drives(thermos)	Even overnight
		182	Use heat energy from braking	
		183	Phase-transform salt	Store energy in phase-transformed salt. Release with phase-transformation. Heat pads outdoor hiking equipment
		184	Heating/Cooling pads	Outdoor hiking(heat), sport cooling bags(cold), store heat/cold, release through breaking
		185	Use phase-transformation of liquid	Heat liquid to vapor, let it transport itself to cooler areas and release energy and return
		186	Use the rotation of the wheel	Think bicycle dynamo
		187	Brake regeneration	Brake with electrical motor to obtain electrical energy
		188	Use heat energy from batteries	In EV, HEV
16	**Surface treatments**			
		189	IR-reflecting surface treatments	
		190	Dielectric nanotechnology	Makes the surface vibrate to remove dirt and water
		191	Paint	Black absorbs heat, white doesn't. Matt vs Glossy
		192	Easy clean	Dirt repellent paint, aerodynamic, raise customer value. Can be used on rims
		193	Cameleont paint	Temperature dependent paint
		194	Irregular surface	Shark skin, golf ball, javelin spear, humpback whale. For aerodynamics.
17	**Interior materials and surfaces**			
		195	First layer of plastic, sandwich behind	
		196	Reflecting(IR) materials	Pigments, proposed FU

		197	Wool	On surfaces that are touched(seats, steering wheel etc.) Removeable clothing to be cleaned. Other "warm" materials can also work. Superomnifobic surface treatment to reduce stainability
		198	Cork as surface	Instead of foil and plastic etc. Or other tree surface
		199	Smart energy efficient interior material	Store heat in cold climate and dissipate in warm climate
18	Investigate further			
		200	Graphene	
		201	Photosensitive pigments	
		202	Front packing a la Mercedes A-class	
		203	Connect your smartphone instead of using your cars battery	
		204	Stupid legislation that hinder automotive industry	Demands set by technology not end result
		205	Textile surfaces for moveable aero devices	
19	Audio in car			
		206	Speakers/headphones in headrest	
		207	Only sound in uccupied seats	
20	Product development changes			
		208	More functional driven design	Airplane is not always handsome but can transport 300 people with low drag
		209	Let high volume car set requirements	Do not specify the whole product family by the most high performance version
		210	Develop cars for markets, not global car	
		211	Build smallest possible car	In each segment
		212	Change attitude towards weight	Premium is hard t combine with lightweight
21	Out of scope			
		213	Start/stop in higher velocities than zero	
		214	Downsizing	
		215	MIT hydrogen gas?	
		216	Boxer engine	
		217	Hydrogen gas production at home	
		218	Generate metan gas onboard	
		219	More gears(splits)	
		220	Bimimicry	Instead of powerful pump many smaller
		221	Generator with high efficiency	
		222	Braking by thinking	
		223	Magnetic trains	Cars connect to magnetic field
		224	Use more recycled materials	

F. SCORING MATRIX

	Selection criteria	Driving case	Weight	Idea nr	1		4		5		7		229		14		20		23
					Rating	Weighted score (Ws)	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating
W:1/2	Net energy usage(Gross taken into consideration																		
		-18 deg	6		3	18	3	18	3	18	3	18	4	24	4	24	3	18	3
		24 deg	6		3	18	3	18	3	18	3	18	4	24	4	24	3	18	3
		43 deg w sun	6		3	18	3	18	3	18	3	18	4	24	4	24	3	18	3
	Combined plus bonus for performance in several driving cases				1,2	21,6	1,2	21,6	1,2	21,6	1,2	21,6	1,2	28,8	1,2	28,8	1,2	21,6	1,2
W:3	Electrical load																		
		-18 deg	4		2	8	2	8	2	8	2	8	2	8	2	8	2	8	2
		24 deg	4		2	8	2	8	2	8	2	8	2	8	2	8	2	8	2
		43 deg w sun	4		2	8	2	8	2	8	2	8	2	8	2	8	2	8	2
	Combined plus bonus for performance in several driving cases				1	8	1	8	1	8	1	8	1	8	1	8	1	8	1
W:4/5	Fuel consumption/Carbon emission																		
		-18 deg	5		3	15	3	15	3	15	3	15	4	20	3	15	3	15	3
		24 deg	5		3	15	3	15	3	15	3	15	4	20	3	15	3	15	3
		43 deg w sun	5		3	15	3	15	3	15	3	15	4	20	3	15	3	15	3
	Combined plus bonus for performance in several driving cases				1,2	18	1,2	18	1,2	18	1,2	18	1,2	24	1,2	18	1,2	18	1,2
W:6	Electrical range																		
		-18 deg	5		3	15	3	15	3	15	3	15	4	20	3	15	3	15	3
		24 deg	5		3	15	3	15	3	15	3	15	4	20	3	15	3	15	3
		43 deg w sun	5		3	15	3	15	3	15	3	15	4	20	3	15	3	15	3
	Combined plus bonus for performance in several driving cases				1,2	18	1,2	18	1,2	18	1,2	18	1,2	24	1,2	18	1,2	18	1,2
W:7	Range																		
		-18 deg	2		3	6	3	6	3	6	3	6	4	8	3	6	3	6	3
		24 deg	2		3	6	3	6	3	6	3	6	4	8	3	6	3	6	3
		43 deg w sun	2		3	6	3	6	3	6	3	6	4	8	3	6	3	6	3
	Combined plus bonus for performance in several driving cases				1,2	7,2	1,2	7,2	1,2	7,2	1,2	7,2	1,2	9,6	1,2	7,2	1,2	7,2	1,2
W:8	Harvest "free" energy																		
		-18 deg	2		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
		24 deg	2		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
		43 deg w sun	2		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
	Combined plus bonus for performance in several driving cases				1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
W:9	Mass		4		3	12	4	16	3	12	3	12	5	20	4	16	3	12	3
W:10	Thermal mass		3		2	6	3	9	2	6	3	9	2	6	4	12	2	6	2
W:12	Can be applied in production short-term		1		3	3	3	3	3	3	3	3	1	1	3	3	4	4	3
W:13	Can be applied in production long-term		3		5	15	5	15	5	15	5	15	4	12	5	15	5	15	5
W:14	Cost effective by emission		3		2	6	1	3	2	6	2	6	2	6	3	9	2	6	2
W:15	Cost effective by range		3		2	6	1	3	2	6	2	6	2	6	3	9	2	6	2
W:16	Compartment comfort compare reference		3		2	6	3	9	3	9	3	9	3	9	2	6	3	9	3
W:17	Cleanability compared to reference		1		3	3	3	3	2	2	3	3	3	3	3	3	3	3	3
W:18	Reflect Scandinavian Design		2		1	2	2	4	2	4	2	4	2	4	3	6	3	6	3
W:19	Scalabillity		3		5	15	2	6	3	9	2	6	2	6	4	12	2	6	3
W:20	Sustainable/Environmentally friendly Life Cycle		1		3	3	2	2	3	3	3	3	2	2	3	3	3	3	3
W:22	News value / Innovation height		4		2	8	3	12	2	8	2	8	3	12	2	8	2	8	1
W:23	Functionallity		3		2	6	3	9	2	6	3	9	3	9	2	6	4	12	3
W:24	Reduced aerodynamic drag		3		1	3	1	3	1	3	1	3	1	3	1	3	1	3	1
	Total score					168,8		171,8		166,8		170,8		195,4		193		173,8	
	-18 Score					158		161		156		160		181		181		163	
	24 Score					158		161		156		160		181		181		163	
	43 w sun Score					158		161		156		160		181		181		163	

Relative performance	Rating
Worse than reference	1
Same as reference	2
Better than reference	3
Much better than reference	4
Very much better than reference	5

	27		28		29		36		39		42		43		45		47		50		53		54	
Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws
18	3	18	3	18	4	24	3	18	3	18	4	24	3	18	2	12	2	12	5	30	4	24	2	12
18	3	18	3	18	4	24	3	18	3	18	2	12	3	18	2	12	2	12	1	6	3	18	2	12
18	3	18	3	18	4	24	3	18	3	18	4	24	3	18	4	24	5	30	4	24	4	24	4	24
21,6	1,2	21,6	1,2	21,6	1,2	28,8	1,2	21,6	1,2	21,6	1	20	1,2	21,6	1	16	1	18	1	20	1,2	26,4	1	16
8	2	8	2	8	3	12	2	8	3	12	3	12	2	8	2	8	2	8	4	16	4	16	2	8
8	2	8	2	8	3	12	2	8	3	12	2	8	2	8	2	8	2	8	3	12	2	8	2	8
8	2	8	2	8	3	12	2	8	3	12	3	12	2	8	4	16	5	20	3	12	4	16	4	16
8	1	8	1	8	1,2	14,4	1	8	1,2	14,4	1	10,66667	1	8	1	10,66667	1	12	1,2	16	1	13,33333	1	10,66667
15	3	15	3	15	3	15	3	15	3	15	4	20	3	15	2	10	2	10	5	25	4	20	2	10
15	3	15	3	15	3	15	3	15	3	15	2	10	3	15	2	10	2	10	1	5	3	15	2	10
15	3	15	3	15	3	15	3	15	3	15	4	20	3	15	4	20	5	25	4	20	4	20	4	20
18	1,2	18	1,2	18	1,2	18	1,2	18	1,2	18	1	16,66667	1,2	18	1	13,33333	1	15	1	16,66667	1,2	22	1	13,33333
15	3	15	3	15	3	15	3	15	3	15	4	20	3	15	2	10	2	10	4	20	3	15	2	10
15	3	15	3	15	3	15	3	15	3	15	2	10	3	15	2	10	2	10	2	10	2	10	2	10
15	3	15	3	15	3	15	3	15	3	15	3	15	3	15	4	20	5	25	3	15	3	15	4	20
18	1,2	18	1,2	18	1,2	18	1,2	18	1,2	18	1	15	1,2	18	1	13,33333	1	15	1	15	1	13,33333	1	13,33333
6	2	4	2	4	3	6	3	6	3	6	3	6	3	6	2	4	2	4	4	8	3	6	2	4
6	2	4	2	4	3	6	3	6	3	6	2	4	3	6	2	4	2	4	2	4	2	4	2	4
6	2	4	2	4	3	6	3	6	3	6	3	6	3	6	3	6	4	8	3	6	3	6	3	6
7,2	1	4	1	4	1,2	7,2	1,2	7,2	1,2	7,2	1	5,333333	1,2	7,2	1	4,666667	1	5,333333	1	6	1	5,333333	1	4,666667
2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
12	3	12	3	12	3	12	3	12	3	12	2	8	3	12	2	8	2	8	1	4	4	16	2	8
6	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2	6
3	5	5	2	2	3	3	3	3	4	4	5	5	4	4	2	2	4	4	2	2	3	3	3	3
15	5	15	4	12	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15	5	15
6	4	12	2	6	2	6	2	6	4	12	4	12	3	9	3	9	3	9	2	6	3	9	2	6
6	4	12	2	6	2	6	2	6	4	12	4	12	3	9	3	9	4	12	2	6	3	9	2	6
9	2	6	2	6	2	6	2	6	3	9	2	6	2	6	3	9	3	9	4	12	1	3	3	9
3	3	3	3	3	3	3	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
6	2	4	4	8	3	6	3	6	3	6	2	4	2	4	2	4	2	4	3	6	1	2	3	6
9	4	12	2	6	2	6	2	6	4	12	2	6	4	12	2	6	4	12	3	9	4	12	4	12
3	2	2	2	2	2	2	2	2	4	4	2	2	3	3	3	3	2	2	2	2	3	3	2	2
4	1	4	4	16	3	12	4	16	3	12	2	8	2	8	5	20	2	8	3	12	2	8	4	16
9	1	3	3	9	2	6	2	6	1	3	2	6	2	6	2	6	2	6	2	6	2	6	3	9
3	3	9	2	6	4	12	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3
168,8		176,6		171,6		189,4		169,8		194,2		164,6667		173,8		162		167,3333		166,6667		179,4		163
158		167		162		175		159		181		179		163		148		146		192		180		149
158		167		162		175		159		181		141		163		148		146		130		154		149
158		167		162		175		159		181		174		163		190		210		170		180		191

57		68		88		96		97		104		106		107		124		126		141		142		144
Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating
3	18	3	18	3	18	5	30	4	24	5	30	5	30	5	30	5	30	4	24	5	30	3	18	3
3	18	3	18	3	18	2	12	2	12	2	12	4	24	4	24	3	18	2	12	5	30	3	18	3
3	18	3	18	3	18	4	24	4	24	4	24	2	12	2	12	4	24	2	12	5	30	3	18	3
1,2	21,6	1,2	21,6	1,2	21,6	1	22	1	20	1	22	1	22	1	22	1,2	28,8	1	16	1,2	36	1,2	21,6	1,2
3	12	3	12	3	12	5	20	4	16	5	20	5	20	5	20	2	8	5	20	2	8	2	8	2
3	12	3	12	2	8	2	8	2	8	2	8	4	16	4	16	2	8	2	8	2	8	2	8	2
3	12	3	12	3	12	4	16	4	16	4	16	2	8	2	8	2	8	2	8	2	8	2	8	2
1,2	14,4	1,2	14,4	1	10,66667	1	14,66667	1	13,33333	1	14,66667	1	14,66667	1	14,66667	1	8	1	12	1	8	1	8	1
3	15	3	15	3	15	5	25	4	20	5	25	5	25	5	25	5	25	4	20	4	20	3	15	3
3	15	3	15	3	15	2	10	2	10	2	10	4	20	4	20	3	15	2	10	4	20	3	15	3
3	15	3	15	3	15	4	20	4	20	4	20	2	10	2	10	4	20	2	10	4	20	3	15	3
1,2	18	1,2	18	1,2	18	1	18,33333	1	16,66667	1	18,33333	1	18,33333	1	18,33333	1,2	24	1	13,33333	1,2	24	1,2	18	1,2
3	15	3	15	3	15	5	25	4	20	5	25	5	25	5	25	2	10	4	20	4	20	3	15	3
3	15	3	15	3	15	2	10	2	10	2	10	4	20	4	20	2	10	2	10	4	20	3	15	3
3	15	3	15	3	15	4	20	4	20	4	20	2	10	2	10	2	10	2	10	4	20	3	15	3
1,2	18	1,2	18	1,2	18	1	18,33333	1	16,66667	1	18,33333	1	18,33333	1	18,33333	1	10	1	13,33333	1,2	24	1,2	18	1,2
3	6	3	6	3	6	5	10	4	8	5	10	3	6	3	6	5	10	3	6	4	8	3	6	3
3	6	3	6	3	6	2	4	2	4	2	4	3	6	3	6	3	6	2	4	4	8	3	6	3
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1,2	7,2	1,2	7,2	1,2	7,2	1	7,333333	1	6,666667	1	7,333333	1	5,333333	1	5,333333	1,2	9,6	1	4,666667	1,2	9,6	1,2	7,2	1,2
1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
2	8	2	8	4	16	1	4	2	8	2	8	1	4	1	4	2	8	2	8	2	8	2	8	2
2	6	2	6	5	15	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2	6	2
5	5	5	5	2	2	2	2	3	3	1	1	3	3	2	2	3	3	5	5	2	2	4	4	4
5	15	5	15	4	12	4	12	5	15	4	12	5	15	5	15	5	15	5	15	5	15	5	15	5
4	12	3	9	3	9	3	9	4	12	3	9	3	9	3	9	4	12	3	9	3	9	3	9	3
4	12	3	9	3	9	3	9	4	12	3	9	3	9	3	9	3	9	3	9	3	9	3	9	3
1	3	2	6	1	3	1	3	2	6	1	3	2	6	2	6	2	6	2	6	2	6	2	6	2
2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
2	4	3	6	2	4	1	2	2	4	1	2	2	4	2	4	2	4	2	4	2	4	2	4	2
4	12	4	12	3	9	3	9	4	12	3	9	3	9	3	9	3	9	5	15	1	3	5	15	2
2	2	2	2	2	2	2	2	2	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2
2	8	2	8	2	8	4	16	3	12	5	20	3	12	4	16	3	12	2	8	3	12	3	12	3
1	3	2	6	2	6	1	3	1	3	1	3	2	6	2	6	2	6	2	6	2	6	2	6	2
1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	1	3	5	15	3	9	3
	176,2		178,2		177,4667		164,6667		175,3333		172,6667		170,6667		173,6667		179,4		159,3333		202,6		181,8	
	163		165		168		194		190		202		198		201		182		190		187		171	
	163		165		164		128		146		136		178		181		156		144		187		171	
	163		165		168		172		190		180		136		139		169		144		187		171	

	147		148		227		228		152		154		155		157		167		174		175		176	
Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws	Rating	Ws
18	3	18	4	24	4	24	3	18	4	24	3	18	4	24	3	18	2	12	3	18	4	24	4	24
18	3	18	4	24	4	24	3	18	2	12	3	18	4	24	3	18	2	12	3	18	4	24	4	24
18	3	18	4	24	4	24	3	18	4	24	3	18	4	24	3	18	4	24	3	18	4	24	4	24
21,6	1,2	21,6	1,2	28,8	1,2	28,8	1,2	21,6	1	20	1,2	21,6	1,2	28,8	1,2	21,6	1	16	1,2	21,6	1,2	28,8	1,2	28,8
8	2	8	2	8	2	8	2	8	4	16	3	12	2	8	2	8	2	8	3	12	4	16	4	16
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162		149		177		171		168		141		164		171		159		139		157		181		176
162		149		177		171		168		183		164		171		159		189		157		181		176

178		192		194		206		207		REFERENCE	
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	175		168		161		183		154		117
	175		168		161		183		154		117
	175		168		161		183		154		117