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Generation of concepts for making an airport building CO2 neutral

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ABSTRACT

Designing of energy systems of buildings can be done according to different points of view. One of these points of view which also plays a big role nowadays is sustainability. Within sustainability there are different aspects that can contribute to sustainability. One of these aspects is the total amount of CO_2 emissions. The Trias Energetica is often used in order to create a design based on reducing the CO_2 emissions.

The design of energy systems can be a very complex assignment due to different factors. One of these factors that make the design complex is the scale of the assignment. An example of a large scale project is an airport. Hierarchical functional abstraction levels can be used to split up the area in different scales and generate an overview which reduces the complexity of the project.

This research focuses on the design of energy systems for a complex project like an airport based on reducing CO_2 emissions. In order to achieve this, the extended version of the trias energetica (5 step method) is combined with the hierarchical functional approach. To apply the 5 step method, first the demand of the scope is calculated. Different concepts are generated as an output of this methodology which includes making use of the asphalt platforms, geothermal, (bio-) kerosene, PV panels and natural cooling. The global calculations for the CO_2 emissions are done and the concepts are discussed after which concepts are combined in order to form the best solution. In the end the CO_2 emissions depend on the CO_2 equivalents of the energy which is used as an input, which can be equivalents of electricity, gas or other fuels. Since this equivalent of electricity can be zero, the total emissions can be zero if only electricity is used as input for the final version.

It can be concluded that this methodology does help to generate concepts in order to make complex assignments such as airports CO_2 neutral. It does help with creating out of the box concepts which are specific for the project, so it can also be applied to other complex projects.

Acknowledgements

Without continual growth and progress, such words as improvement, achievement, and success have no meaning.

- Benjamin Franklin

With this thesis, my time as a student has come to an end. When looking back, I can say that I grew a lot during these 6,5 years. The last year of my master I worked on this thesis with the cooperation of RHDHV. I have learned much working on this thesis, struggling with it, growing with it and finally finalizing it. It was not easy to start without a ready-to-go assignment. It was not easy to align with both the university and the company and it was not easy to dig into the background knowledge that was new for me, but essential in order to complete this thesis.

I did not make it easy for myself and therefore I questioned myself in the last few weeks if I could say that this master, including this thesis, was a success. During my master, I thought success was achieving high grades. I cannot deny that I still value high grades, but the quote of Benjamin Franklin verbalizes success and achievement in a better way. To answer my question if during this master I was successful, I now can say that I was. I undertook continual growth and progress during the past years. I did not only make progress on hard skills but also on soft skills and on personal development. Since I could not have been successful without the people that were involved during this time, I want to thank a few people in special.

First of all I would like to thank my parents, Max and Elly Dekkers, for facilitating me to study. Not only by encouragement but also by providing in anything materialistic that I needed in order to study. I would like to thank Wim Maassen for giving me the opportunity to formulate my own research with a lot of freedom and without any restrictions, and for recommending me to participate in the Rotterdam100 which was a great experience. In addition I would like to thank Wim Zeiler for keeping the academic aspects of this thesis in mind and providing me with feedback. Special thanks go to Rik Maaijen who helped me from the beginning, every week, with literally everything. From the contents to developing excel skills to putting everything in perspective to listening to my complaints; thank you!

Finally I would like to thank the family and friends around me who made these years as a student successful, with special thanks to my sorority La Donna è Mobile, the board of UniPartners 2013-2014 and my boyfriend Sven, for all the support and help in the last months.

LIST OF ABBREVIATIONS

APU	Auxiliary Power Unit
ATES	Aquifer Thermal Energy Storage
BASS	Bagagge Afhandelings Systeem
BREEAM	Building Research Establishment Environmental Assessment Method
CHP	Combined Heat Power
CO2	Carbondioxide
COP	Coefficient of performance
GPU	Ground Power Unit
HP	Heat Pump
HVAC	Heating, Ventilation, Air Conditioning
IEA	International Energy Agency
L_HVAC	Lighting and Heating, Ventilation, Air Conditioning
LDC	Load Duration Curve
LEED	Leadership in Energy and Environmental Design
LTO	landing and takeoff cycle
NSA	noodstroom aggregaat
NZEB	Nearly Zero Energy Building
PCA	Pre Conditioned Air
PV	Photovoltaics
RES	Road Energy Systems
TUD	TU Delft
TUE	TU Eindhoven

CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

In December 2015, 195 countries adopted the first-ever universal, legally binding global climate deal at the Paris climate conference (European Commission, 2016). This agreement is due to enter into force in 2020, and aims to reduce risks and impacts of climate change. This global agreement was a break-through in the history of global sustainability and underlines the fact that the subject plays a big role nowadays. In the built environment, sustainable certification methods such as BREEAM or LEED are assessed in order to reach the previous stated goals. In the Netherlands, the Trias Energetica (AgentschapNL, 2013) strategy is additionally used to accomplish an energy efficient design.

In November 2016, the press released that Amsterdam has plans for 2050 of becoming gas-free (Volkskrant, 2016). This means that heating and cooling in the new buildings will not take place by gas boilers but through electricity and for example by making use of thermal storage. The supply of fossil fuels will be cut off for existing buildings. The thought behind this plan is the need for reduction of fossil fuel use and CO_2 emissions, according to the agreement of the Paris climate conference.

The gas-free future of Amsterdam also applies to Amsterdam Schiphol Airport. Airports are specific areas that use as much energy on a yearly basis as small cities. Currently, heating is supplied by thermal storage systems, the electrical grid and gas supply. Schiphol is aware of the need for an all-electric future. At the moment, the vision regarding sustainability is stated in Schiphol's Climateplan. Implementation of this vision is clarified by the documents: 'Blauwdruk energie' and 'Visie duurzame mobiliteit'.

1.2 PROBLEM DEFINITION

Based on the CO_2 emissions stated in the 'Visie duurzame mobiliteit', an estimation was made (figure 1) for the distribution of total energy demand of Amsterdam Schiphol Airport (SchipholGroup, 2009). Ever since this graph was made, a lot of changes regarding environmental sustainability took place. For example electrical buses were purchased, and cooperation between SchipholTaxi and Tesla motors was established which resulted in 167 electrical Tesla taxis at Schiphol Airport.

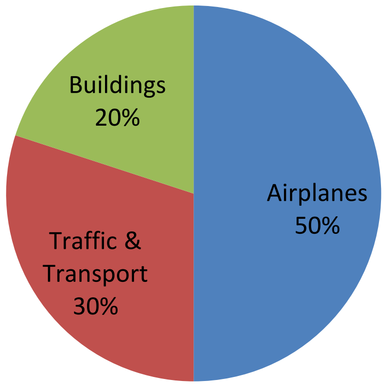


Figure 1 Distribution of CO_2 contributors of Amsterdam Schiphol Airport (airplanes include landing and taxiing and exclude total flight)

However, the amount of flights increased and also the buildings undertook expansion. Schiphol expects a further growth of amount of flights and further expansion of the buildings until 2020, which results in a total estimated energy demand of 557 GWh/year, according to the 'Blauwdruk energie'. For comparison; in 2015 households of Eindhoven had an energy demand altogether of 310 GWh (CBS, 2016). The contributors to this amount of 557 GWh/year can be found in appendix I and belong to the 20% of the buildings as was stated in figure 1 (SchipholGroup, 2008).

At the moment, there is not much of a methodology at Amsterdam Schiphol Airport for implementation of sustainable solutions. The climate plan is not a guidebook, but in reality loose ideas are generated after which the board decides whether or not to carry out the idea. Most ideas are based on use of renewable energy sources such as PV-panels. Those solutions proved to be efficient in the built environment, but there is a possibility that there are solutions available that are more suitable for a sustainable future for airports.

Airports are not comparable with other buildings in the built environment. Airports consist of unique features; typical buildings, airplanes, traffic and transport areas, whereby standard certification assessment methods are not sufficient. Focus should not only be set on the use of renewable energy sources, but also on other ways to reduce the CO_2 footprint. Energy demand should be minimized and distributed as efficient as possible. In order to achieve this, use should be made of airport specific characteristics

1.3 Research question

Based on the vision of Schiphol, the lack of methodology of how to accomplish this vision and based on the current national and international developments in terms of sustainability goals, the research question of this thesis is stated as follows:

Can integral design support the generation of different energy scenarios, based on the 5 step energy approach, to make Schiphol airport CO_2 neutral?

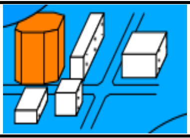
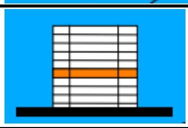
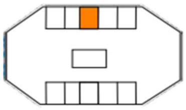
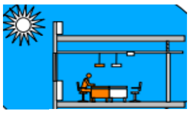
One step of this approach focuses on bringing the energy demand down. In order to apply this step, the total energy demand should be known. Therefore in order to answer this main question, the subquestion which is answered in the preliminary study is:

What is the energy demand of Schiphol airport?

1.4 Objective and scope

The aim of this study is to present a methodology which generates different energy scenarios that will make Schiphol airports buildings (terminal 3 and F+G pier) CO_2 neutral in an integral way. Functions have a very significant role in the design process and therefore, a function oriented strategy allows various levels of the built environment to be separately discussed and generated (sub) solutions to be presented (Wim Zeiler, 2010). In the built environment there are functional decompositions on hierarchical functional abstraction levels (table 1).

Table 1 Hierarchical functional abstraction levels and corresponding scope Schiphol

	Illustration	*Functional abstraction level*	*Scope Schiphol airport*
1		**Built Environment level**	**Schiphol Surface area**
2		**Building level**	**Terminal 3, F&G piers**
3		**Floor level**	**Check in area, luggage reclaim area, security, circulation area, offices, commercial area**
4		**Room level**	
5		**Working Place level**	
6		**User level**	

Different stakeholders are involved with the energy consumption. For example on floor level, offices are rented by external companies. Since the model is hierarchical, i.e. every abstraction level is a part of the above mentioned level and is the covering level for the next mentioned level, this research focuses on levels 1, 2 and 3. However, Schiphol does not have detailed insights in the energy demand of buildings. In order to get information on floor level, a research was conducted during the preliminary literature review on this topic. To be able to get detailed information, terminal 3 was studied in detail accompanied with the physically attached piers; F and G. The final conclusion will be drawn based on the buildings of terminal 3, F pier and G pier, as well as on the close surroundings of these building parts. In terms of the functional abstraction levels, the scope of this research covers the 'Built Environment', 'Building' and 'Floor' levels, as can be seen in figure 2.

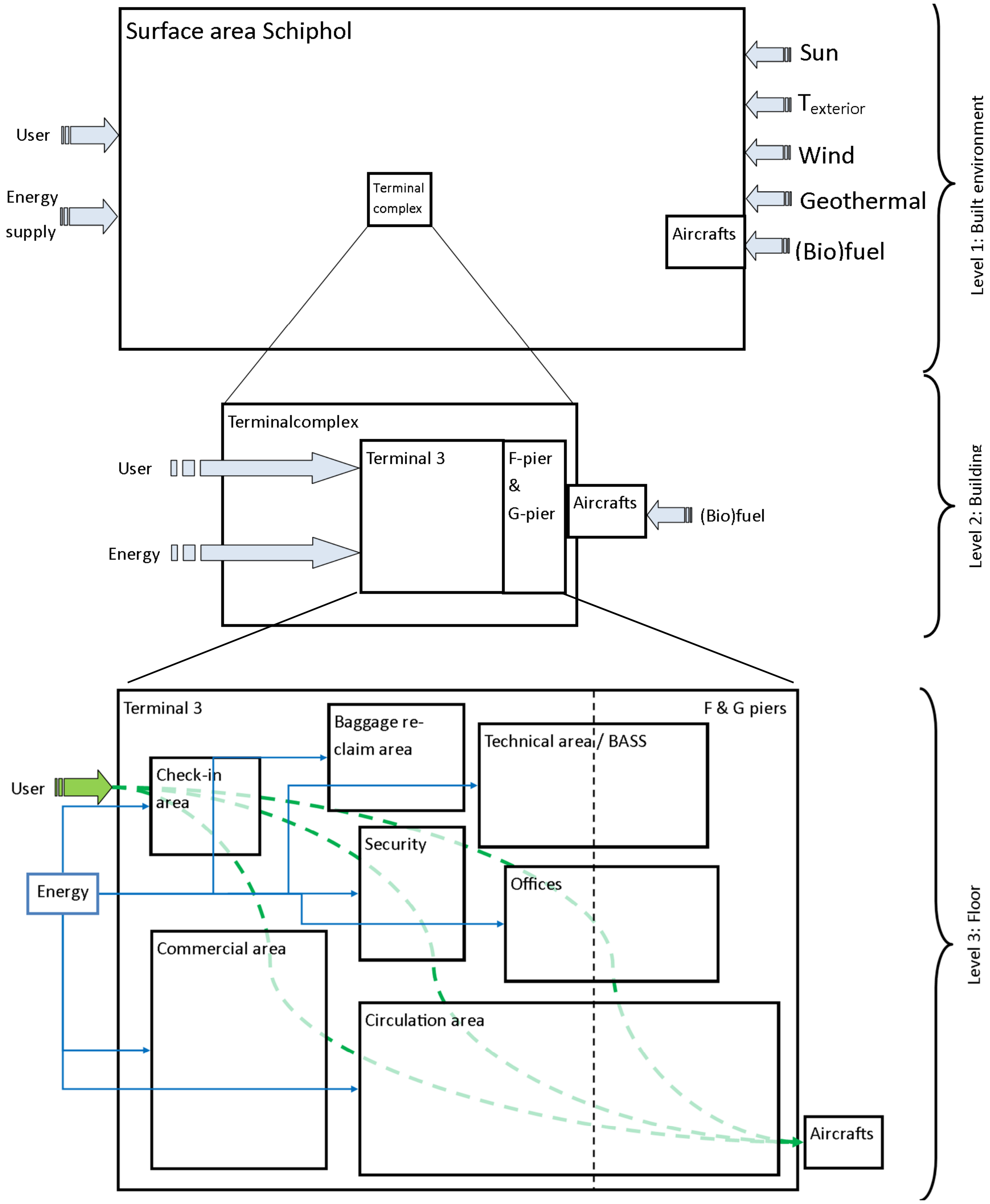


Figure 2 Scope of this research (appendix II)

1.5 RESEARCH METHODOLOGY

This paragraph elaborates on the methodology, but before that, a close look is taken at the Trias Energetica. The Trias Energetica is a strategy to implement energy saving measures which include reducing the demand, uses renewable energy sources and limits the use of fossil fuels as much as possible (figure 3) (Schrooten). This strategy was introduced under the name Trias Energica in 1996 by Novem, the Dutch enterprise for energy and environment. Later this strategy was worked out by Delft University of Technology and it is ever since commonly used in the built environment in the Netherlands and abroad.

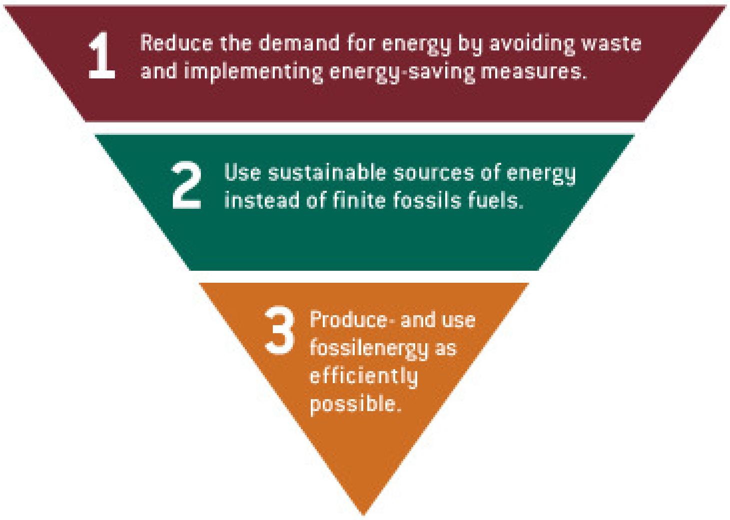


Figure 3 Trias Energetica (www.eurima.org)

The Trias Energetica is a 3 step method which is applied as follows:

- Step 1: Reduce the energy demand. This means reduction of the energy demand by passive measures based on the physical building properties. An example is to apply walls with a high insulation value so heat losses are minimized.
- Step 2: Use of renewable energy sources. This step focuses on heat recovery systems or use of renewable sources like the sun or wind.
- Step 3: Use fossil fuels as efficient as possible. This last step is done after the previous two steps and focuses on the efficiency of the systems.

Instead of using this 3 step method as guidance, use has been made of the so called '5 step method', developed by Eindhoven University of Technology and Royal HaskoningDHV. The 5 step method (figure 4) is an extension of the Trias Energetica, and acts as a guide when pursuing nearly or net Zero Energy demand buildings (NZEB) in the built environment. The goal of this research is to make Schiphol CO_2 neutral, therefore this method is used to generate potential sustainable concepts combined with the previously mentioned hierarchical functional abstraction levels (table 1).

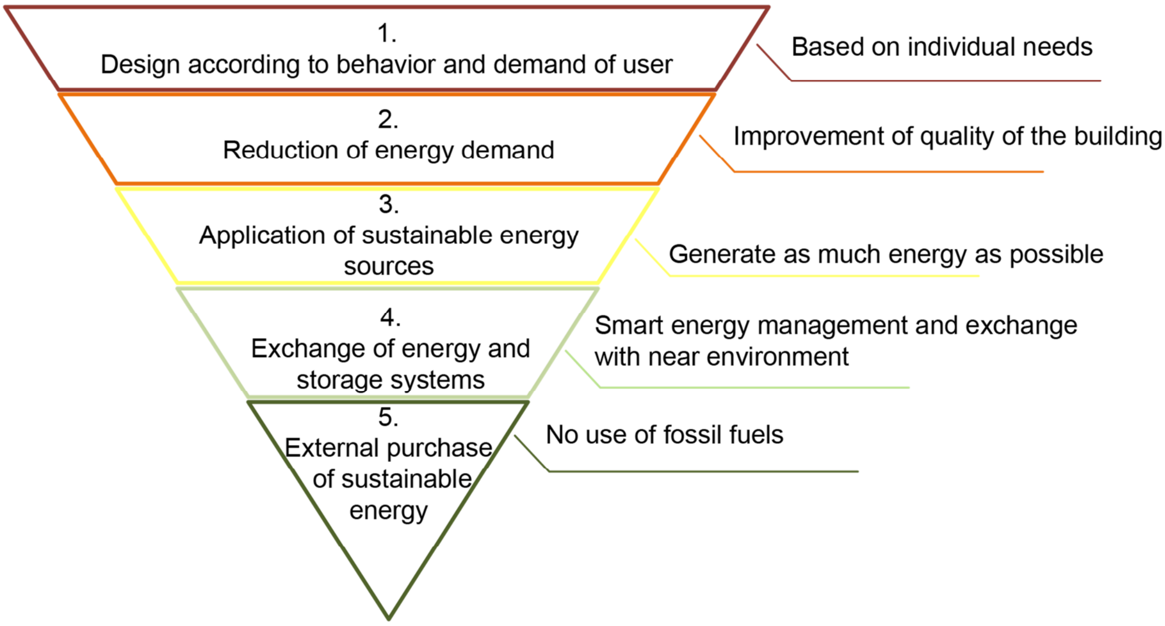


Figure 4 TU/e & RHDHV's 5 step method

According to the preliminary literature research, airports have unique characteristics which can be divided in 3 main common parts namely buildings, airside and landside. Especially the combination of these parts is what makes airports unique. These parts contribute to the hierarchical functional abstraction level 1 of the 'Built Environment' (paragraph 1.4). The buildings are the main contributor to the total energy demand and they belong to level 2, the 'Building level'.

All buildings on Schiphol Airport have a certain demand, which is examined by a previous literature study and is explained in chapter 2. First, detailed insights in this energy demand must be obtained. This was done in previous literature research and will be explained in chapter 2 'Building level', after which the 5 step method is applied. Then in chapter 3, the 5 step method is applied in level 1 'Built environment' while making use of the characteristics of the airport environment. In chapter 4, all applicable solutions for the generation, buffering and conversion of heat, cold and electricity for Schiphol airport, are put in a morphological chart. After this, combinations are made based on different renewablle energy sources and a calculation is made of the CO_2 emissions. After this, a final combination of concepts is made and worked out into detail.

1.6 Scientific relevance

Prior to the most used sustainable methods and theories for designs of offices and residential buildings is the Trias Energetica (Trias Energetica, 2016). However airport buildings have considerable different characteristics and scale in their design and use than residential and office buildings. This comes with a sizable difference in energy consumption. Integration between buildings, aircrafts and airport environments might offer a great variety of opportunities in terms of CO_2 reduction. In order to structurally unravel the complexity of airports and make use of potential existing connections such as between buildings and aircrafts, insights in the different levels of airports are needed. This research will conclude whether an integral design supports the generation of different energy scenarios, based on the 5 step approach, to make Schiphol airport CO_2 neutral.

2. BUILDING LEVEL

This chapter focuses on the building level. Paragraph 2.1 elaborates on the energy demand and the 5 step method is applied in paragraph 2.2. In order to reduce the CO_2 emissions, it is necessary to know what the actual energy demand is. For buildings, energy demand consists mainly of lighting, heating, ventilation, air-conditioning (L_HVAC) and electrical appliances. The total demand on 'Building level' is calculated according to the demand on different areas on 'Floor level' (figure 5).

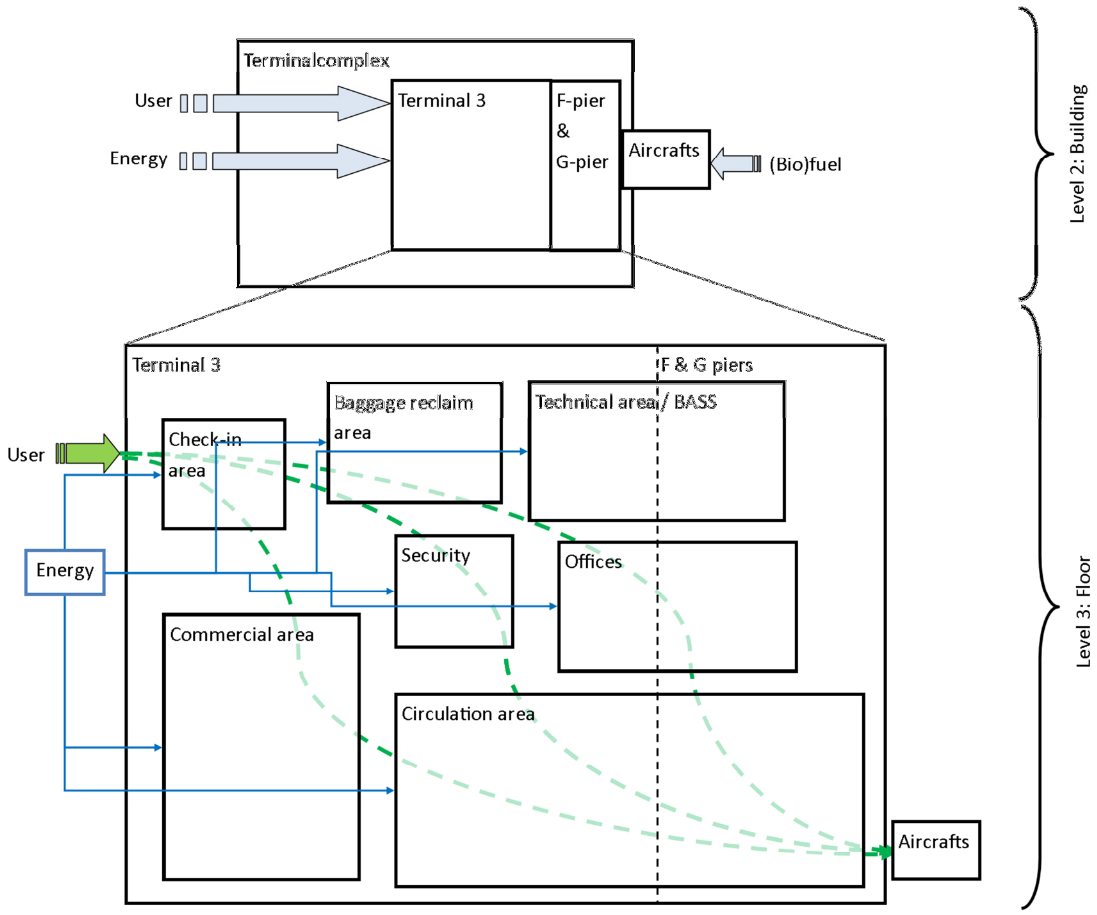


Figure 5 'Building' and 'Floor' level. Energy demand flow (blue arrows) of functions within T3 and F&G piers. Connections are visible between T3&piers and between piers&aircrafts. User moves through different functions in the terminal complex to the aircraft (green dotted arrows).

As can be seen in figure 5, the energy demand of the building level (level 2) is built up by the demands of different components on floor level (level 3); check-in area, baggage area, technical area, security, offices, commercial area and circulation area. Since aircrafts make a physical connection with the building through the gate of the pier, aircrafts are included in this chapter 'Building level'.

2.1 Demand building level

2.1.1 Demand buildings

The main part of the energy demand of the surface area (Schiphol as a whole) is caused by the terminal complex, as can be seen in figure 6.

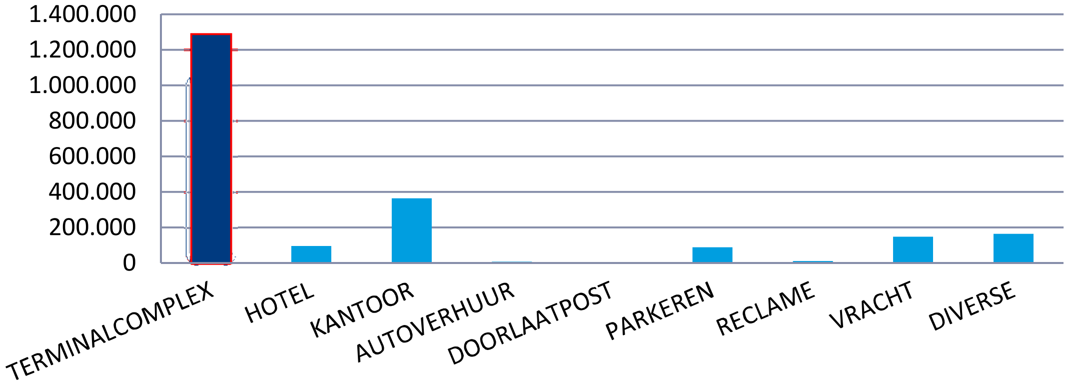


Figure 6 Primary energy use Schiphol 2009 [GJ,p]

Within the terminal complex, different functions and processes take place. In order to get detailed insights in the energy flows, a model was built based on the design requirements of the different functions within the buildings of Schiphol. The functions within the buildings have different requirements due to differences in design guidelines, internal heat gains and more. Next to a number of input parameters, also user occupancy has impact on the total energy demand (appendix III). The demand of terminal 3 together with the attached piers F and G was calculated in a preliminary study, of which the results can be found in figure 7. This figure represents the blue energy arrows from figure 5 which are connected to the buildings. The energy which is connected to the aircraft is calculated in paragraph 2.2.

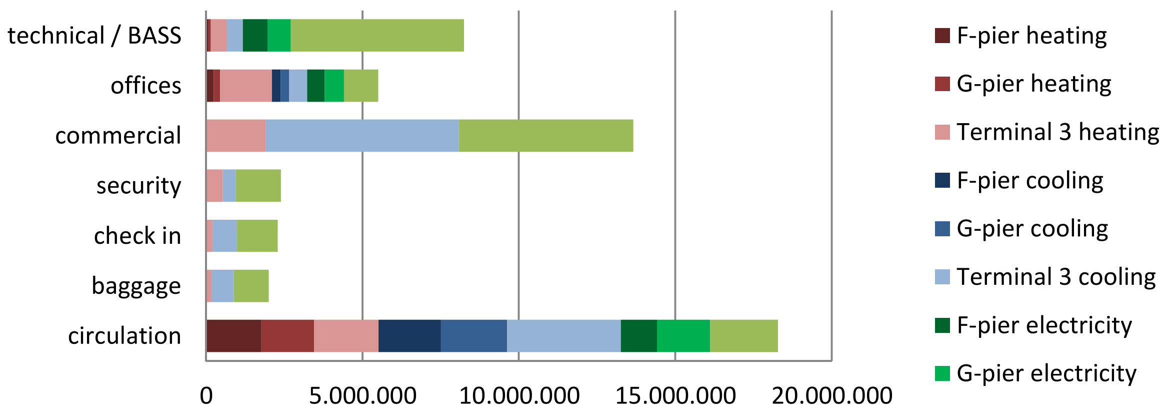


Figure 7 Total energy demand F+G piers and Terminal 3 by function [kWh]

The demand in the figures is divided in heating, cooling and electricity. These components are calculated according to the formulae which can be found in appendix IV.

The total amount of energy demand associated to the building part can be seen in figure 8, where BASS stands for the luggage handling system, which is put together with the technical area because of the similarities in the design guidelines and occupancy.

Figures 7 and 8 are acquired with the same data. It can be seen that terminal 3uses significantly more energy than the F & G pier. Terminal 3 has a larger surface area than those piers and more intensive user occupancy. Commercial area is mainly located in the terminal building which is one of the reasons that the electricity demand is high. Heating and cooling demand are similar in the piers but in the terminal, the cooling demand is significantly higher than the heating demand. The commercial area is also one of the reasons for this difference.

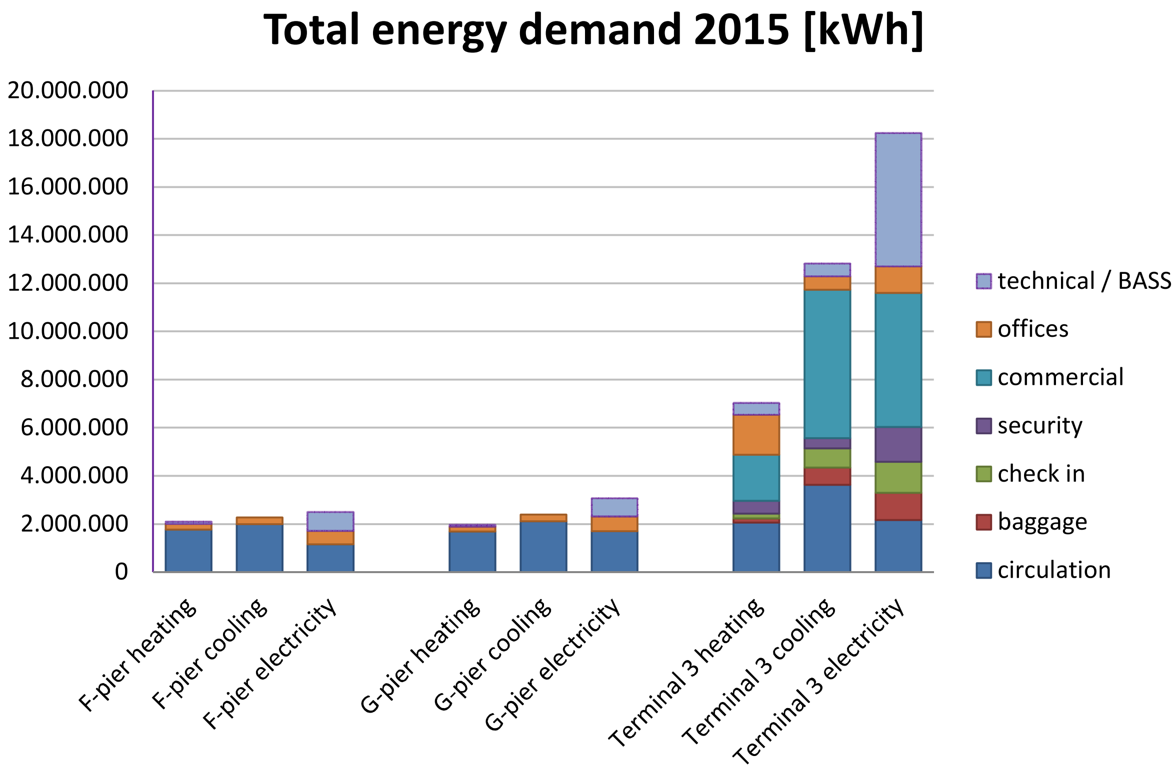


Figure 8 Total energy demand F+ piers and Terminal 3 by part of the building

Added up, the total heating, cooling and electrical demand (appendix V) is 52,0 GWh:

- $Q_{total,heating}$: 10,9 GWh (1)
- $Q_{total,cooling}$: 17,5 GWh (1)
- Q_{elec}: 23,6 GWh (2)

2.1.2 DEMAND AIRCRAFTS

According to Schiphol [klimaatplan, 2007], 50% of the total CO_2 emissions of Schiphol airport is caused by aircrafts. This includes the energy used for take-off and landing, but it also includes the energy used for L_HVAC and electrical appliances when the aircrafts engines are turned off. When the engines are not running, energy is provided externally. This can be done in several ways.

When the engines are switched on, this energy demand is generated by the auxiliary power unit (APU) of the aircraft. The fuel for the engines is kerosene. So, when the aircrafts engines are switched on, L_HVAC and electrical appliances are supplied by kerosene. The airlines are responsible for the purchase of this kerosene.

However, when the engines of an aircraft are switched off (which is the case when it is attached to the pier), the aircraft still needs energy. Commonly, energy is then supplied by a ground power unit (GPU) which uses diesel as fuel. Because of the goal of Schiphol to make less use of fossil fuels, on 70 gates (SchipholGroup, 2017), Schiphol provides preconditioned air (PCA) and electricity access (400Hz) through the buildings. In those cases the supply changes in stakeholders; from the airline (kerosene) to the airport. The stakeholders within the scope of this research, involved with the power methods of the aircraft, are represented in figure 9.

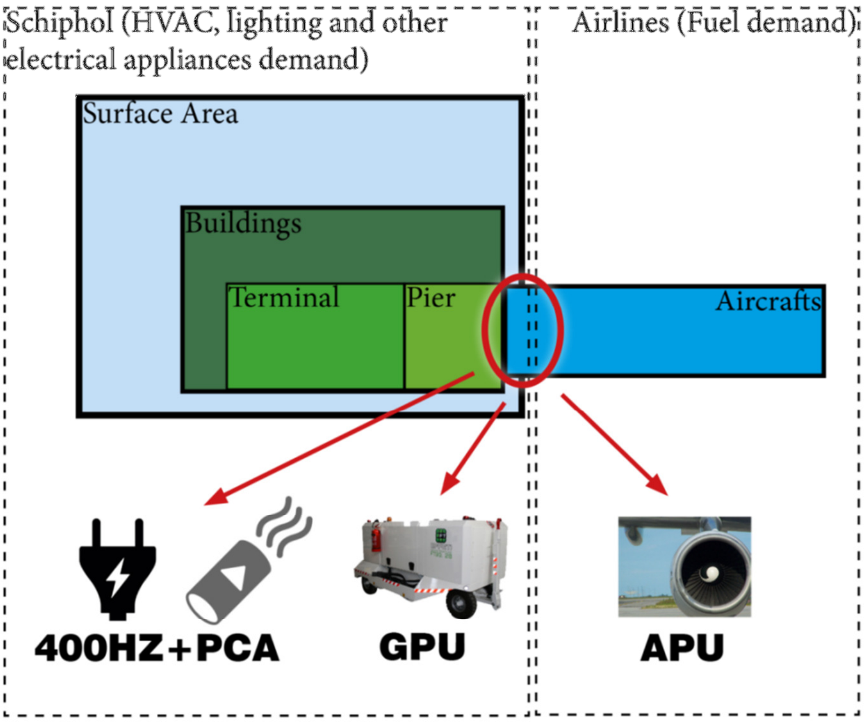


Figure 9 Stakeholder involvement energy demand

Figure 10 illustrates the connection between the aircraft and the building.

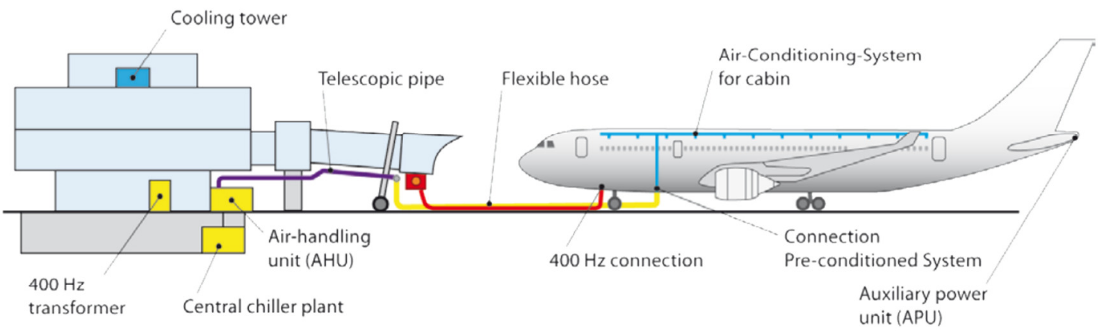


Figure 10 Energy exchange between building and aircraft

The demand of energy used by aircrafts supplied by Schiphol can be calculated. For this, the amount of passenger flights (433,904 passenger flights annually) is multiplied by the electricity use per minute and the mean of the time the aircraft's engines are turned off, based on the specifications of the fleet mix. The calculations can be found in appendix VI. The total use of energy used by aircrafts when the engines are switched off and thus the total energy for aircrafts provided by Amsterdam Schiphol airport calculated for 2015 is nearly 63 GWh.

This study is scoped down to terminal 3 and the F and G pier, which contain 16 gates out of the total of 95 gates, assuming that the use of all gates is divided equally (appendix VII). Therefore, the total aircraft related energy demand of the scope is:

$$Q_{elec,aircrafts}: 16/95 * 63 \text{ GWh} = 10.8 \text{ GWh}$$

This demand is partly provided by GPU's, and partly by 400Hz and PCA supply of the buildings. In 2016, and average of 54.9% of the aircrafts attached to the piers were supplied by Schiphol's PCU and 400Hz access points (Appendix VIII) and 45.1% was supplied by GPU's (figure 11). Unfortunately, the GPU is very flexible and reliable and therefore much easier to use for airlines. The 400Hz supply needs to be attached and is heavier and needs to be used by two employees on the platform (Samson, 2017).

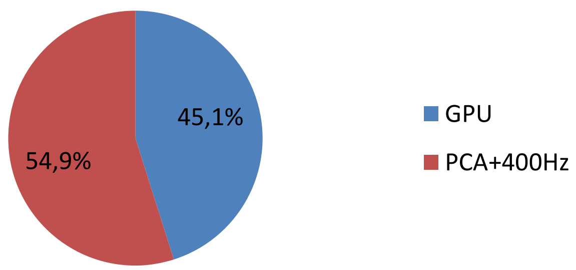


Figure 11 Supply of aircrafts attached to the piers (Schiphol 2016)

Appendix VII shows the list of gates (in total 70 out of 95) which are provided with the PCA unit and 400 Hz supply. All of the demand of the flights of this scope (8 gates out of 8 for the F pier and 8 gates out of 8 for the G pier) can be provided by the buildings.

The part of 45,1% supplied by GPU's of Terminal 3 and F & G piers is:

$$45.1\% * 10.8\text{GWh} = 4.9 \text{ GWh}$$

The remaining 54,9% supplied by PCA and 400Hz units of Terminal 3 and F & G piers is:

$$54.9\% * 10.8\text{GWh} = 5.9 \text{ GWh}$$

According to Royal Schiphol Group, each LTO cycle (landing + take-off cycle) uses 7.7 liters of diesel. However, when a flight takes off at Schiphol airport and lands on another airport, only the part of diesel used at Schiphol airport has to be counted. The total passenger flights shown in appendix V are a combination of incoming and outgoing flights. Assuming that 50% of these flights are departing flights and 50% of the total flights are incoming flights, irrespectively of the distribution of the 7.7 for landing and take-off, half of the 7,7 liters is accountable for Schiphol airport. Therefore amount of diesel used at Schiphol airport by the GPU's in this scope, providing 4.9 GWh of energy is:

433,904 passenger flights * 7.7 liters * 0.5 * 45.1% GPU supply = 750,000 liters diesel

2.2 APPLYING 5 STEP METHOD ON 'BUILDING LEVEL'

Buildings are the main contributors of the energy demand. Therefore energy optimizing opportunities should start with applying the 5 step method on terminal 3 and piers F and G and therefore bringing this demand down. First opportunities that followed from the detailed insights that were given by modelling the current demand, are investigated by following the 5 step method reduce this demand of 52 GWh as calculated in paragraph 2.2.1.

STEP 1: DESIGN ACCORDING TO BEHAVIOUR AND DEMAND OF USER

Technical areas for example are not excessively used by persons and therefore they do not require a strict temperature regulation. Functions that are excessively used during both day and night require a more constant temperature so it can be thoughtful to locate those functions in an area that is not much influenced by fluctuating heat gains like daylight. Next to this, functions which are not constantly used but high peaks occur in the user intensity should be conditioned according to the use. If an area is not used, for example an empty pier, it is a waste of energy to supply L_HVAC to this area. Ideally heat exchanges between the processes which imply that hourly insights also offer opportunities for energy use improvement. An optimal distribution between central and local heating and cooling can be found.

Step 2: Reduction of energy demand; central and local demand

The reduction of energy demand has its limits; the comfort level of the user should not be reduced. What is interesting is that the air flow temperature is centrally regulated and thus the same for different areas while the temperature need is different for different areas. Next to this, over the years changes and expansions of the buildings regularly take place at Schiphol while the installations are not changing similarly. Specific insights in energy flows provide huge opportunities for energy use improvement in terms of centrally regulated air supply. Next to reduction of the energy demand, the total energy use also depends on the losses. Reduction of these losses can be achieved by shorten distribution distances, and appliance of materials for facades, roofs and windows with a high insulation value.

Step 3: Application of renewable energy sources

On building level, unique aspects of buildings can be used in a way by making use of the large roof area of buildings by putting PV panels on it. Schiphol however uses the surface of the roofs for service and installations. Furthermore Schiphol does not want PV panels on the roofs since strict regulations are maintained regarding sight of the air traffic crew and PV panels can cause glare due to the mirror reflection. Renewable energy sources such as the sun, exterior temperature, wind and geothermal are shown in figure 2 on level 1 which is the overlaying layer of the layer of this chapter and therefore in chapter 3 elaborations on this part will take place.

Step 4: Exchange of energy and storage systems; local buffering systems

Within the building

The model provides information about the energy demand per hour per function. So next to a total heating or cooling demand, each function shows its hourly cooling or heating demand. Aquifer thermal energy storage (ATES) is a widely used solution in order to become more sustainable. Often, this system is explained as that during winter a building needs heating and during summer a building needs cooling. However, on 'Building level' the heating and cooling demand fluctuates every hour. The demand even fluctuates between the different parts of the building in the same hour. On a given point in time, it occurs that area A requires heating and area B requires cooling. What happens now is that at process A, reheating takes place while at process B recooling takes place.

Even during a random summer's day, it can be seen that heating takes place in both the terminal and piers at 8:00 both heating and cooling takes place (figure 13).

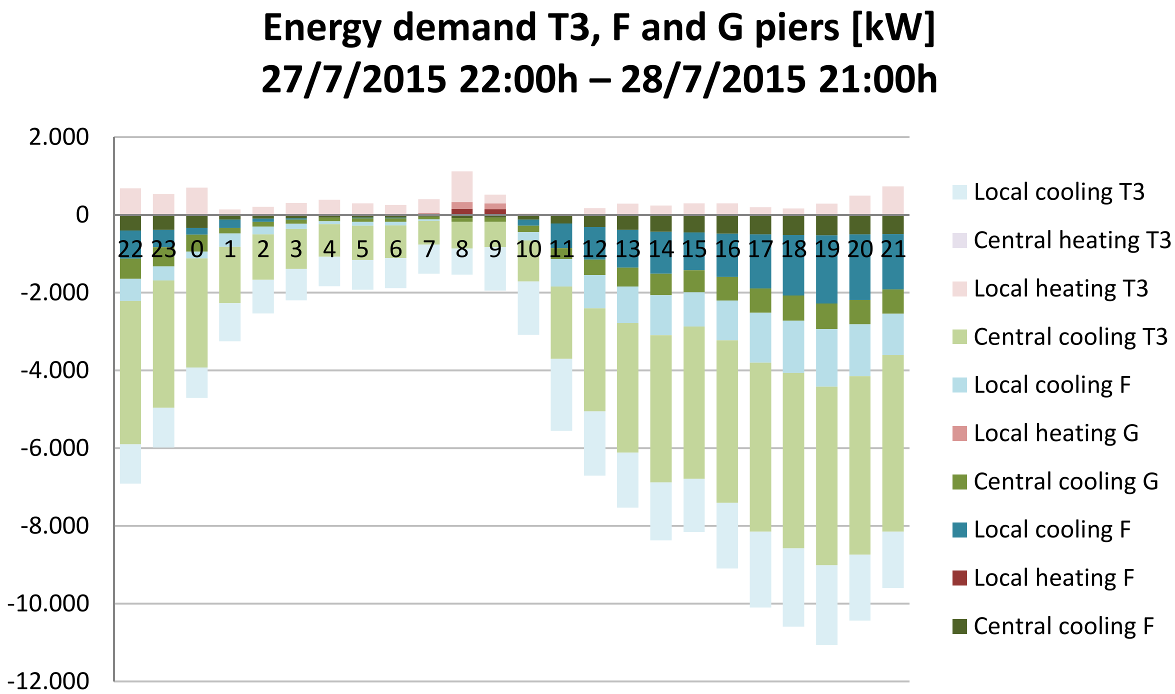


Figure 12 Hourly energy demand summer's day 2015

The hourly heating and cooling saving potential was calculated. In the hypothetical case that energy exchange takes place with an efficiency of 80%, optimal heat exchange results in a decrease of total heating demand of 33% and a decrease of total cooling demand of 20% (figure 14). For this calculation the hourly differences of heating and cooling between terminal 3 and F and G piers are added up.

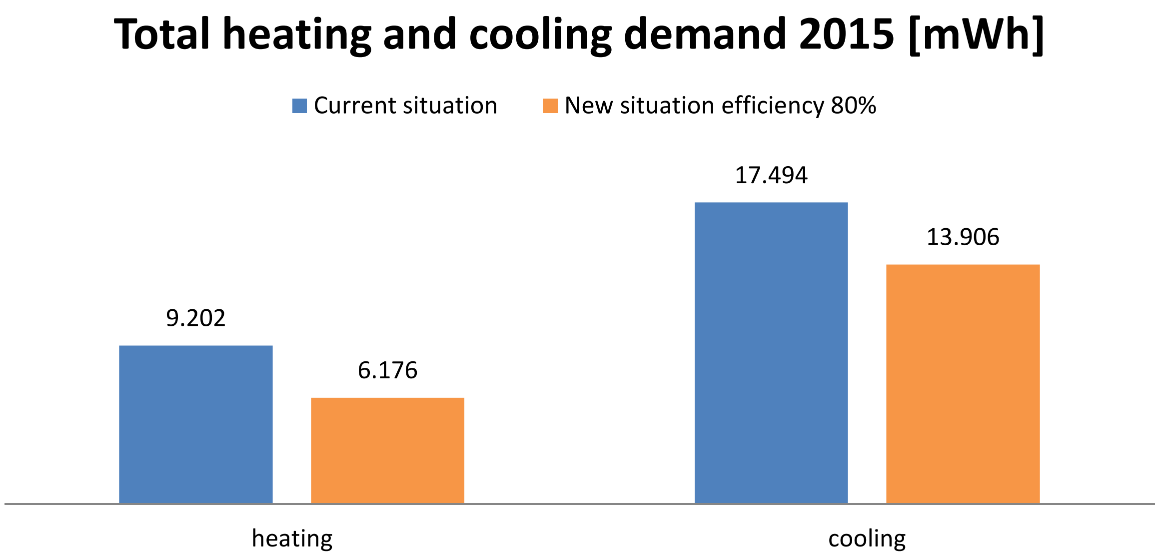


Figure 13 Total heating and cooling demand current and improved situation

Since an efficiency of 100% is not realistic, the calculation is made where in the case of simultaneous heating and cooling occurs in T3 and F and G piers, heating and the cooling demand of that hour is subtracted from each other and divided by the factor 0.8, to keep a heat exchange efficiency of 80%.

Building with the aircrafts

All gates (the place where an aircraft is entered from the pier) of the scope are provided with PCA (pre-conditioned air) systems and a 400 Hz connection. However in reality, Schiphol makes less use of those systems than they are supposed to (Ministerie van Infrastructuur en Milieu, Handhavingsrapportage Schiphol, 2014). The reason for this is firstly due to the fact that only 70 out of 95 gates are equipped with the 400Hz supply. A second reason is that the GPU's are easier to use (appendix IX). As was mentioned before, in 2016, only 54.9% of the aircrafts energy demand was supplied by Schiphol's 400Hz access point and 45.1% was supplied by GPU's. Ideally, this changes to 0% GPU use in order to reduce the fossil fuel demand (figure 15). In this way, the demand will be included in the 5 step method and will decrease the CO_2 emissions that were otherwise caused by diesel-driven GPU's.

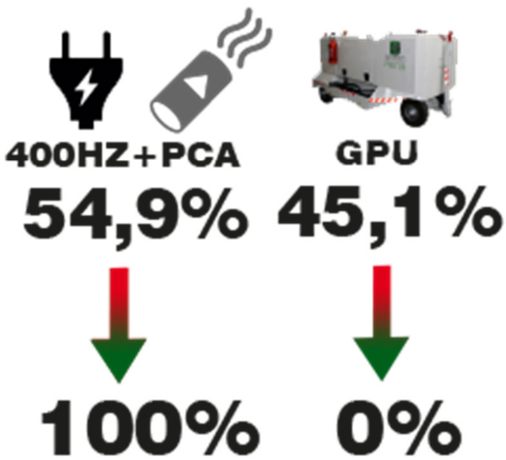


Figure 14 Change of supply aircrafts from GPU to building

The 45,1% energy supply by GPU's, accounts for 750,000 liters of diesel annually, as was calculated in paragraph 2.1.2. The CO_2 equivalent of diesel in the Netherlands is 3.23 kg CO_2/liter (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017). So by getting rid of the GPU's, the amount of CO_2 emissions on this scope is reduced by:

$$750{,}000\ [l] * 3.23 \left[\frac{\text{kg}}{l}\right] = 2.4 \text{ kton } CO_2$$

The total demand of all aircrafts if supplied by GPU's would equal to:

$$\frac{750{,}000\ [l]}{45.1\%} * 3.23\ [\frac{kg}{l}] = 5.4\ kton\ CO_2$$

The energy demand of the aircrafts however will be added up to the demand of building level. Therefore the total calculated energy demand (formulae 1 and 2) of the 'Building level' is:

52.0 [GWh] + 10.8 [GWh] = 62.8 [GWh]

In terms of CO_2 emissions, the demand of 10.8 GWh equals:

$$10.8 * 10^6 [KWh] * 0{,}355 \left[\frac{kg}{kWh}\right] = 3.8\ kton\ CO_2$$

Concluding that the demand for aircrafts going from GPU's to building supply, the CO_2 emissions are reduced from 5.4 kton to 3.8 kton by applying this step.

Step 5: External purchase of sustainable energy

Like step 3, step 5 is applicable for the larger scale of Schiphol airport. Step 5 is applied to fill the gap which is left after applying steps 1 to 4. Chapter 4 will elaborate on this step in the larger scale.

3. Built environment level

This chapter focuses on the built environment level of which the previously discussed building level is a part as can be seen below. Paragraph 3.1 elaborates on the energy demand and the 5 step method is applied in paragraph 3.2.

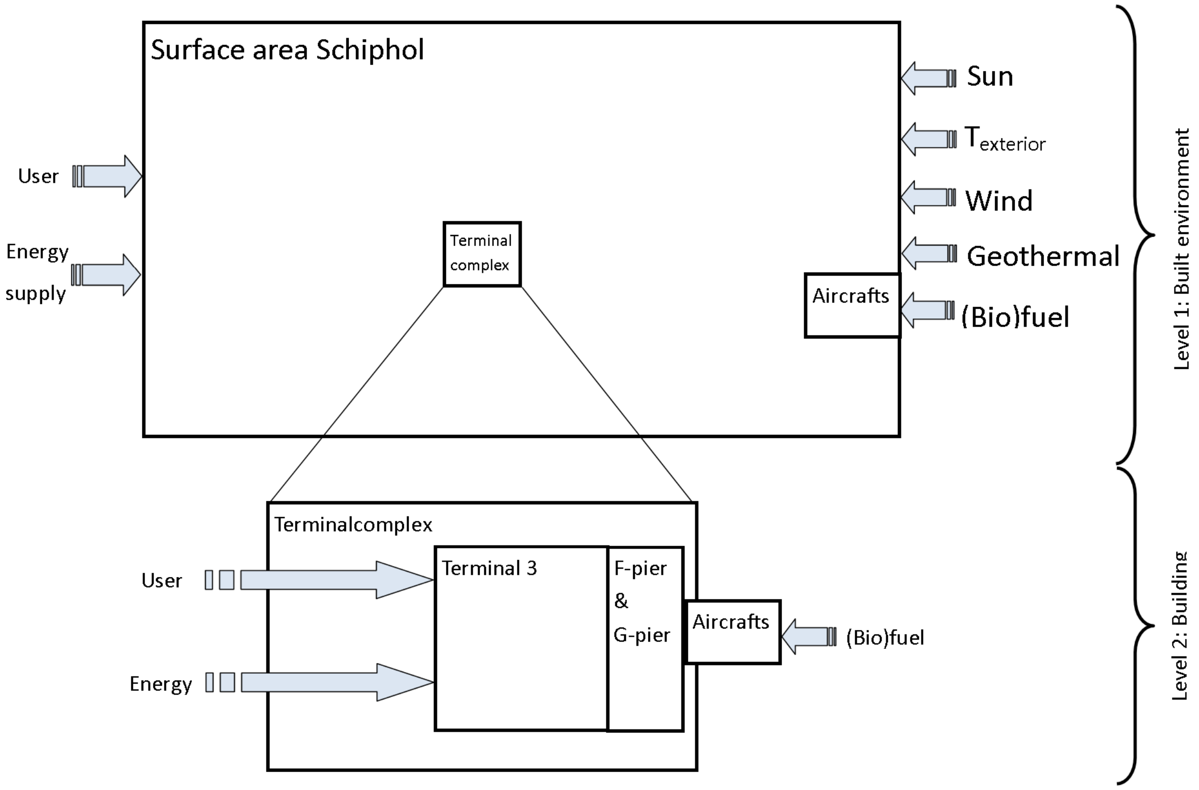


Figure 15 Scope chapter 3

3.1 Demand built environment level

In chapter 2, insights are given in the hourly heating and cooling demand of the different functions in the terminal complex. This offers optimization possibilities in both energy exchange or energy reduction fields regarding the contribution for buildings

The terminal complex is not the only energy consumer on this level. Other consumers are; hotels (Hilton, Sheraton and Citizen), offices, car rental, parking areas, advertising billboards, and the air traffic control tower. Next to these buildings, CO_2 is emitted by cars and public transport on the site.

3.2 APPLYING 5 STEP METHOD ON 'BUILT ENVIRONMENT LEVEL'

STEP 1: DESIGN ACCORDING TO BEHAVIOUR AND DEMAND OF USER

The user is not directly involved on the 'Built environment' level, as he/she enters the site by the terminal complex and also leaves the site on this building level as can be seen in figure 2.

STEP 2: REDUCTION OF ENERGY DEMAND

Reduction of the total energy on the 'Built environment' level can be achieved by multiple stakeholders. For example the emissions of fuel by taxi's and public transport can be reduced by using cars and buses with relatively low CO_2 emissions. Use can even be made of electrical transportation systems. Furthermore for the landing aircrafts, the taxi distance can be shortened by designing the landing aprons in an efficient way.

STEP 3: USE OF SUSTAINABLE ENERGY SOURCES

There are plenty of renewable energy sources available in the world, but this research takes a close look at the sources available for the scope of Schiphol airport (figure 16).

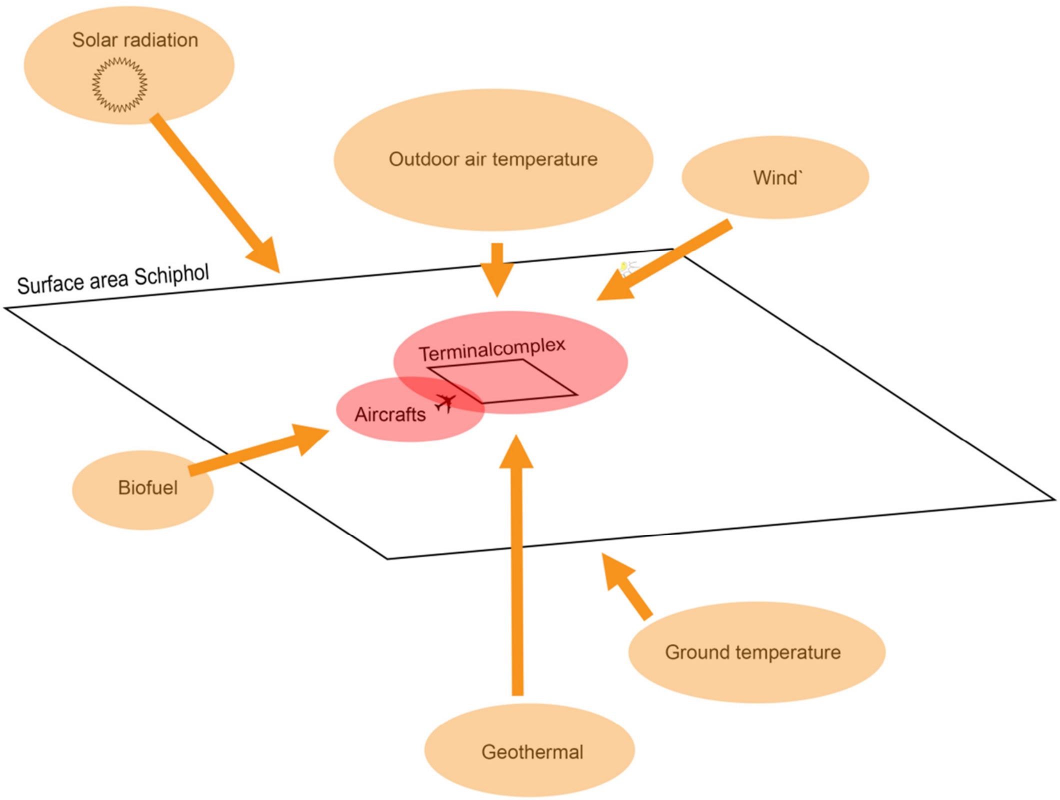


Figure 16 Available renewable energy sources (orange) and main demand (red)

At Schiphol Airport and in all airports over the world, asphalt platforms cover a big amount of the total surface area. Those big surfaces offer the opportunity to be used as renewable energy generation since it is exposed to the outdoor air temperature, the radiation of the sun, wind, and the ground temperature.

Use can be made of the scale of this 'Built environment level' at Schiphol airport. As was mentioned before, the demand of Schiphol airport is higher than the demand of all households in Eindhoven for 2015. Therefore Schiphol can be compared to a small city. At the moment, Schiphol is investigating if bio fermentation is achievable (Greenport Aalsmeer;). 12.000 Ton of input can be delivered by the green areas next to the landing and take-off platforms, but other organic waste flows can also be considered.

Furthermore, deep in the ground Schiphol has the potential for application of geothermal energy by its access to hot water of 75°C on 2 km depth (appendix X). However a quickscan was done in 2010 by IF technology and hot water of 85°C could be obtained at Schiphol area. Wind energy is potentially a very useful source of renewable energy for airports. However, Schiphol airport has limitations on the placements of obstacles that may restrict the practical location of wind turbines near the airport, because the turbine is regarded as a physical barrier and a possible interference to radio navigation systems (Barret, 2014).

Step 4: Exchange of energy and storage systems

The available renewable energy sources require additional systems in order to transform the energy from the source to the heating, cooling and electrical demand. This transformation requires steps of generation, conversion, distribution and buffering. Buffering of heat and cold at Schiphol airport applicable on this level can take place through an aquifer thermal energy storage (ATES). The electricity grid offers the possibility of submitting and extracting energy.

Step 5: External purchase of sustainable energy

At the moment, Schiphol purchases the amount of energy externally. Because of the sustainability goals of the airport, Schiphol purchases energy which is generated by renewable energy sources. Schiphol takes the CO_2 emissions into account while purchasing energy externally. Next to this, Schiphol has access to biofuel due to aircrafts which are currently partly fuelled by biokerosene (Schiphol, 2017), which has a smaller CO_2 footprint than regular kerosene. Furthermore the developments of biofuel are full in progress and the CO_2 emissions are expected to decrease up until 2050, as will be discussed later in this report. Next to this, Schiphol realized electricity access points on the surface area in order to encourage electrical vehicles on the site.

4. SYSTEM RESULTS

The 5 step method is assessed on different hierarchical functional abstraction levels of Schiphol Airport. On one hand, the demand can be reduced and on the other hand, the supply must be produced in an efficient and sustainable way. Becoming CO_2neutral can be achieved by taking extreme measures into account which reduce the demand. For example, the supply can be decreased by lowering the heating and cooling supply of terminals. But since costumer comfort has high priority at Schiphol Airport, the benefits of this measure do not outweigh the disadvantages. There are many other energy saving measures available for Schiphol airport, of which some are discussed in chapter 2.

However, different concepts are generated in this chapter and calculation of the sustainable and efficient supply of the demand will be done, based on the current demand as calculated in chapter 3.1, with implementation of the demand of the aircrafts (step 4 paragraph 2.2). This is done because before implementation of energy saving measures, more research is needed on other aspects such as costs, stakeholder impacts or safety. The numbers below are equal to 100% to the heating, cooling or electrical demand from now on in this chapter;

- Heating demand: 10.9 GWh
- Cooling demand: 17.,5 GWh
- Electrical demand: 23.6 + 10.8 GWh = 34.4 GWh

4.1 COMBINATION OF CONCEPTS

In order to fulfil the energy demand on 'Building level', heat, cold and electricity must first be generated from the source and possibly also conversed and/or buffered. In order to generate concepts based on the available systems in the building level and built environment level of this scope use is made of a morphological chart. This chart includes the renewable energy sources which were generated with the 5 step method in all of the applicable functional abstraction levels. Next to this, generation methods of heat and cold are implemented, as well as conversion methods. The morphological chart is used to generate possible energy infrastructures for heat, cold and electricity that will eventually fulfil the (reduced) demand.

Different aspects of the morphological chart (appendix XI) can be connected, starting by the renewable energy source on 'Built environment' level. The final aspect of the chart is the energy demand on 'Floor level' because that is the level of energy supply Schiphol is accountable for. The 5 concepts generated based on the renewable energy sources available for Schiphol Airport are: Asphalt, Geothermal, Biofuel, All-electric and Natural cooling. Those concepts are elaborated on in this chapter and calculations can be found in the appendices.

4.1.1 *CONVENTIONAL*

In order to compare the potential solutions with the current situation, the conventional situation is assessed. The current generators of electricity, cooling and heating for terminal 3 are used as the starting point to cover the demand. What is different from the reality is that now the demand of the aircrafts of this scope is also taken into account, which increased the electricity demand from 23.6 to 34.4 GWh.

System illustration

The conventional situation supplies the heating demand by gas boilers, the cooling demand by chillers and the electricity demand by the electrical grid. Figure 17 shows an illustration of the system, where the green, blue and red arrows represent the respectively electricity, cooling and heating demand. Instead of the total energy balance per system, only the energy input is shown that contributes to the total emissions of CO_2. Residual flows are not shown in the illustrations.

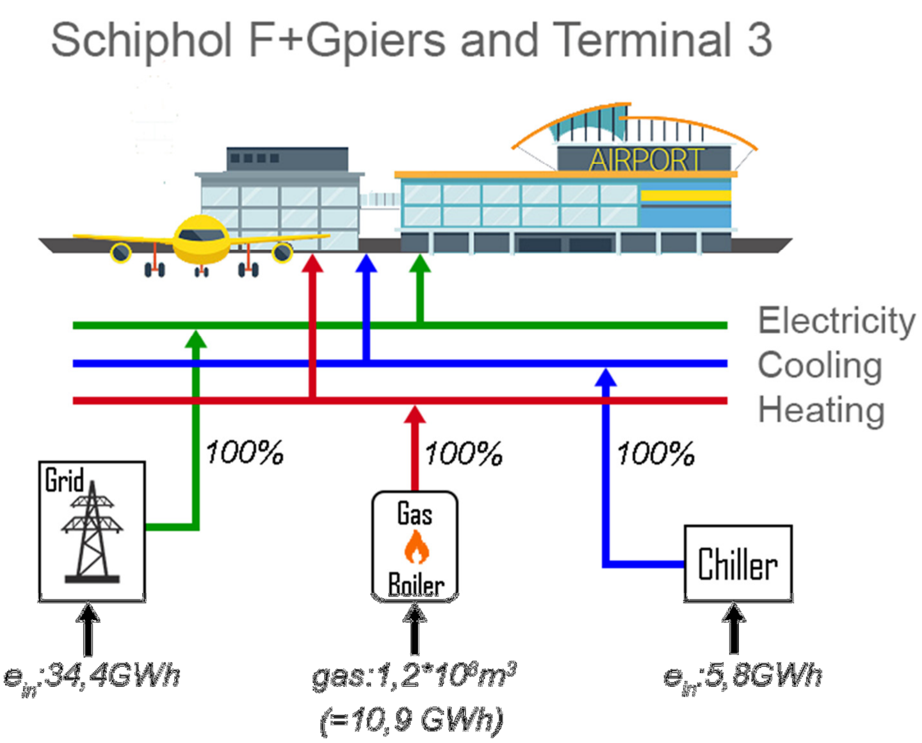


Figure 17 Conventional system illustration

System calculation

To cover the energy demand of this research's scope, more than $1{,}2 \cdot 10^6 m^3$ per year is needed and a total 40.2 GWh of electricity. This comes down to a total of 16.6 kton emissions of CO_2 per year. Input parameters can be found in appendix XII.

Elaboration

Boilers do not offer a sustainable solution because gas is a fossil fuel. For this reason this concept is not future proof. Biogas however is a good alternative for the gas boilers. The CO_2 equivalent of biogas obtained from landfill is for example only 0,398 kg/m^3 which is considerably lower than the 1.887 kg/m^3 which is emitted at the moment.

4.1.2 *Asphalt*

Airports contain big surfaces covered with asphalt. There are different types of asphalt and depending on the airport; each type of asphalt covers another percentage of the total surface. The types of asphalt vary from parking platforms and bridges to aprons and highways. Almost 17 km^2 of Schiphol's surface area is covered with different types of asphalt (appendix XIII). These surfaces are exposed to solar radiation which can be used for energy generation.

System illustration

In this concept the asphalt heats up the water to 30°C and is transferred to a heat pump which heats it up to 55°C. Then a special heat pump is implemented called the 'hydro heat pump' (te Roller, 2015) which can produce steam of 140°C. A turbine converts the steam to electricity. The remaining electricity is provided by the grid. The lower the temperature of the residual flow of the turbine, the higher the efficiency of generating electricity (van Kemenade & Speetjens, 2016). For this calculation the residual flow is therefore too low to be used for other purposes and it is lead back to the asphalt. Therefore cooling and heating occur like the conventional variant.

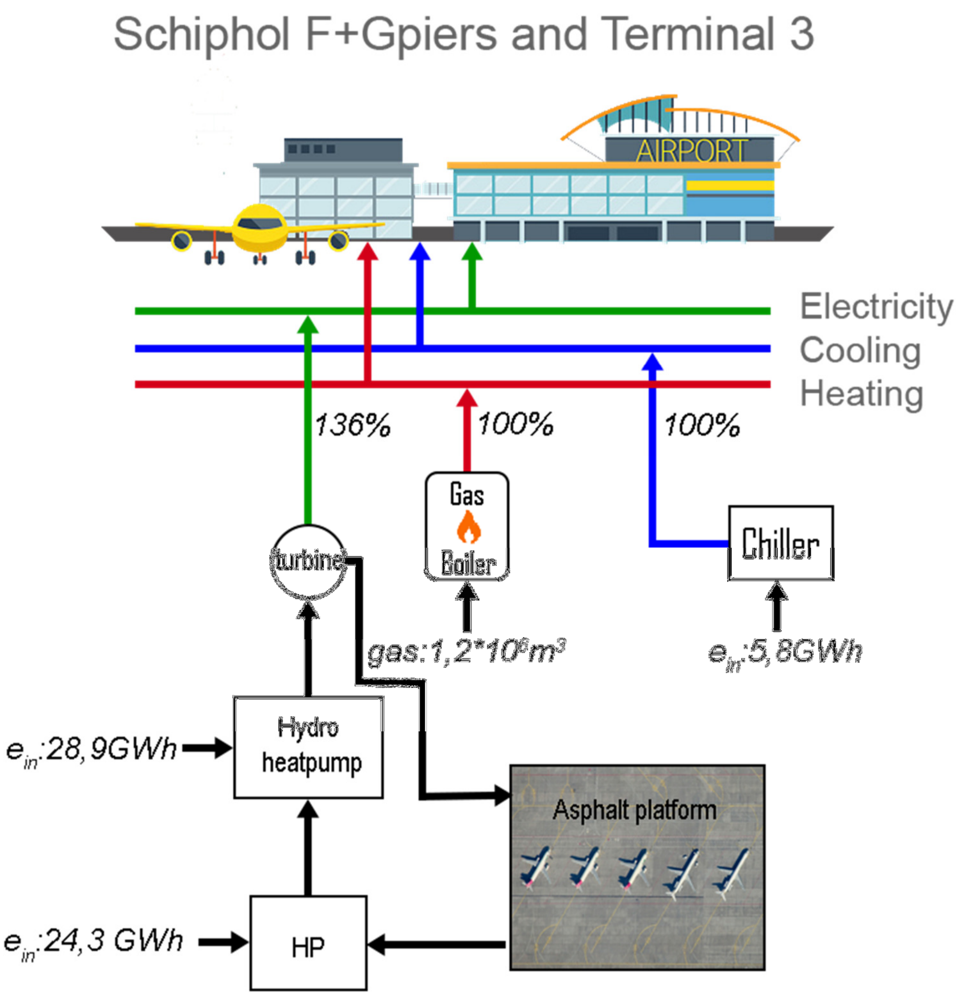


Figure 18 Asphalt system illustration

System calculation

If only the platforms of the aprons are taken into account, to a total thermal energy potential of almost 350 TJ per year can be achieved. For the highest efficiency of the turbine possible, the ΔT of the input and output temperature must be as high as possible. For that reason an outlet temperature of 10°C is lead back to the asphalt so a Carnot efficiency of 0.31 can be achieved. In order to cover the energy demand of the scope including the generation and demand of the heat pumps, a total of 46.8GWh of electricity is needed as well as $1.2*10^6$ m^3 of gas which comes down to a total of 19.0 kton emissions of CO_2 per year (appendix XIV).

Elaboration

The advantage of this system is that the asphalt can being used during winter; the temperature of the platforms can be kept above 0°C to avoid slipperiness. This means that the asphalt will be snow-free the entire year. It can be seen that the electricity produced with a turbine is lower than the energy needed for the production and therefore this is a very inefficient system. This calculation is done by only making use of a small part of the available asphalt (appendix XIII). Since more asphalt is available, this concept can become more attractive by making use of a larger surface area.

4.1.3 *GEOTHERMAL*

The soil under the surface area of Schiphol offers great potential for the application of geothermal energy.

System illustration

One geothermal doublet offers 15.6 GWh of heating supply (according a study done by IF technology for Schiphol airport). This is more than the required 10.9 GWh for this scope. The remaining supply is conversed by an absorption cooling machine to provide a part of the cooling demand. A regular compression cooling machine provides the remaining demand. Since with this concept no electricity is generated, the electrical demand is provided by the grid.

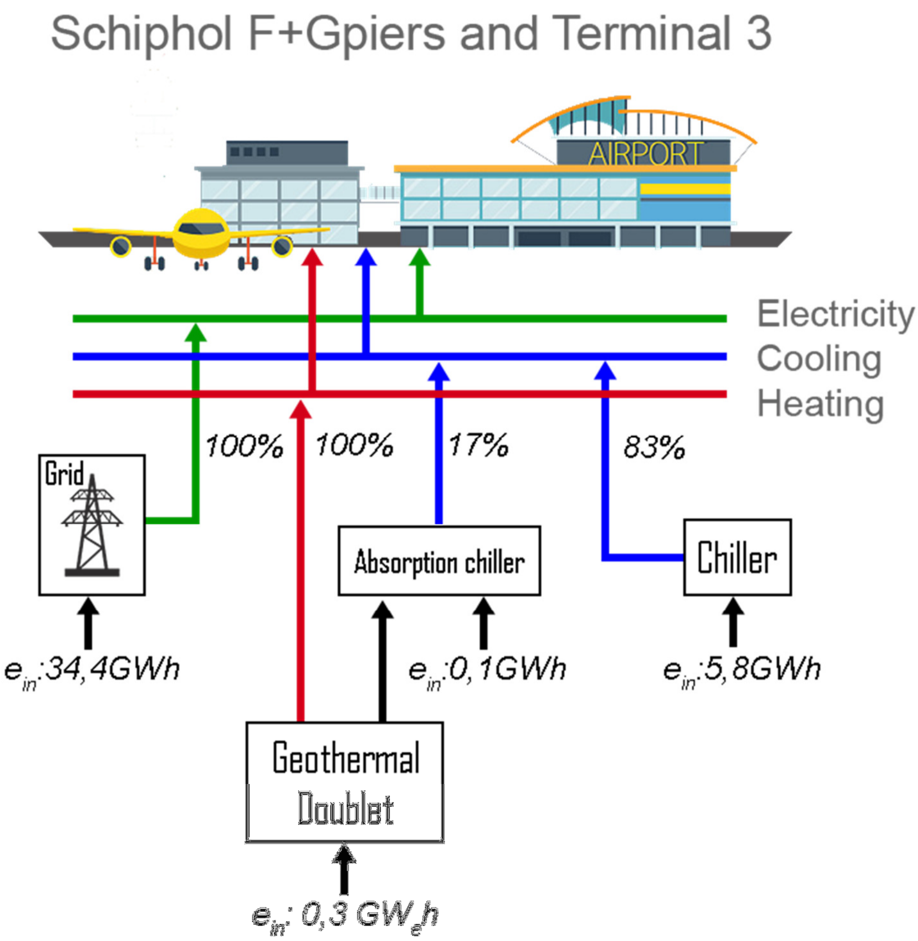


Figure 19 Geothermal system illustration

System calculation

The expected throughput of a geothermal doublet is 100m^3/h. The temperature of the hot source is 85°C. Therefore the absorption chiller has a relatively low COP value. The total CO_2 emissions are solely caused by the electrical demand and come down to 14.0 kton per year (appendix XV).

Elaboration

SDE (Stimulering Duurzame Energieproductie) subsidy makes the application of geothermal energy attractive (RVO, 2016). It looks that this system does not need a lot of input energy. This is due to the fact that instead of the total energy balance per system, only the energy input is shown that contribute to the total emissions of CO_2. The thermal GWh from the geothermal doublet are therefore not implemented in the illustration.

4.1.4 *BIOKEROSENE*

Aircrafts are fuelled with kerosene. Within Schiphol's vision of sustainability, KLM is implementing a strategy since 2009 which includes that 2% of the fuel of aircrafts is biokerosene. Due to safety reasons, the total amount of biokerosene in an aircraft is restricted to 10% to 50%. Dutch government stimulates the use of sustainable biokerosene with the corporate biofuel programme (Rijksoverheid, 2016). The biokerosene is according to step 5 of the 5 step method purchased externally.

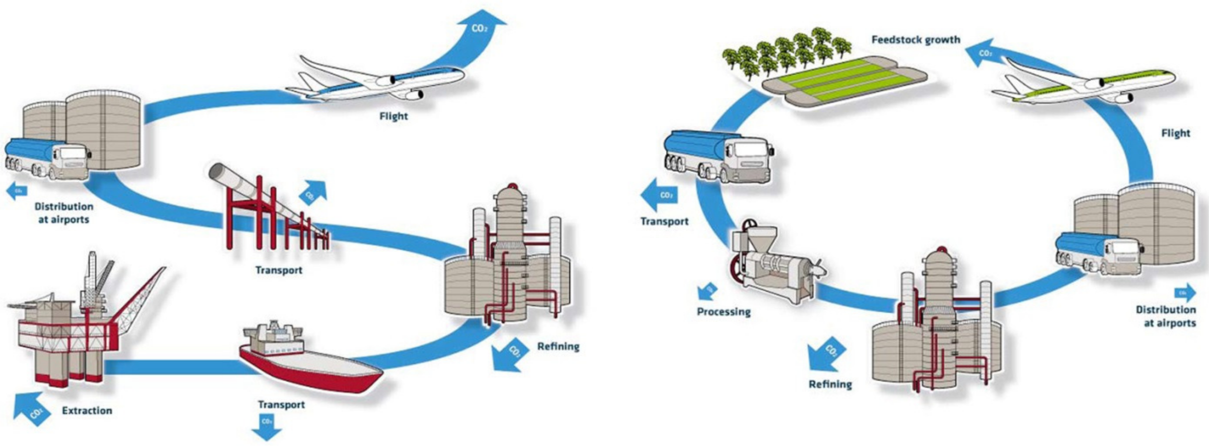


Figure 20 Emissions regular kerosene (left) and biokerosene (right)

Schiphol is already purchasing biokerosene for the airlines and this variant calculates how much extra biokerosene is needed to also fulfil the demand of the buildings and what the corresponding CO_2emissions are. Biokerosene can be produced from a variety of feedstocks, with different carbon footprints so the CO_2 emissions equivalents vary (SkyNRG). Therefore, this calculation is initially done with the CO_2 emission equivalent of regular kerosene.

System illustration

In this concept, use has been made of a heat pump to cover the heating demand. The corresponding cooling load of the thermal energy storage is calculated and covers 47% of the cooling demand. The remaining cooling demand is produced by an absorption chiller which is connected to a combined heat power unit (CHP-unit), fuelled by (bio-)kerosene. 2.2 kton of kerosene is needed to cover this cooling demand. This CHP-unit produces electricity with a generator. The remaining electrical demand is purchased by the energy grid.

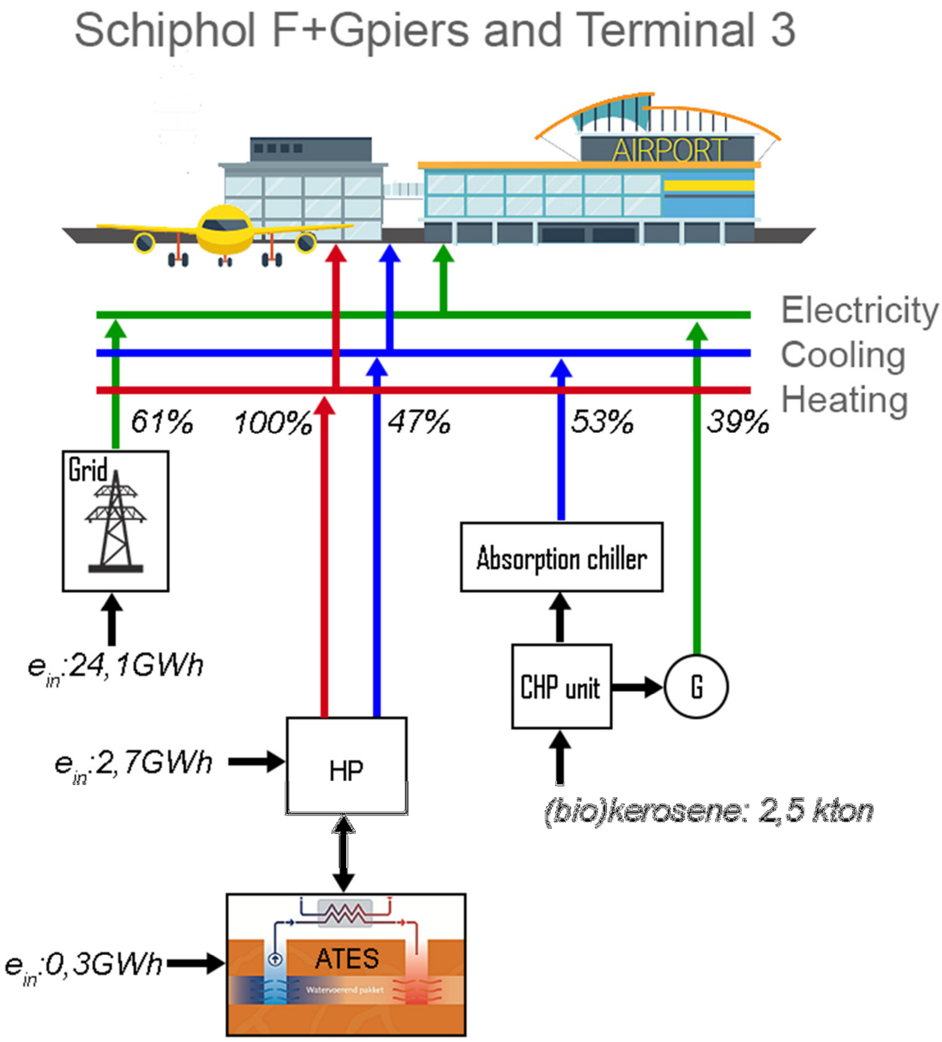


Figure 21 (Bio)kerosene system illustration

System calculation

The CO_2equivalent is not equal to zero, as can be seen in figure 20, due to transport and other factors. Expected is that by 2050, the equivalent of kerosene will be 0.82 kg/kg (Ministerie van infrastructuur en milieu, 2014), (appendix XVI). This calculation is however done with the equivalent of regular kerosene (appendix XVII, 4a) and with the expected future equivalent (appendix XVII, 4b). To cover the energy demand of this research's scope by making use of biokerosene, 2.2 kton is needed per year which results in a total of 10.6 kton CO_2 emissions per year. By making use of regular kerosene, this comes down to a total of 16.4 kton per year.

Elaboration

Next to using biofuel for aircrafts and buildings, it is also possible to utilize biofuels in internal combustion engines which could be used for transportation vehicles on the surface area of the airport, such as luggage transportation vehicles (Connect & Duurzame Logistiek, 2010). When in the future, the CO_2 emission equivalent for biokerosene lowers, it can be applied on a larger scale than only aircrafts and buildings. A benefit of this system is that the supply system of kerosene is already established at Schiphol.

4.1.5 All – Electric PV

Due to the plan of Amsterdam of becoming gas free, focus from the government is lying on an all-electric future. Photovoltaics generate electricity directly from the sun. According to the International Energy Agency (IEA), the global installed capacity of PV grows logarithmical and will reach 1721 GW by the year 2030 (International Energy Agency, 2013). Since Schiphol airport has a large surface area, PV panels could offer a sustainable solution. Airports are large, isolated and shading-free which presents the perfect platform for the use of solar energy (Sergio Ortega Alba, 2016).

System illustration

This concept includes PV-panels on the roofs of terminal 3 and the 2 piers. The generated electricity covers 10% of the total demand and the remaining demand is provided by the grid. Heat and cold is supplied with thermal energy storage and a heat pump. The remaining cooling demand is provided by chillers.

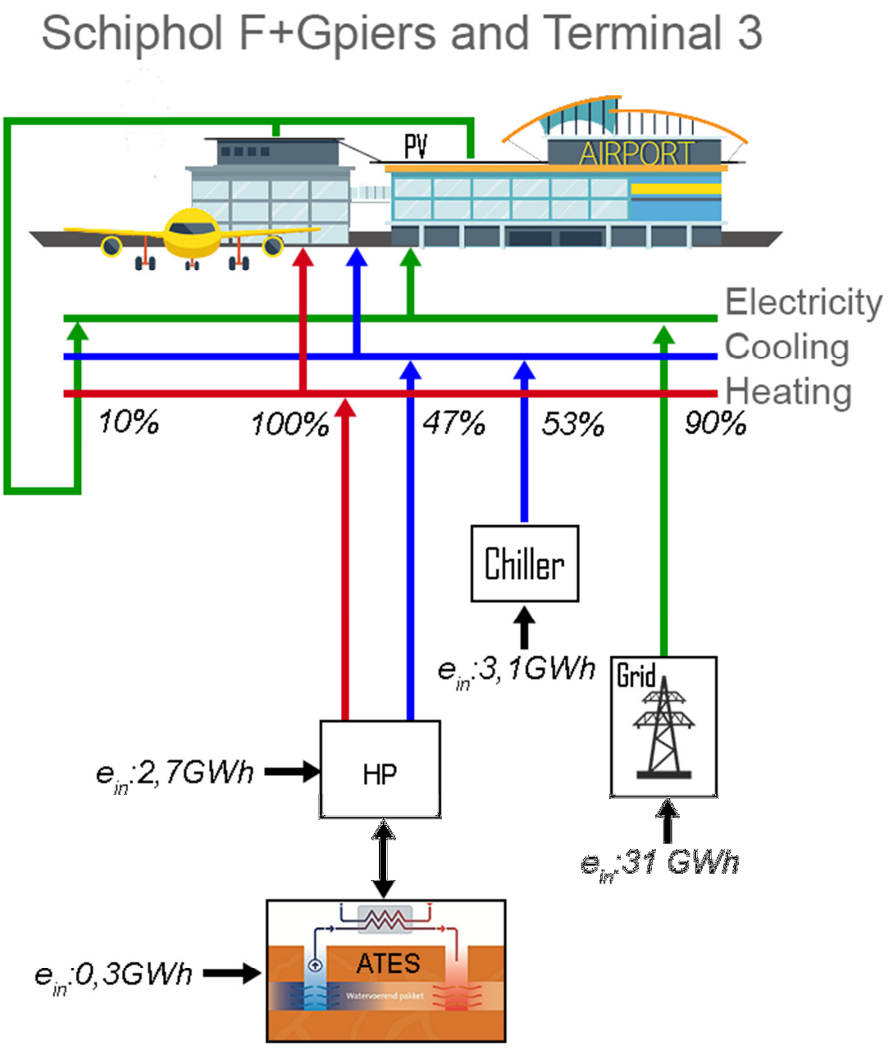


Figure 22 all-electric PV system illustration

System calculation

The roofs of terminal 3 and the F and G piers contain a flat surface area of over 50.000m^2. This produces 3.4 GWh of electricity and only covers a small percentage of the total demand. The calculation can be found in appendix XVIII. This concept comes down to a total electricity demand of 37.1 GWh and therefore a total CO_2emission of 13.2 kton per year.

Elaboration

As for the possible reflections of sunlight from solar panels that may affect the vision of cabin crews or control towers, it is concluded that their effects are less dangerous than other surfaces existing at airports or surrounding areas such as large groups of cars or lakes (Barret, 2014). The potential of this type of renewable energy is big because the emission of the self-produced energy from the solar panels is equal to zero. A large surface area has to be available because only the surface area of the roofs of the scope covers 10% and therefore does not suffice.

However since this research does not only focus on the 'Building level', a look is taken at the bigger picture such as the 'Built environment level'. A study was done on this level to see where PV panels can be placed without interfering with the current processes and stakeholders at Schiphol Airport. Roofs of buildings are considered, as well as grass areas (farmland excluded). If roofs on parking areas are established, these surfaces can also be considered.

In order to give an indication of the possibilities, the potential electrical gains of the PV panels on these surface areas are calculated in appendix XIX. The assumption is made that 135 kWh/m^2 can be achieved with a coverage of the area of 50%.

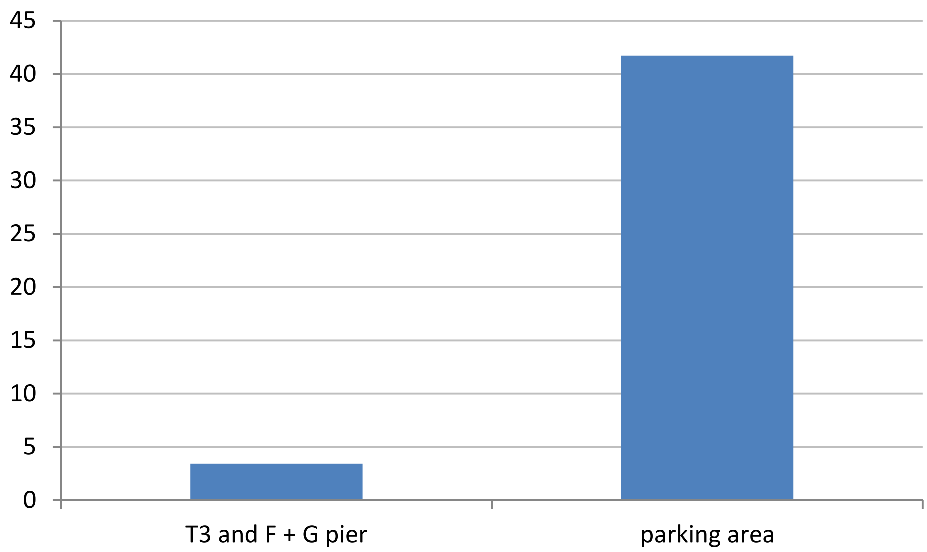


Figure 23 Potential gains PV [GWh]

It can be seen in figure 23 that if for example the parking area is taken into account, 42 GWh can be produced. This is enough to cover the demand of the scope of this research. All buildings together add up to over 100 GWh and if the grass area is partly covered with PV, over 600 GWh is achievable. It can be said that there probably is enough surface area available at Schiphol airport in order to cover the total energy demand of the 'built environment' level.

4.1.6 NATURAL COOLING

All previous mentioned concepts are based on heating or electricity and therefore another point of view is generated which is based on cooling. The natural cooling concept consists of 'free cooling' and 'adiabatic cooling'. The peak load is fulfilled by a conventional chiller.

System illustration

This concept only covers the cooling demand. The heating and cooling demand is calculated based on the conventional variant. Free cooling can take place when cooling is needed inside the terminal and/or pier, while the outdoor temperature is low enough to cool. Adiabatic cooling also depends on the relative humidity, which is linked to the enthalpy value. To make an estimation of the potential of free cooling, a look is taken at the hourly cooling demands in the terminal and pier combined with the hourly enthalpy values. Hence a look is taken at the yearly load duration curve (LDC) which gives insight in the cooling demand for the purpose of processes through the year (Appendix XX). Adiabatic cooling is suitable for comfort cooling and is calculated based on where free cooling reached the maximum capacity.

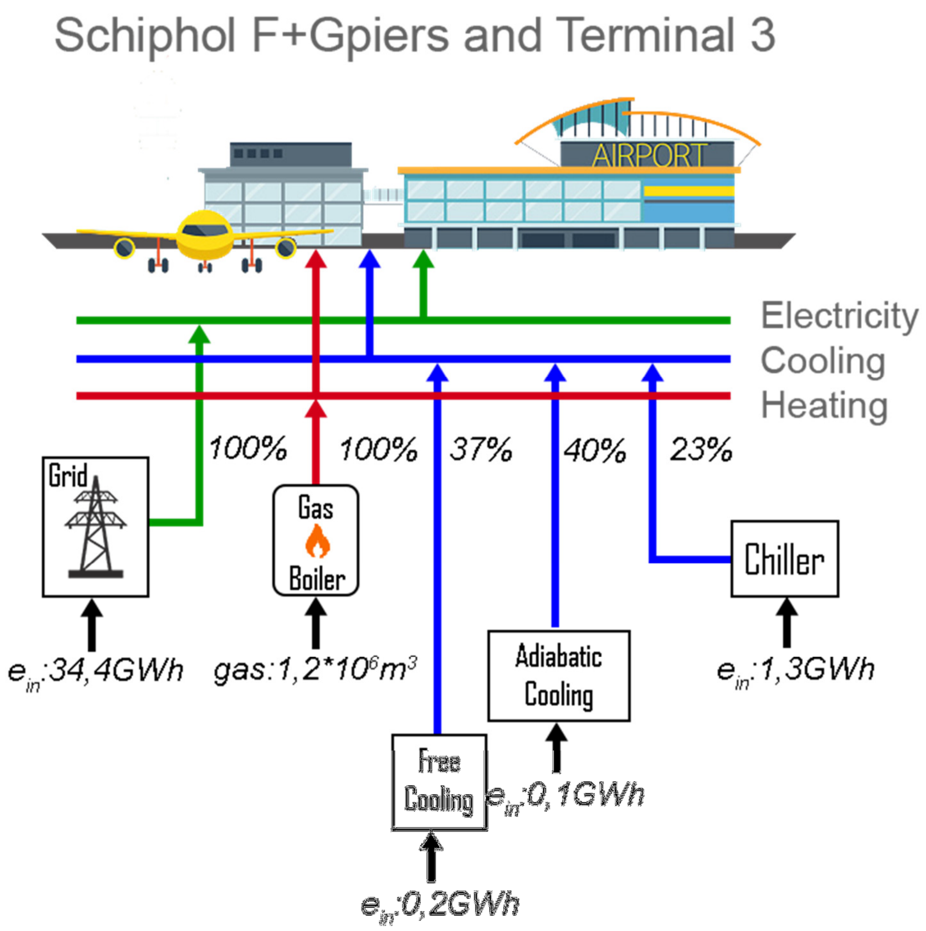


Figure 24 Natural cooling system illustration

System calculation

The maximum inlet temperature is 16.5 °C of which the enthalpy value 44.9kJ/kg is at a relative humidity of 95% (Mollier diagram). This means that adiabatic cooling is applicable when the enthalpy value is 44.9 kJ/kg or lower. Table 2 shows the chosen parameters and the calculated cooling demand for each system, based on the yearly load duration curve (LDC) (Appendix XIII).

Table 2 Cooling demand 'Natural cooling' concept

Cooling system	Cooling type	Boundary condition	Pmax	Demand
			[kW]	[%]
Chiller	Peak		-	23%
Adiabatic	Comfort	Max. enthalpy = 44,9 [kJ/kg]	6000	40%
Free	Processes	Max. outdoor temp = 18 [°C]	1000	37%

This comes down to a total energy demand of 1,6GWh on behalf of the cooling load. Added up with the electricity demand of 34.4 GWh and gas demand of $1,2*10^6$ m^3, the total CO_2 emissions are 15.0 kton per year (appendix XXI).

Elaboration

Despite that free cooling and adiabatic cooling is not always suitable for residential or office buildings in the Netherlands, it offers a good solution for Schiphol airport. This can be seen on the yearly duration curve of Schiphol airport which shows that there is a high amount of constant cooling necessary throughout the entire year. A weakness of making use of this concept is that is not very flexible. Future changes of the building and therefore of the demand requires major adjustments.

4.2 Overview concepts

The CO_2emissions of the concepts created in paragraph 4.1 can be found in figure 25.

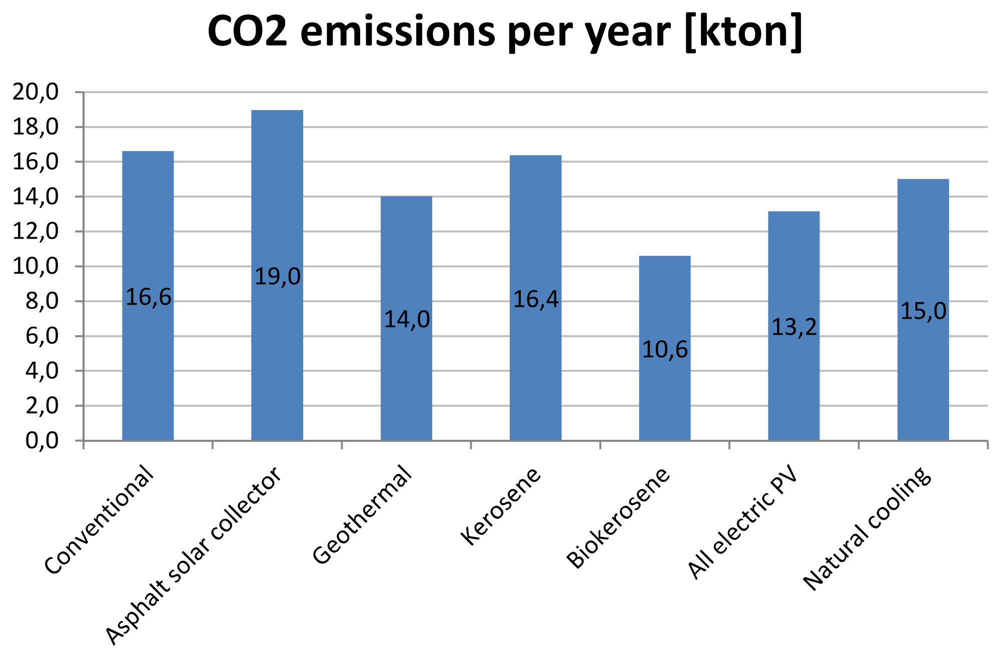


Figure 25 CO2 emissions of all concepts

As was mentioned before, some concepts do not cover all the three demands of heating cooling and electricity. In order to compare complete concepts in that case the conventional system was applied for that demand. This means that a combination of concepts as visualized in figure 25 can lead to a lower total of CO_2 emissions. Next to this, the CO_2 equivalent of electricity is now set for Schiphol airport according to their electricity supplier (0.355 kg/kWh). However, step 5 of the 5 step method tells us that the energy which is externally purchased should be sustainable. There are suppliers available with a lower CO_2 equivalent decreasing to 0 kg/kWh (figure 26), showing that only a small change of changing the supplier changes the hierarchy of the concepts in terms total emissions.

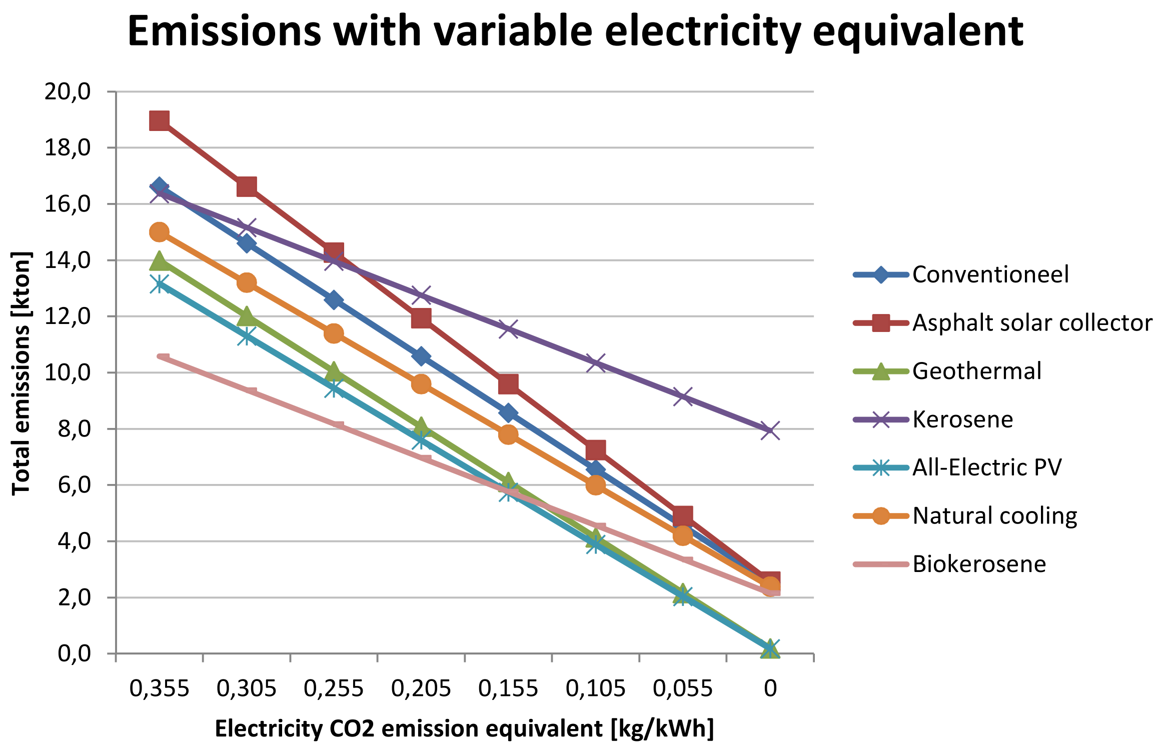


Figure 26 Emissions with decreasing CO_2 emission equivalent

It can be seen in figure 26 that the asphalt solar collector variant has the highest reduction potential, from 19 to 3 kton of CO_2 emissions. The geothermal and the all-electric PV variant offer the possibility to reduce the total emissions to zero. For these reasons, the asphalt variant is combined with the PV variant to be calculated into detail.

4.3 FINAL CONCEPT

The combination of concepts is from now on called asphaltcombination and it has a summer and a winter situation. All calculations are done with daily values. This means that the hourly demand values are combined to daily values and monthly gains of the asphalt are conversed to daily values too. The energetic gains belonging to the asphalt are based upon another research done by TNO. Input parameters of this study can be found in appendix XXII.

4.3.1 SUMMER SITUATION

The summer situation starts with the asphalt platform which, just like the previous concept based on asphalt, heats up water to approximately 30°C. A heat pump heats it up to 60°C and a hydro heatpump (te Roller, 2015), converts it to steam of 140°C. The steam is led to a turbine which generates electricity. The efficiency can be calculated (van Kemenade & Speetjens, 2016) and it depends on the inlet and outlet temperature. The outlet temperature is 90°C which is used for heating and for input for the absorption chiller. The absorption chiller produces cold for the building and the residual flow of 70°C can be used for the building and can go back to the heatpump where it is mixed with the flow of 60°C .

These temperature flows determine the efficiencies of the subsystems. The calculations can be found in appendix XXIII.

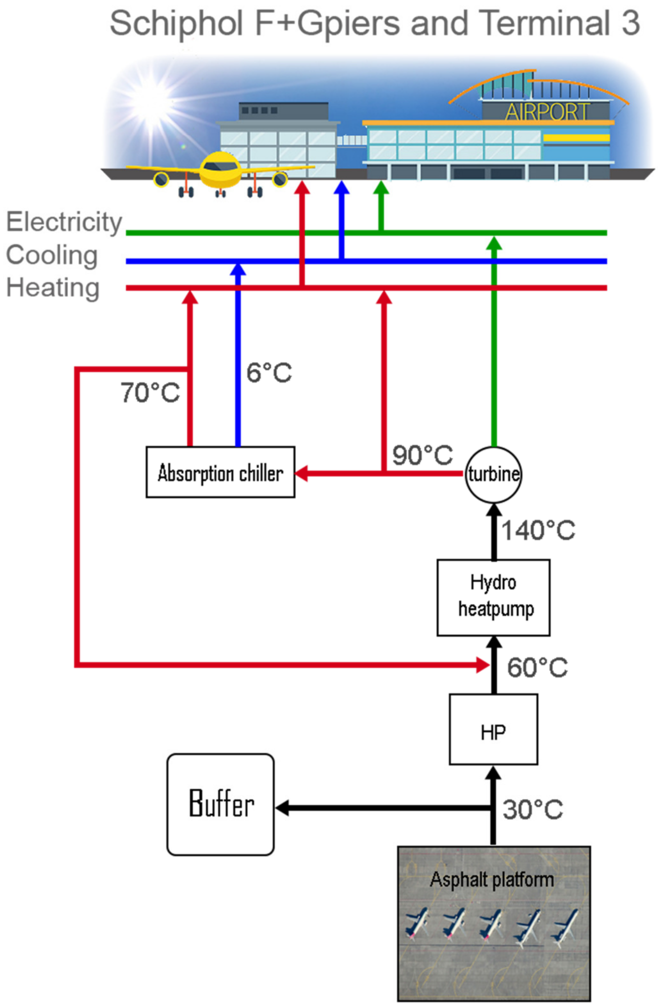


Figure 27 Summer situation asphaltcombination

The summer calculation is made starting from the cooling demand back to the generation of energy from the asphalt. So the amount of surface area of asphalt needed for supplying the building of heating and cooling in summer can be calculated.

4.3.2 WINTER SITUATION

The winter situation cuts the system in two. One part starts from the buffer of 30°C and is conversed by two heat pumps to steam 140°C, which is lead to a turbine that generates electricity and heat of 90°C to cover the heat demand of the building.

The other part is starting from the asphalt that transports cold to the buildings. The residual flow the building of approximately 20°C is lead back to the asphalt which gives the extra benefit of heating up the asphalt.

The winter calculation is made starting from the heating demand back to the energy needed from the buffer. This buffer is loaded during summer so the amount of surface area of asphalt needed for supplying the building of heating and cooling in winter is added up to the area needed for the summer.

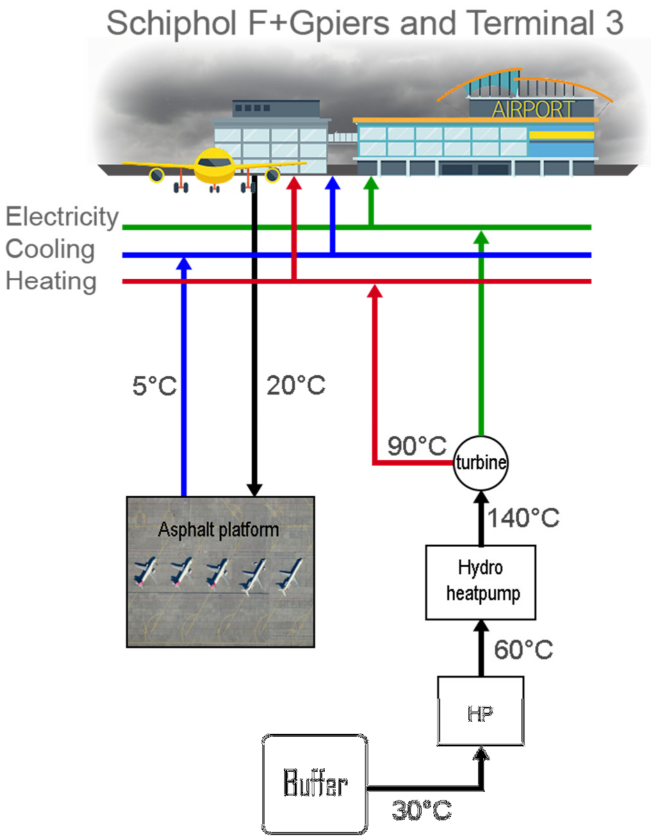


Figure 28 Winter situation asphaltcombination

4.3.3 TOTAL CALCULATION

Based on the cooling demand of 17.5 GWh and a heating demand of 10.9 GWh of the buildings, the energy balance of the asphaltcombionation, leads to an efficiency of 103% (figure 29).

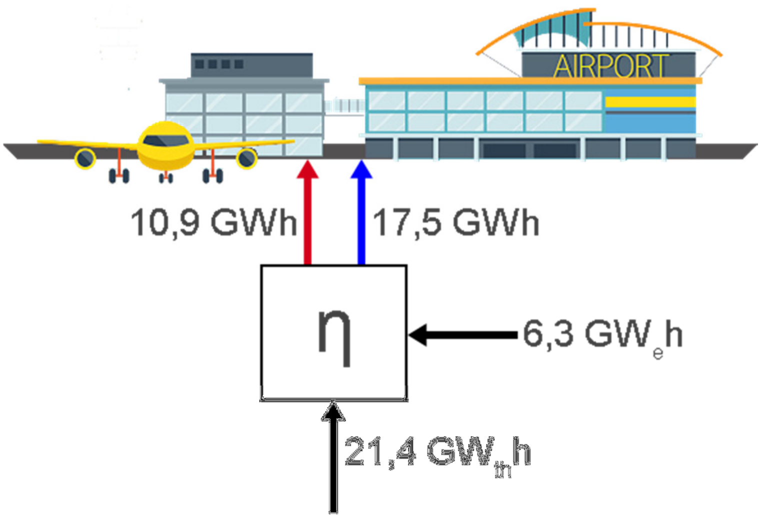


Figure 29 Total efficiency η of the system of 103%.

The thermal energy is produced by the sun as a renewable source and does not have a CO_2 equivalent. This demand can be fulfilled by applying the solar asphalt system to 105,950 m^2 of asphalt. The electrical energy which is needed for the system, next to the energy which is needed as a demand for terminal 3, the piers and the aircrafts, can be produced by PV panels. The total electrical demand was 34.4 GWh + 6.3 GWh = 40.7 GWh.

With the assumption which was made earlier in chapter 3.1.5 that 135 kWh/m^2 can be achieved and a coverage of 50% is established, the demand of 40.7 GWh can be fulfilled by covering 602,407 m^2 with PV panels. This means that the surface area of the parking area at Schiphol which was calculated before (appendix XIX) suffices.

5. CONCLUSION

Can integral design support the generation of different energy scenarios, based on the 5 step energy approach, to make Schiphol airport CO_2 neutral?

The answer on the main question is that indeed the 5 step method in combination with a hierarchical functional abstraction levels approach supports generation of different energy scenarios. The 5-step method is focused on bringing the demand down and producing renewable energy or purchasing renewable energy. The functional abstraction level approach looks at different levels which creates an overview and helps with giving structure to a complex problem such as an airport. Since renewable electricity is available with a CO_2 equivalent of 0, the goal of becoming CO_2 neutral can be achieved by eliminating energy carriers that have a higher equivalent than zero, such as fossil fuels.

FROM CURRENT SCOPE TO SCHIPHOL IN TOTAL

The model that serves as a solution is based on the demand of only this scope. Terminal 3 and the F and G piers with the aircrafts are now calculated, which accounted for almost 63 GWh (with 28.4 GWh of heating and cooling). Schiphol has two other terminals and 5 more piers, not to forget all other energy consumers in the area. Expected was for 2020 for entire Schiphol that the total demand grows to 557 GWh annually, of which the heating and cooling demand stand for 230 GWh (Appendix I). In order to hypothetically draw a conclusion when the concept model of this research would be applied for this total demand, 51GWh of electricity is necessary to cover this (figure 30).

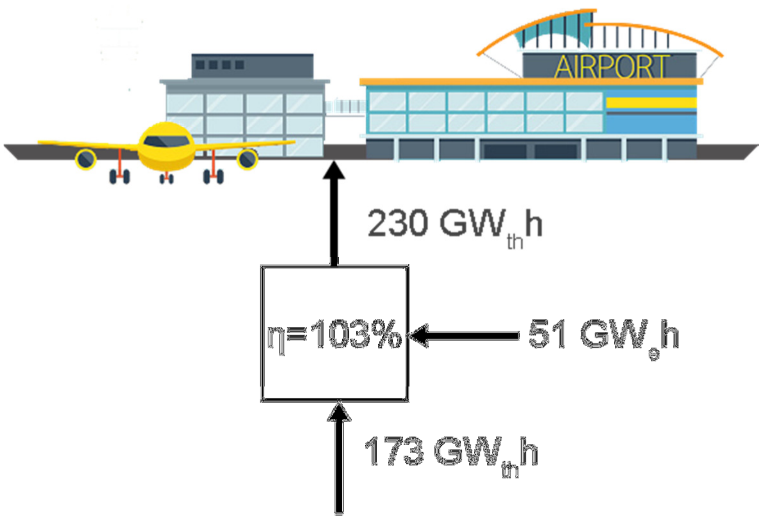


Figure 30 Applying concept to total estimated demand of entire Schiphol in 2020

This 51 GWh is added up to the expected electrical demand of 330 GWh, which comes down to a total electrical demand of 381 GWh. However, losses play a much bigger role on such a scale and the power ability of the systems should be taken into account and therefore this calculation is only an indication. This thermal energy supply of 173 $GW_{th}h$ can be achieved by 640,000 m^2 of asphalt. 381 GW_eh can hypothetically be produced by covering a surface of 5,6 km^2 with PV panels.

6. DISCUSSION

METHODOLOGY

What is missing in order to complete the generation of different energy scenarios is a step that focuses on the buffering and conversion of energy. The hierarchical functional abstraction approach divides the large scope in smaller parts, but different climate situations require different solutions. Next to this, an important factor of reducing the energy consumption is not only to reduce the demand, but also to reduce the energy losses by making use of an efficient design. When looking at a large scope such as an airport, those losses apply for a non-negligible part of the total consumption.

Making use of the hierarchical functional abstraction levels combined with a morphological chart is a good start with taking buffering and conversion into account. If only use is made of the abstraction levels with a morphological chart, focus lies mainly on the use of renewable energy sources and the exchange of energy. So for this reason the 5-step method complements the morphological chart. This research was conducted by keeping CO_2 reduction in mind while applying the methods. Nonetheless other aspects can be considered which are important for decision making. A Kesselring analysis can help with taking the functional and realizable aspects into account. Input parameters such as costs, flexibility or stakeholder involvement can also play an important role.

CONCEPT SOLUTION

Reduction of steps 1 and 2 are not taken into account in the final combination, which means that the total demand still has potential for reduction. However, the demand will never be reduced to zero by reducing the CO_2 emissions to zero, the generation part always is involved. However, regardless of the demand, as long as the equivalent of the renewable energy sources is zero, the goal of becoming CO_2 neutral can always be achieved.

The final asphaltcombination solution is calculated with moderate values which were determined in 2003 (0,4 kWh/m2/year). Appendix XXII shows that more recent studies (SOLINTEL, 2014) already achieved higher amounts of energy per square meter which lead up to 1,4 kWh/m2/year. This value is dependent of a lot of parameters such as solar radiation and pipe depth and it is not known which parameters would be suitable for in this case Schiphol, which is the reason that the calculations are done with a relatively low yield value.

7. RECOMMENDATIONS

RETURN OF INVESTMENT

Using an integral design method with a function based approach can generate different energy scenarios in order to make Schiphol airport energy neutral. However in order to compare the concepts, a business case is necessary. Extra benefits can be taken into account because, in the end, Schiphol is a company which is focused on making profits. For example the possibility of keeping the platforms snow free the entire year, which leads to less delays due to the weather which is beneficial for Schiphol. Another example is investigating how the asphalt system influences the lifespan of the asphalt. Cooling and heating of asphalt prevents rut formation and cracks which leads to less maintenance.

EXTRA BENEFITS OF BUFFER

It can be calculated what the benefits are of applying a bigger surface with the asphalt collector than what is needed for the annual demand. Almost 17 km^2 of asphalt is available as can be seen in appendix XIII. This leads to generation of more heat in summer which is stored to the buffer and more cold in winter. It can be researched which purpose this extra heat and cold can fulfil.

REQUIREMENTS ASPHALT

Now, calculations are made for a year based on a summer and a winter variant, where in winter the mean of the energy potential of the asphalt of 0,05 GJ/m^2 is taken and in summer the mean of 0,10 GJ/m^2. These values are linked to certain input parameters of the asphalt system and calculated by TNO in 1999. The potential energy values vary as can be seen in appendix XXIII. These values depend on different input parameters. A detailed study of the asphalt characteristics and requirements can determine which parameters are suitable.

HOURLY MODEL

Now, use is made of a daily model. The hourly demand was available but there was only a monthly potential energy gain of the asphalt known. It should be researched if there is a potential of making use of day and night variants, where during the day the radiation of the sun is used for heating up the water and during the night, for cooling the buildings. This however requires hourly asphalt values.

SURFACE AREA AND DISTRIBUTION LOSSES

In the final concept the assumption is made that parts of the surface area of airports can be used for PV and asphalt collectors. It should be research what the requirements are for for example satefty at airports. Furthermore, if for such reasons it is preferable to cover areas with these systems which are located on the other side of the airport than where the demand or storage is required, distribution losses and buffering problems should be considered as well.

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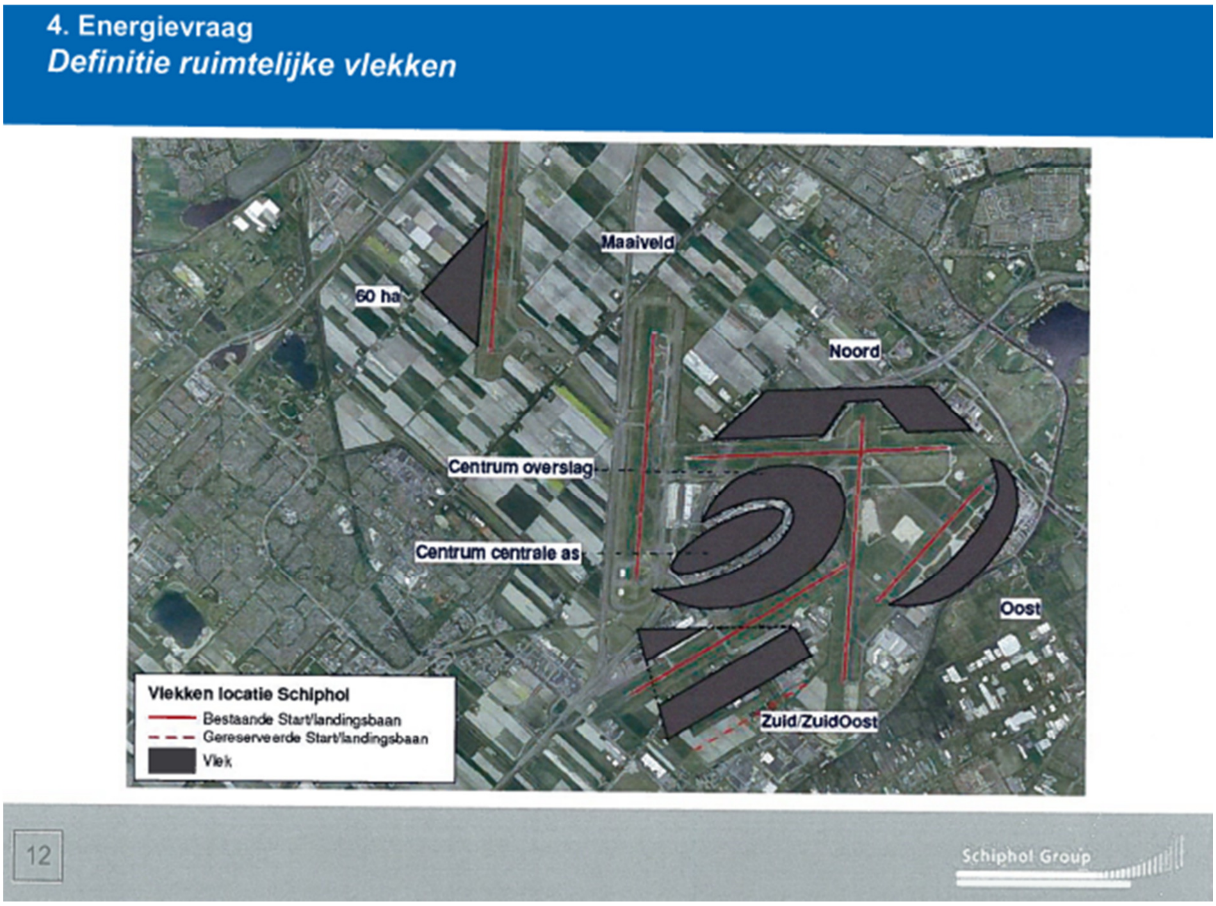
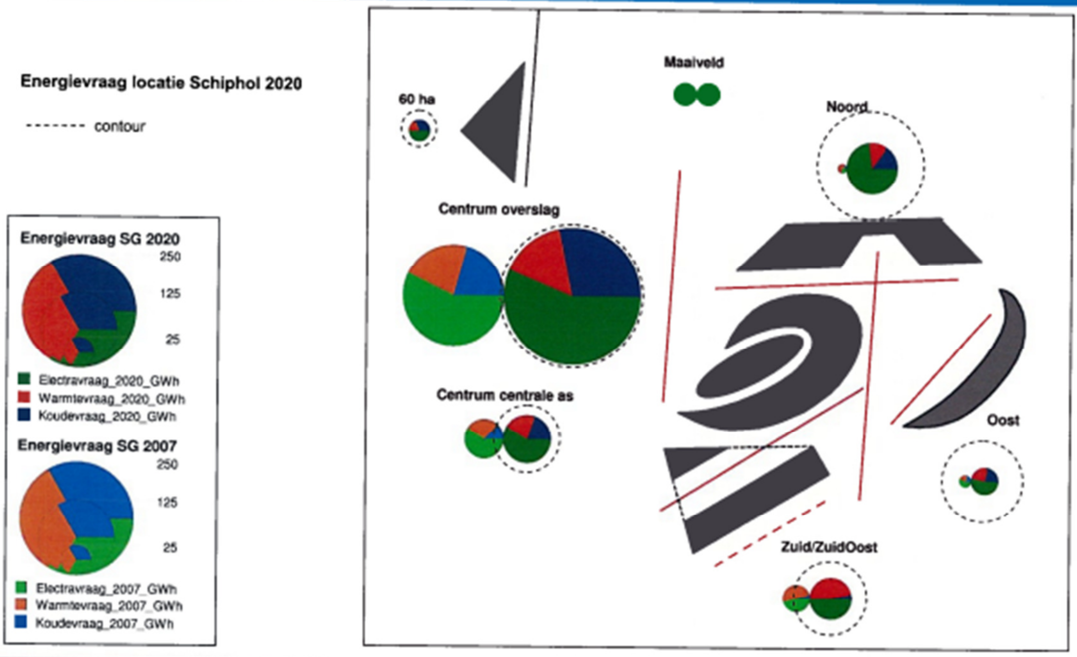
9. APPENDICES

APPENDIX I: EXPECTED ENERGY DEMAND SCHIPHOL GROUP (SCHIPHOLGROUP, 2008)



4. Energievraag
Ontwikkeling energievraag Schiphol Group naar 2020 (1)



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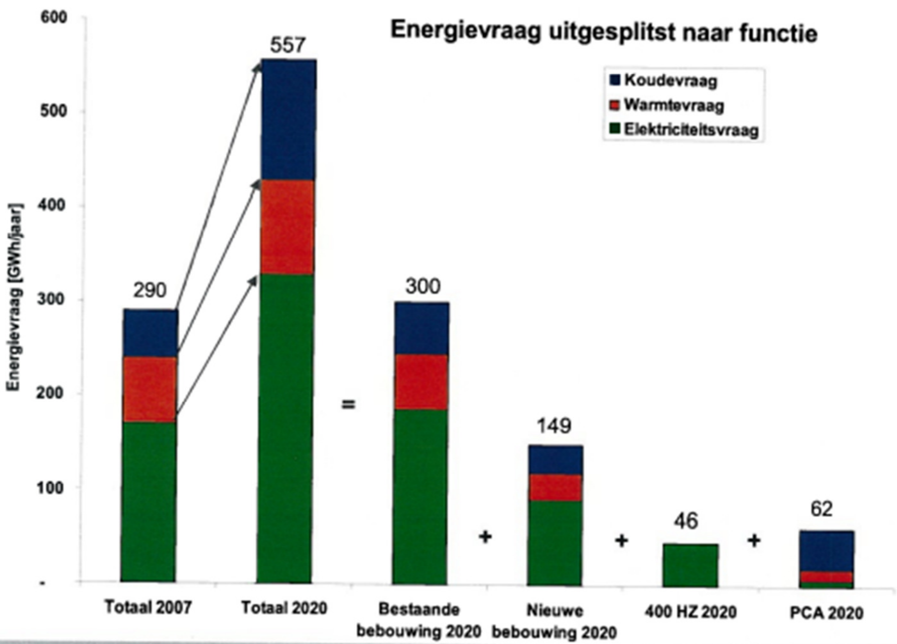
4. Energievraag
Ontwikkeling energievraag Schiphol Group naar 2020 (2)



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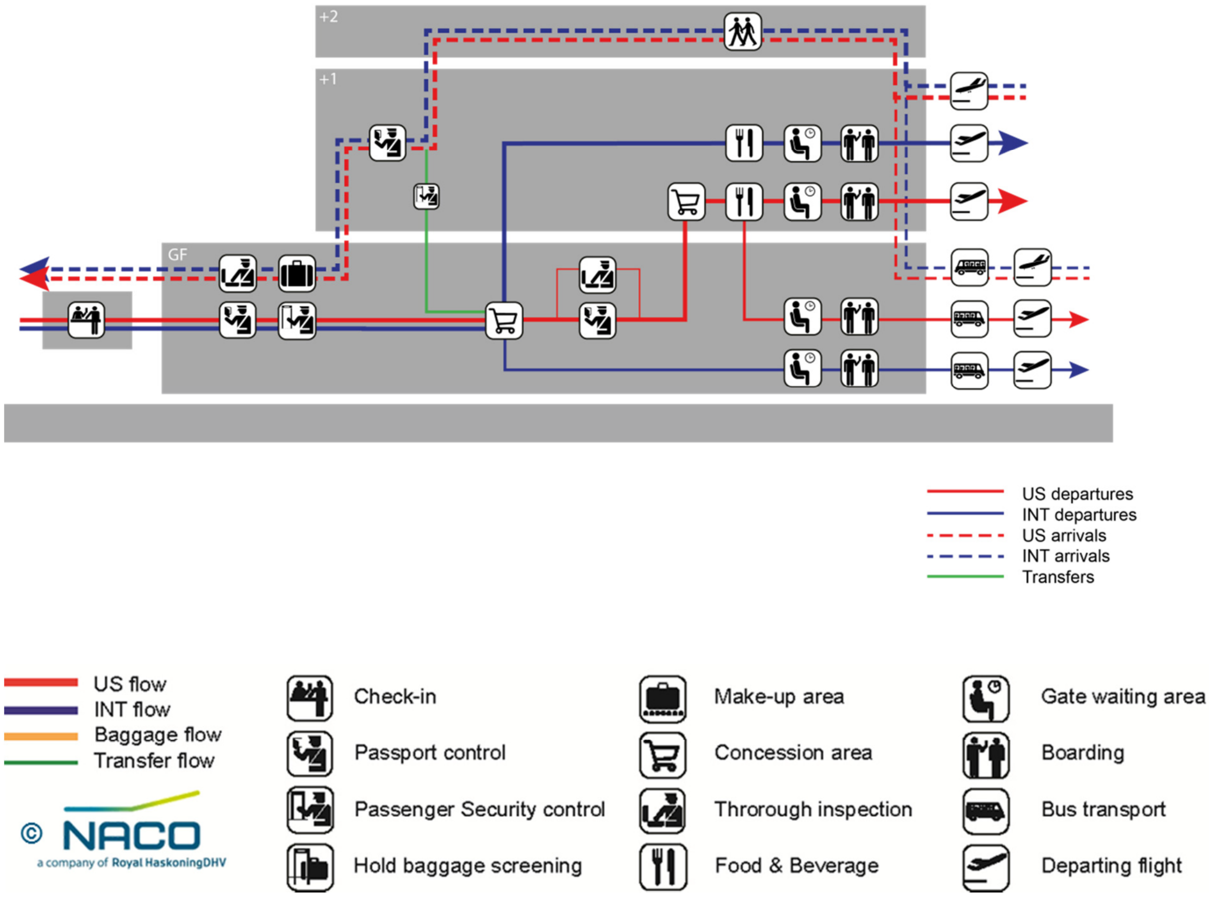
APPENDIX II: USER FLOW IN SCOPE

The user flow in figure 2 is meant as an illustration of energy that enters from outside and circulates through the terminal and the piers, before leaving the scope again. The users consist of employees and passengers who do not follow the path in one specific order as figure 2 implies. The passenger flow in reality occurs in general according to the passenger scheme below:



Terminal arrival passenger and cargo flow from curb to aircraft (example)

Every airport is different and some processes can be avoided in some airports but the order of processes is quite generic. The exit and entrance of a terminal serves as the connection between the terminal and external connections such as the railway station, bus station and car parking. The gate serves as the connection between landside and airside.

Appendix III Input paramters building model

		Surface area facades							Surface area		Glass percentage			Window frame percentage		
		(N)	(NE)	(E)	(SE)	(S)	(SW)	(W)	roof	floor	facade	roof	floor	facade	roof	floor
		m²	m²	m²	m²	m²	m²	m²	m²	m²	%	%	%	%	%	%
F	Circulation_F	1147	525	1976	576	1108	446	2006	9328	412	95	0	0	15	0	0
	Technical_F	258	0	109	0	0	0	129	1033	0	0	0	0	0	0	0
	Office_F	0	184	429	184	0	184	335	670	3744	50	0	0	15	0	0
G	Circulation_G	2419	0	2692	0	2292	0	2692	14736	1265	95	0	0	15	0	0
	Technical_G	0	0	111	0	110	0	238	1126	1214	0	0	0	0	0	0
	Office_G	0	0	648	0	18	0	515	0	4802	50	0	0	15	0	0
T3	Circulation_T3	631	0	1714	0	0	0	415	16682	9620	95	0	0	15	0	0
	Commercial_T3	1344	0	206	0	863	0	728	0	0	95	0	0	15	0	0
	Office_T3	3255	0	179	0	3255	0	179	1963	614	50	0	0	15	0	0
	Technical_T3	1717	0	279	0	1717	0	279	981	10005	0	0	0	0	0	0
	Baggagereclaim_T3	0	0	0	0	0	149	0	0	0	50	0	0	15	0	0
	Check-in_T3	0	0	0	0	0	0	275	0	0	50	0	0	15	0	0
	Security_T3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

				RC value						Infiltration			
		GFA	floor height	facade	(basement) floor	roof	U-value glass	ZTA_glass	T_soil	D (dragcoefficient)	C (luchtdichtheidscoefficient)	n (stromingsexponent)	facade factor (verdeling over gevel)
		m²	m	m².K/W	m².K/W	m².K/W	W/m².K	-	°C	-	$dm^3/s.Pa^n.m^2$	-	-
F	Circulation_F	13935	4	2,5	2,5	2,5	2,5	0,75	12	1,05	0,5	0,66	2,5
	Technical_F	2441	4	2,5	2,5	2,5	2,5	0,75	12	1,05	0,5	0,66	2,5
	Office_F	4414	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5
G	Circulation_G	19225	4	2,5	2,5	2,5	1,5	0,4	12	1,05	0,5	0,66	2,5
	Technical_G	2340	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5
	Office_G	4802	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5
T3	Circulation_T3	16446	4	2,5	2,5	2,5	2,5	0,75	12	1,05	0,5	0,66	2,5
	Commercial_T3	24519	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5
	Office_T3	11079	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5
	Technical_T3	34341	4	2,5	2,5	2,5	2,5	0,7	12	1,05	1	0,66	2,5
	Baggagereclaim_T3	7201	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5
	Check-in_T3	7125	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5
	Security_T3	9205	4	2,5	2,5	2,5	2,5	0,7	12	1,05	0,5	0,66	2,5

						Temperature					Air supply temperature								
		Metabolism person	max. occupancy	Lighting	Equipment	heating (lower than)	cooling (higher than)	night	recirculation	Ventilation	day	night	T_retour	RV_retour	Supply pressure	Outlet pressure	η fan	WTW η th	WTW η v.
		W/pers	n/m²	W/m²	W/m²	°C	°C	°C	%	m³/h.m²	°C	°C	°C	%	Pa	Pa	%	%	%
F	Circulation_F	160	0,15	8,5	14	20	24	19	0	5	15,5	15,5	21	50	1200	800	80	50	0
	Technical_F	110	0	6	50	12	30	12	0	4	15,5	15,5	21	50	1200	800	80	50	0
	Office_F	110	0,05	8	10	21	24	18	0	10	15,5	15,5	21	50	1200	800	80	50	0
G	Circulation_G	160	0,15	8,5	14	20	24	18	0	5	15,5	15,5	21	50	1200	800	80	50	0
	Technical_G	110	0	6	50	12	30	12	0	4	15,5	15,5	21	50	1200	800	80	50	0
	Office_G	110	0,05	8	10	21	24	19	0	10	15,5	15,5	21	50	1200	800	80	50	0
T3	Circulation_T3	160	0,2	9	8	20	24	19	0	15	15,5	15,5	21	50	1200	800	80	50	0
	Commercial_T3	160	0,035	15	8	20	24	29	0	12	15,5	15,5	21	50	1200	800	80	50	0
	Office_T3	110	0,05	8	10	21	24	20	0	10	15,5	15,5	21	50	1200	800	80	50	0
	Technical_T3	200	0,01	0	50	19	25	18	0	10	15,5	15,5	21	50	1200	800	80	50	0
	Baggagereclaim_T3	200	0,2	8	10	21	24	19	0	10	15,5	15,5	21	50	1200	800	80	50	0
	Check-in_T3	160	0,3	8	25	21	24	20	0	12	15,5	15,5	21	50	1200	800	80	50	0
	Security_T3	180	0,05	8	10	21	24	19	0	12	15,5	15,5	21	50	1200	800	80	50	0

		Air Handling Unit															
				Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
		day	night	from	to	from	to	from	to	from	to	from	to	from	to	from	to
		%	%	h	h	h	h	h	h	h	h	h	h	h	h	h	h
F	Circulation_F	100	50	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Technical_F	100	100	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Office_F	100	100	7	18	7	18	7	18	7	18	7	18	6	7	6	7
G	Circulation_G	100	50	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Technical_G	100	100	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Office_G	100	100	7	18	7	18	7	18	7	18	7	18	6	7	6	7
T3	Circulation_T3	100	50	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Commercial_T3	100	100	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Office_T3	100	100	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Technical_T3	100	50	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Baggagereclaim_T3	100	50	6	23	6	23	6	23	6	23	6	23	6	23	6	23
	Check-in_T3	100	50	6	21	6	21	6	21	6	21	6	21	6	21	6	21
	Security_T3	100	50	6	23	6	23	6	23	6	23	6	23	6	23	6	23

F-PIER (LIGHTING, EQUIPMENT, USER OCCUPANCY)

Circulation

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Dinsdag	3	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Woensdag	4	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Donderdag	5	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Vrijdag	6	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zaterdag	7	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zondag	1	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Dinsdag	3	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Woensdag	4	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Donderdag	5	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Vrijdag	6	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Zaterdag	7	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Zondag	1	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	1	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Dinsdag	3	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Woensdag	4	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Donderdag	5	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Vrijdag	6	0	0	0	0	0	0	1	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Zaterdag	7	0	0	0	0	0	0	0	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	0	0
Zondag	1	0	0	0	0	0	0	0	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	0	0

Technical

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Dinsdag	3	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Woensdag	4	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Donderdag	5	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Vrijdag	6	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zaterdag	7	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zondag	1	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Dinsdag	3	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Woensdag	4	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Donderdag	5	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Vrijdag	6	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Zaterdag	7	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Zondag	1	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Offices

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Dinsdag	3	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Woensdag	4	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Donderdag	5	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Vrijdag	6	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zaterdag	7	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zondag	1	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Dinsdag	3	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Woensdag	4	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Donderdag	5	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Vrijdag	6	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Zaterdag	7	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Zondag	1	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0

G-PIER (LIGHTING, EQUIPMENT, USER OCCUPANCY)

Circulation

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Dinsdag	3	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Woensdag	4	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Donderdag	5	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Vrijdag	6	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zaterdag	7	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zondag	1	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Dinsdag	3	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Woensdag	4	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Donderdag	5	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Vrijdag	6	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Zaterdag	7	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Zondag	1	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	1	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Dinsdag	3	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Woensdag	4	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Donderdag	5	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Vrijdag	6	0	0	0	0	0	0	1	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Zaterdag	7	0	0	0	0	0	0	0	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	0	0
Zondag	1	0	0	0	0	0	0	0	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	0	0

Technical

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Dinsdag	3	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Woensdag	4	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Donderdag	5	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Vrijdag	6	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zaterdag	7	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zondag	1	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Dinsdag	3	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Woensdag	4	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Donderdag	5	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Vrijdag	6	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Zaterdag	7	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50
Zondag	1	50	50	50	50	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	50	50

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Offices

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Dinsdag	3	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Woensdag	4	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Donderdag	5	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Vrijdag	6	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zaterdag	7	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zondag	1	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Dinsdag	3	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Woensdag	4	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Donderdag	5	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Vrijdag	6	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Zaterdag	7	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Zondag	1	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0

TERMINAL 3 (LIGHTING, EQUIPMENT, USER OCCUPANCY)

Circulation

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Dinsdag	3	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Woensdag	4	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Donderdag	5	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Vrijdag	6	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zaterdag	7	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zondag	1	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Dinsdag	3	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Woensdag	4	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Donderdag	5	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Vrijdag	6	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Zaterdag	7	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20
Zondag	1	20	20	20	20	20	20	20	65	95	95	95	95	95	95	95	95	95	95	65	40	40	40	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	1	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Dinsdag	3	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Woensdag	4	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Donderdag	5	0	0	0	0	0	0	2	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Vrijdag	6	0	0	0	0	0	0	1	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	1	0
Zaterdag	7	0	0	0	0	0	0	0	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	0	0
Zondag	1	0	0	0	0	0	0	0	20	60	80	80	70	50	70	70	40	70	40	30	30	20	20	0	0

Commercial

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Dinsdag	3	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Woensdag	4	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Donderdag	5	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Vrijdag	6	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zaterdag	7	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60
Zondag	1	60	60	60	60	60	60	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	60	60

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	50	50	50	50	50	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	50
Dinsdag	3	50	50	50	50	50	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	50
Woensdag	4	50	50	50	50	50	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	50
Donderdag	5	50	50	50	50	50	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	50
Vrijdag	6	50	50	50	50	50	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	50
Zaterdag	7	50	50	50	50	50	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	50
Zondag	1	50	50	50	50	50	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	50	50

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Offices

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	40	40	40	40	40	40	95	95	95	95	95	95	95	95	95	95	95	95	95	95	40	40	40	40
Dinsdag	3	40	40	40	40	40	40	95	95	95	95	95	95	95	95	95	95	95	95	95	95	40	40	40	40
Woensdag	4	40	40	40	40	40	40	95	95	95	95	95	95	95	95	95	95	95	95	95	95	40	40	40	40
Donderdag	5	40	40	40	40	40	40	95	95	95	95	95	95	95	95	95	95	95	95	95	95	40	40	40	40
Vrijdag	6	40	40	40	40	40	40	95	95	95	95	95	95	95	95	95	95	95	95	95	95	40	40	40	40
Zaterdag	7	40	40	40	40	40	40	50	50	50	50	50	50	50	50	50	50	50	50	50	50	40	40	40	40
Zondag	1	40	40	40	40	40	40	50	50	50	50	50	50	50	50	50	50	50	50	50	50	40	40	40	40

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Dinsdag	3	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Woensdag	4	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Donderdag	5	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Vrijdag	6	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Zaterdag	7	20	20	20	20	20	20	30	40	50	50	50	50	40	50	50	50	40	20	20	20	20	20	20	20
Zondag	1	20	20	20	20	20	20	30	40	50	50	50	50	40	50	50	50	40	20	20	20	20	20	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	30	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	30	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0

Technical/BASS

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Dinsdag	3	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Woensdag	4	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Donderdag	5	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Vrijdag	6	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zaterdag	7	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zondag	1	30	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20
Dinsdag	3	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20
Woensdag	4	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20
Donderdag	5	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20
Vrijdag	6	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20
Zaterdag	7	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20
Zondag	1	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Baggage reclaim

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Dinsdag	3	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Woensdag	4	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Donderdag	5	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Vrijdag	6	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zaterdag	7	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30
Zondag	1	30	30	30	30	30	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	30	30

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	60	60	80	80	80	80	80	80	80	80	80	80	80	80	80	60	20	20
Dinsdag	3	20	20	20	20	20	20	60	60	80	80	80	80	80	80	80	80	80	80	80	80	80	60	20	20
Woensdag	4	20	20	20	20	20	20	60	60	80	80	80	80	80	80	80	80	80	80	80	80	80	60	20	20
Donderdag	5	20	20	20	20	20	20	60	60	80	80	80	80	80	80	80	80	80	80	80	80	80	60	20	20
Vrijdag	6	20	20	20	20	20	20	60	60	80	80	80	80	80	80	80	80	80	80	80	80	80	60	20	20
Zaterdag	7	20	20	20	20	20	20	60	60	80	80	80	80	80	80	80	80	80	80	80	80	80	60	20	20
Zondag	1	20	20	20	20	20	20	60	60	80	80	80	80	80	80	80	80	80	80	80	80	80	60	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	30	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0
Dinsdag	3	0	0	0	0	0	0	30	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0
Woensdag	4	0	0	0	0	0	0	30	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0
Donderdag	5	0	0	0	0	0	0	30	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0
Vrijdag	6	0	0	0	0	0	0	30	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0
Zaterdag	7	0	0	0	0	0	0	30	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0
Zondag	1	0	0	0	0	0	0	30	35	40	40	40	40	40	40	40	40	40	40	40	40	40	40	0	0

Check-in

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Dinsdag	3	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Woensdag	4	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Donderdag	5	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Vrijdag	6	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Zaterdag	7	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Zondag	1	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20
Dinsdag	3	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20
Woensdag	4	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20
Donderdag	5	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20
Vrijdag	6	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20
Zaterdag	7	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20
Zondag	1	20	20	20	20	20	20	40	40	40	40	40	40	40	40	40	40	40	40	20	20	20	20	20	20

Bezetting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	0	0	0	0	0	0	20	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	20	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	20	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	20	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	20	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	20	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	20	40	50	50	50	50	40	50	50	50	40	30	0	0	0	0	0	0

Security

Interne warmtelast - verlichting (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Dinsdag	3	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Woensdag	4	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Donderdag	5	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Vrijdag	6	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Zaterdag	7	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50
Zondag	1	50	50	50	50	50	50	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	50	50

Interne warmtelast - apparaten (0-100%)																									
	nr.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0
Maandag	2	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Dinsdag	3	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Woensdag	4	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Donderdag	5	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Vrijdag	6	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Zaterdag	7	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20
Zondag	1	20	20	20	20	20	20	50	60	80	80	80	80	60	80	80	80	60	30	20	20	20	20	20	20

Bezetting (0-100%)																									
	nr.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**0**
Maandag	2	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Dinsdag	3	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Woensdag	4	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Donderdag	5	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Vrijdag	6	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Zaterdag	7	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0
Zondag	1	0	0	0	0	0	0	50	60	80	80	80	80	60	80	80	80	60	30	0	0	0	0	0	0

APPENDIX IV: FORMULAE FOR CALCULATION DEMANDS

The total energy consumption consists of demand and losses due to distribution or generation. Where smaller buildings losses are almost negligible small, in larger buildings such as this scope those losses possibly play a bigger role.

$$Q_{total} = Q_{inf} + Q_{trans} + Q_{air} - Q_l - Q_{eq} - Q_{user} \quad (1)$$

Where:

Q_{total}= Heating or cooling demand
Q_{inf} = Infiltration heat loss
Q_{trans} = Transmission heat loss
Q_{air} = Ventilation cooling load
Q_l = Lighting heat load
Q_{eq} = Equipment heat load
Q_{user} = User heat load

And:

$$Q_{elec}= Q_{vent} + Q_l + Q_{eq} \quad (2)$$

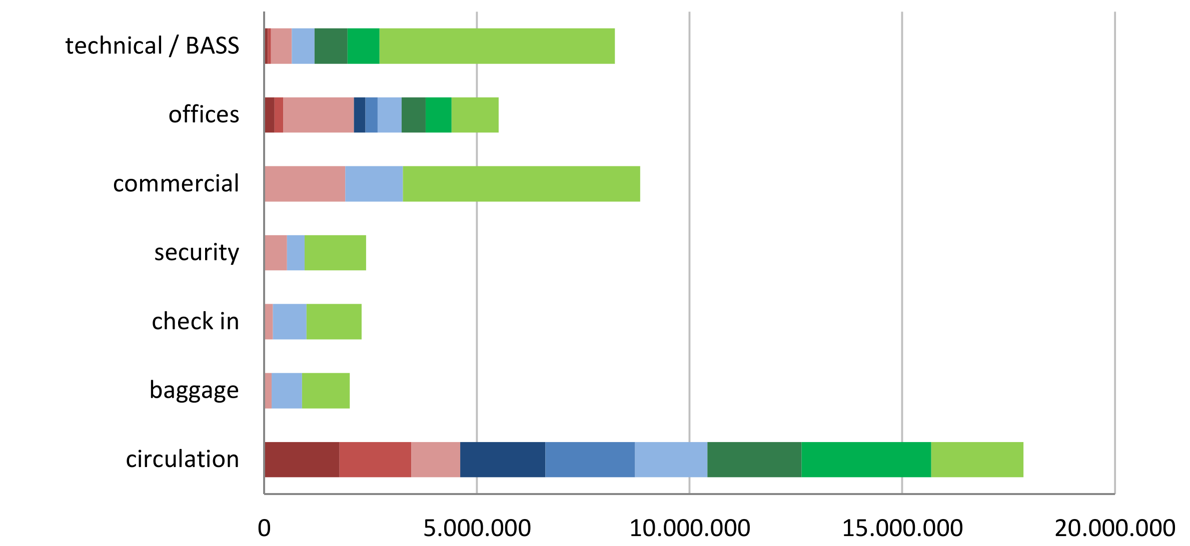
Where:

Q_{elec} = Electrical demand
Q_{vent} = Ventilation electrical load
Q_l = Lighting load
Q_{eq} = Electrical appliances load

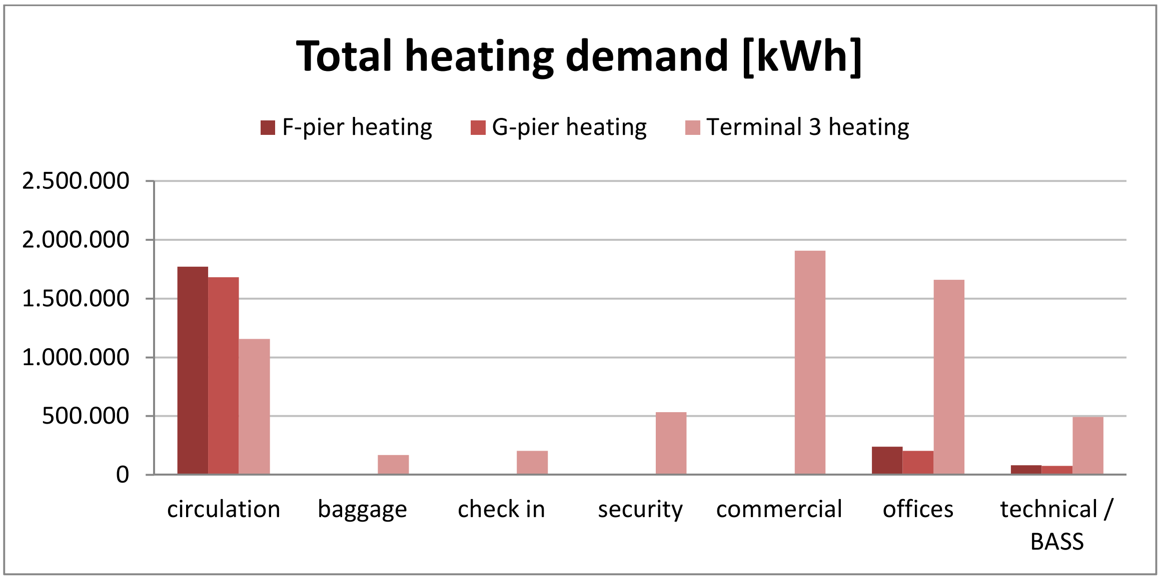
It can be seen that ventilation load (cooling and electrical) is taken into account in both heating/cooling demand and electrical demand.

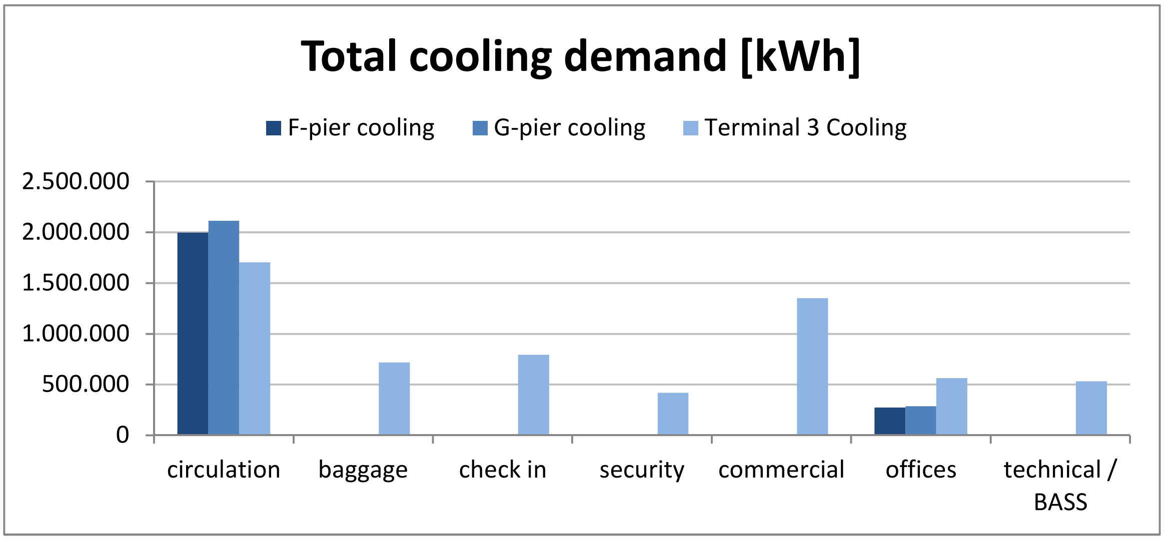
Appendix V: Calculated energy demand of the scope

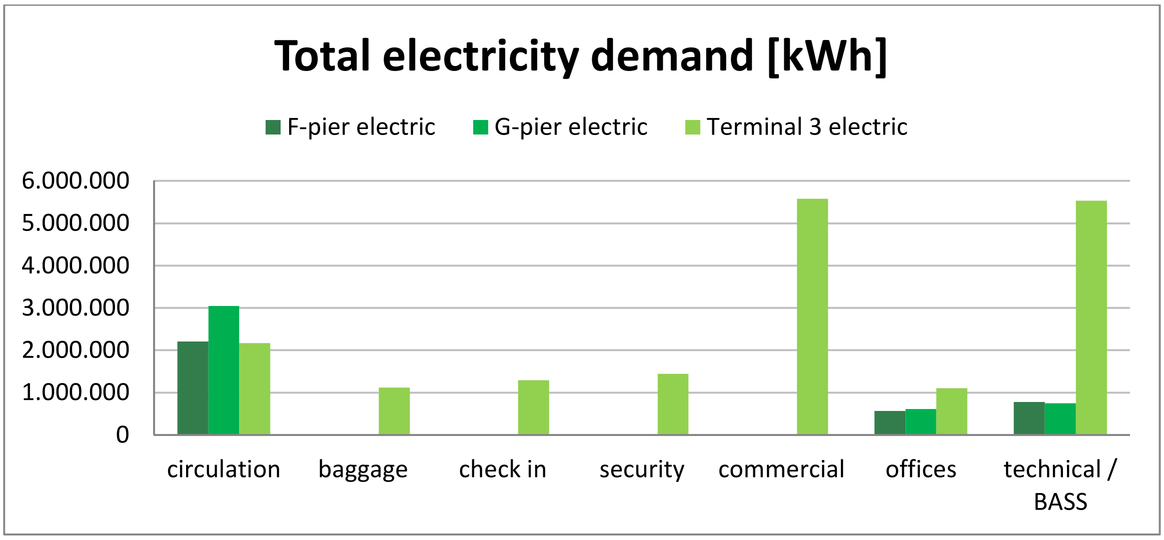
	circulation	baggage	check in	security	commercial	offices	technical / B/	total
F-pier heating	1.772.099					240.605	80.632	**2.093.335**
F-pier cooling	1.997.418					272.702	0	**2.270.121**
F-pier electricity	1.155.638					563.227	781.039	**2.499.904**
G-pier heating	1.681.946					205.069	77.027	**1.964.041**
G-pier cooling	2.112.924					285.053	0	**2.397.978**
G-pier electricity	1.702.768					612.736	748.723	**3.064.226**
Terminal 3 heating	2.061.445	169.518	204.110	532.179	1.908.132	1.661.289	491.650	**7.028.323**
Terminal 3 cooling	3.631.904	718.619	792.695	417.822	6.170.020	563.706	530.707	**12.825.473**
Terminal 3 electricity	2.170.348	1.120.576	1.290.076	1.446.087	5.576.765	1.104.311	5.534.975	**18.243.139**
total	**18.286.490**	**2.008.713**	**2.286.882**	**2.396.088**	**13.654.917**	**5.508.697**	**8.244.752**	52.386.539



	circulation	baggage	check in	security	commercial	offices	technical / BASS
F-pier heating	1.772.099					240.605	80.632
G-pier heating	1.681.946					205.069	77.027
Terminal 3 heating	1.155.638	169.518	204.110	532.179	1.908.132	1.661.289	491.650
F-pier cooling	1.997.418					272.702	0
G-pier cooling	2.112.924					285.053	0
Terminal 3 Cooling	1.702.768	718.619	792.695	417.822	1.352.570	563.706	530.707
F-pier electric	2.209.245					563.227	781.039
G-pier electric	3.047.917					612.736	748.723
Terminal 3 electric	2.170.348	1.120.576	1.290.076	1.446.087	5.576.765	1.104.311	5.534.975


Total heating demand [kWh]
F-pier heating
G-pier heating
Terminal 3 heating
2.500.000
2.000.000
1.500.000
1.000.000
500.000
0
circulation
baggage
check in
security
commercial
offices
technical / BASS


Total cooling demand [kWh]
F-pier cooling
G-pier cooling
Terminal 3 Cooling
2.500.000
2.000.000
1.500.000
1.000.000
500.000
0
circulation
baggage
check in
security
commercial
offices
technical / BASS


Total electricity demand [kWh]
F-pier electric
G-pier electric
Terminal 3 electric
6.000.000
5.000.000
4.000.000
3.000.000
2.000.000
1.000.000
0
circulation
baggage
check in
security
commercial
offices
technical / BASS

APPENDIX VI: ENERGY DEMAND FOR HVAC OF FLIGHTS

category of aircraft	**A**	**B**	**C**	**D**	**E**	**F**	**total**
mainly cargo / passenger	cargo	cargo	passenger	passenger	passenger	passenger	
exampe aircraft type of this category	*BE40*	*CRJ7*	*A320*	*B763*	*A333*	*A388*	
% of fleet mix (total)	0,38%	2,60%	79,52%	3,11%	13,84%	0,54%	100,00%
% of fleet mix (passengers)			82%	3,5%	14%	0,50%	100,00%
Demand aircraft type [kW/h]			90	120	140	180	
Demand aircraft type per year [kW/h]			73,8	4,2	19,6	0,9	**98,5**

The fleet mix of Schiphol of 2015 is divided into categories A – F where categories A and B are mainly used for cargo transport and C- F are mainly used for passenger transport. Category C is the smallest type of aircraft for passenger transport and category F the largest. The demand of these types vary according to the size of the type. However the fleet mix does not contain the same amount of aircrafts for each type so the percentage of the fleet mix is multiplied by the demand of the aircraft type in order to calculate the mean demand per aircraft per year which is 98,5 kW/h.

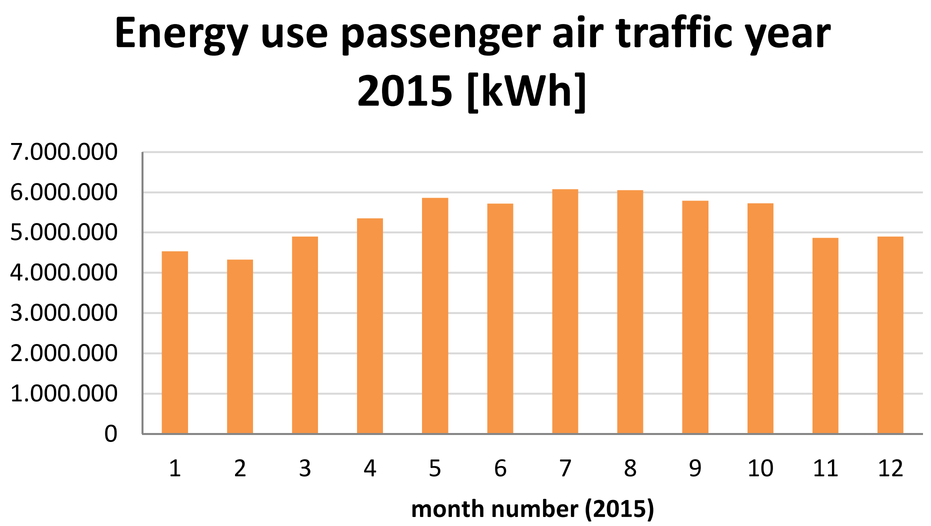
In order to calculate the total amount of KWh which is used for the aircrafts, the mean demand per aircraft per year is multiplied by the passenger flights and the time at the gate. This results in a total energy demand of over 64 GWh as can be seen in the table on the next page.

According to Royal Schiphol Group, each LTO cycle (landing + takeoff cycle) uses 7,7 liters of diesel. Assuming that 50% of the total flights is a departing flight and 50% of the total flights is an incoming flight, the amount of diesel which is saved is:

50% * 7,7liters * 433904 passenger flights = 1.670.530 liters.

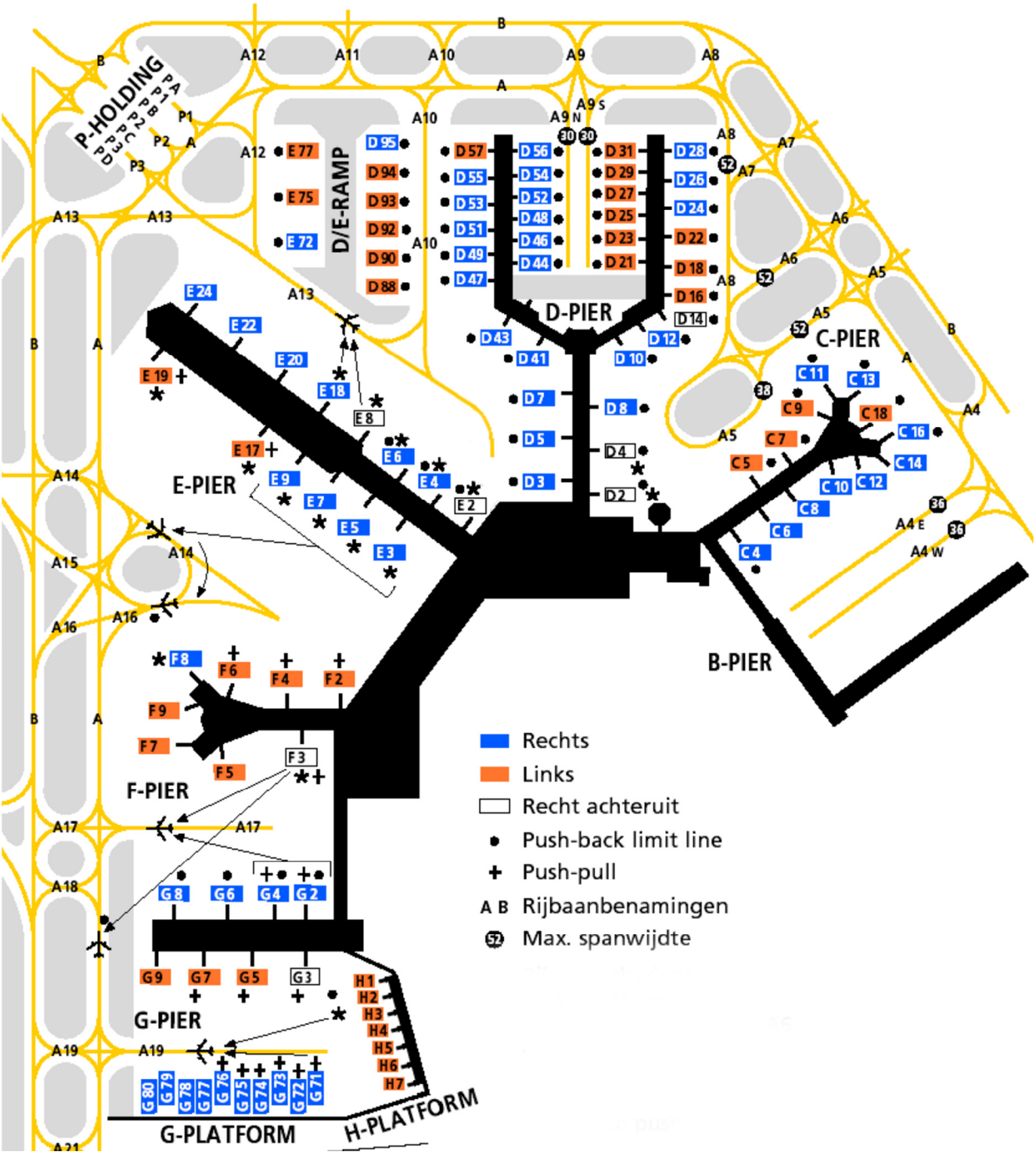
This is equal to a reduction of 5,4 kton of CO_2-emissions. (3,23 kg/l CO_2equivalent of diesel)

month	total flights	passenger only	time engines off [min]	HVAC + electricity [kW/h]	total use [kWh]	Diesel [l]	CO2 emissions [kton]
1	33029	30701	90	98,5	4.536.073	118.199	0,4
2	31631	29300	90	98,5	4.329.075	112.805	0,4
3	35756	33157	90	98,5	4.898.947	127.654	0,4
4	38772	36230	90	98,5	5.352.983	139.486	0,5
5	42413	39646	90	98,5	5.857.697	152.637	0,5
6	41548	38730	90	98,5	5.722.358	149.111	0,5
7	43785	41131	90	98,5	6.077.105	158.354	0,5
8	43559	40983	90	98,5	6.055.238	157.785	0,5
9	41867	39179	90	98,5	5.788.697	150.839	0,5
10	41581	38745	90	98,5	5.724.574	149.168	0,5
11	35745	32926	90	98,5	4.864.817	126.765	0,4
12	35835	33176	90	98,5	4.901.754	127.728	0,4
total	465521	433904	90	98,5	**64.109.316**	1.670.530	**5,4**



Estimation of externally powered energy demand of passenger aircrafts

Appendix VII: Gates overview Schiphol airport

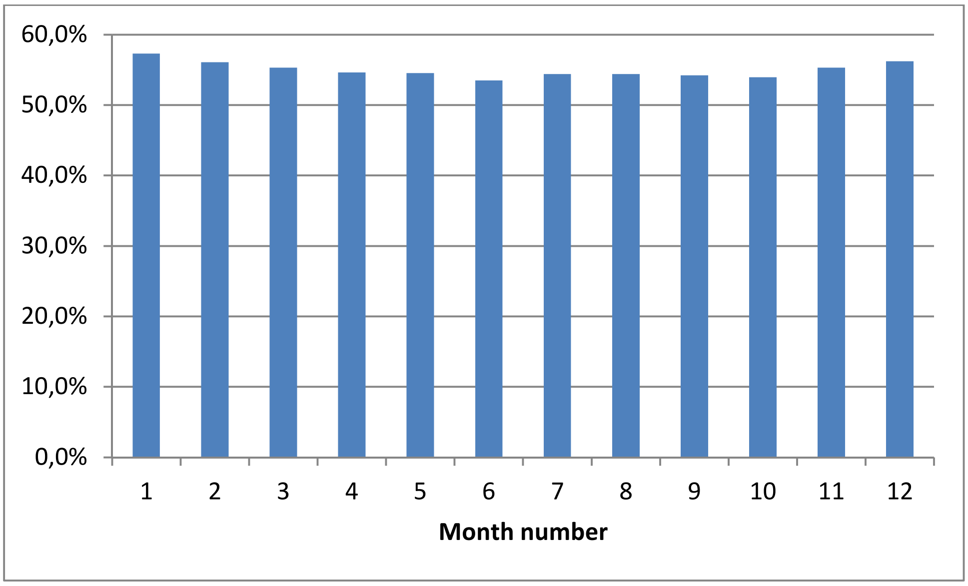


APPENDIX VII: LIST OF GATES PROVIDED WITH PCA AND 400HZ CONNECTION

	B	D	E	F	G	H
1	B13	D02	E03	F02	G02	H01
2	B15	D03	E05	F03	G03	H02
3	B16	D04	E07	F04	G04	H03
4	B17	D05	E08	F05	G05	H04
5	B20	D07	E09	F06	G06	H05
6	B23	D08	E17	F07	G07	H06
7	B24	D10	E18	F08	G08	H07
8	B27	D12	E19	F09	G09	
9	B28	D14	E20			
10	B31	D16	E22			
11	B32	D18	E24			
12	B35	D22				
13	B36	D24				
14		D26				
15		D28				
16		D41				
17		D43				
18		D47				
19		D49				
20		D51				
21		D53				
22		D55				
23		D57				

APPENDIX VIII PERCENTAGE OF FLIGHTS HANDLED BY 400 HZ SUPPLY

Schiphol airport 2016:



Average; 54,9%

APPENDIX IX: E-MAIL CONVERSATION SCHIPHOL REGARDING GPU USE

From:	Samson, Michelle
To:	Hanneke Dekkers
Subject:	RE: Gebruik GPU schiphol
Date:	maandag 13 februari 2017 13:51:51
Attachments:	image001.png 400Hz GJ2016_v1.xlsx

Hi Hanneke,

We weten wel hoeveel diesel er aan Airside verbruikt (opgave door KES) wordt, maar niet welk deel daarvan naar de GPU's gaat.
De diesel wordt namelijk ook gebruikt voor voertuigen en voor NSA's. De verdeling hiervan is bij ons intern niet bekend.
Wel wordt er gerapporteerd over het APU gebruik; maar daar ben je niet naar op zoek toch?

Nou neem ik natuurlijk niet genoegen met dit antwoord. Dus ik heb via andere kanalen wel een aantal schattingen voor je gevonden:

- Per landing wordt 7.7 Liter diesel verbruikt (zie pagina 243 van MER deelrapport 4)
  Let op: dit is per LTO cycle en is dus gelijk aan twee vluchten (start + landing)
- Er is in 2016 gemiddeld 54.9% elektrisch afgehandeld (de rest dus met GPU)
  Zie excel voor aantal vluchten en welke elektrisch zijn (bestand vertrouwelijk!)

Het 400 Hz. gebruik is afhankelijk het gebruik van afhandellaar, beschikbaarheid apparaat, en beschikbaarheid op de VOP. Niet voor elke afhandeling is het geschikt/gewenst.
De GPU is (helaas) veel wendbaarder en voor airlines makkelijker in het gebruik. De 400hz dient aangekoppeld te worden en is zwaarder en moet met 2 man op het platform gebruikt worden.
De voornaamste reden waarom Schiphol de 400hz stimuleert is het luchtkwaliteit en verminderen van dieselgebruik.

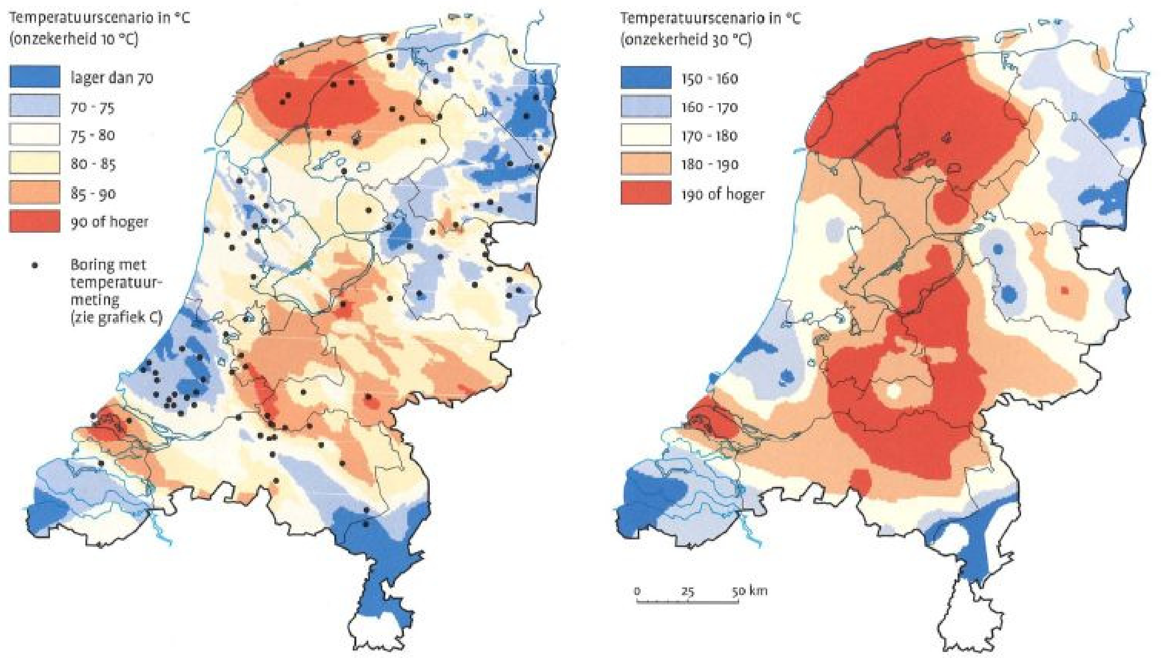
Let op, bovenstaande cijfers zijn allemaal schattingen en moeten dus geïnterpreteerd worden met een bepaalde voorzichtigheid.

We zijn uiteraard benieuwd naar je afstuderen. Stuur je een kopie van het resultaat?
PS: als er iets gepubliceerd wordt wil ik het intern voor de zekerheid wel afstemmen!

Ik hoop dat ik je hiermee geholpen heb, succes!

Groetjes,
Michelle

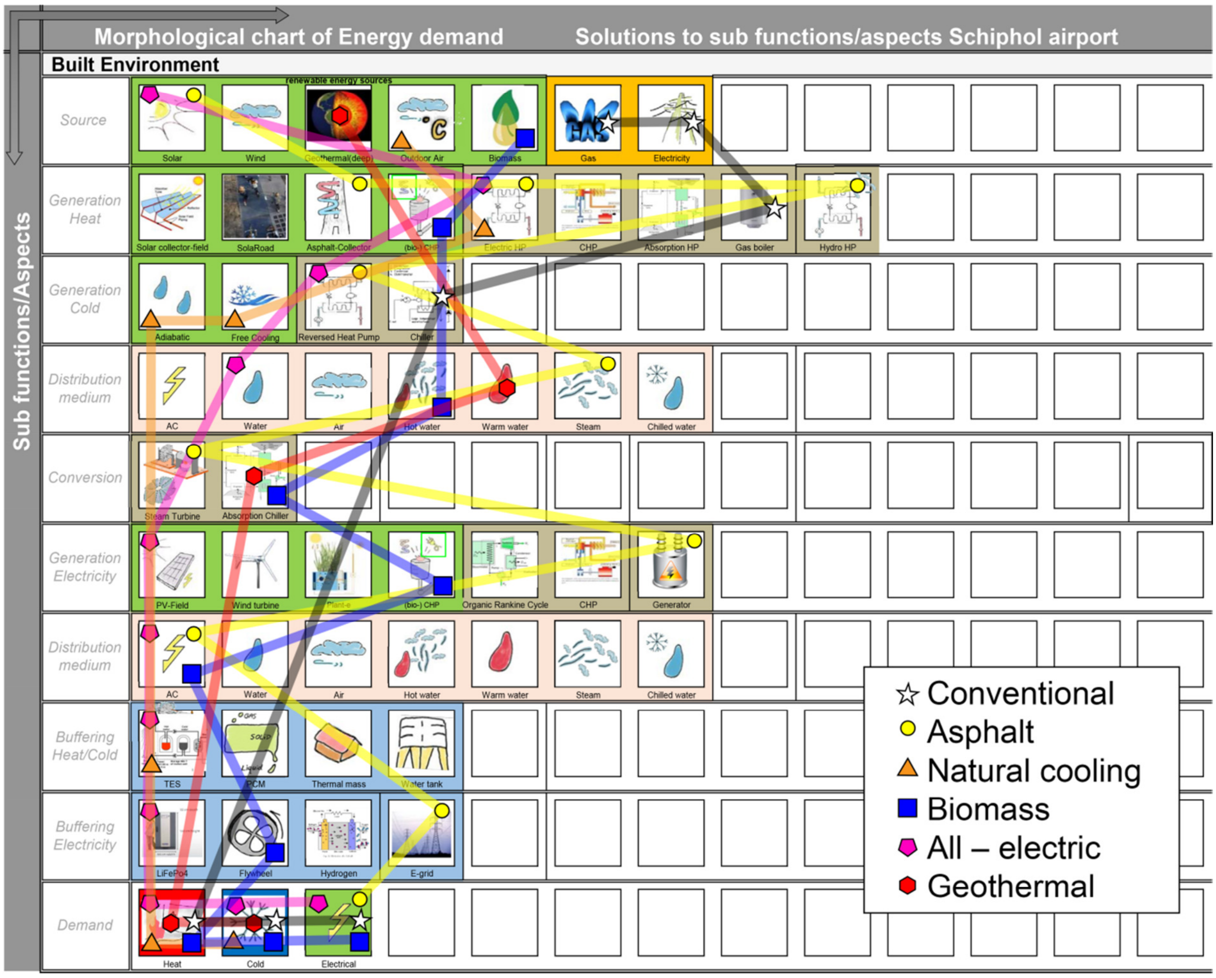
APPENDIX X: GEOTHERMAL POTENTIAL (SOURCE: DE GROENE ENERGIEMAATSCHAPPIJ)



- 2 km diepte
- 5 km diepte

APPENDIX XI: MORPHOLOGICAL CHART

The morphological chart is created starting with the energy source (fossil or renewable) to the generation of heat and/or cold and/or electricity, to the distribution, after which buffering can take place, to the demand.



APPENDIX XII: CONVENTIONAL VARIANT PARAMETERS

Variant1 : Conventioneel		
Warmte: 10,9 GWh		
Ketelrendement	0,9	onderwaarc
Gas inhoud	31,7	MJ/m3
Warmtevraag	39240	GJ
Gasverbruik	1237,855	dam3/jr
Koude: 17,5 GWh		
Koelmachine rendement	3	[-]
Elektrische vraag	5,833333	GWh
Elektra: 34,4 GWh		
Vraag	34,4	GWh
Emissies CO2:		
Totaal biokerosine	0	kton
Totaal Gas	1238	dam3/jr
Totaal elektriciteit	40,2	GWh
Biok. Equiv.*	3,15	kg/ltr
Gas equivalent**	1,887	kg/m3
Elektra equivalent***	0,355	kg/kWh
Totaal CO2	**16,6**	**kton/jaar**

* The equivalent of regular kerosene is used as stated by Schiphol. (Royal Schiphol Group, 2014)

** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

*** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

APPENDIX XIII: ASPHALT POTENTIAL

The table below shows the total surface area of all asphalt platforms on schiphol

surface	m2	km2
bridges	36.402	0,04
arteries	87.622	0,09
shuttle bus	152.527	0,15
main roads	289.208	0,29
aprons connected to gate	402.312	0,40
aprons	476.368	0,48
parking	618.071	0,62
service roads	969.799	0,97
runways	990.435	0,99
highways	1.409.056	1,41
terrain	11.306.957	11,31
total	16.738.757	16,74

The possibility of using the asphalt as a heat collector depends on different aspects. Every type has other requirements for strength, cleanness and structure. Furthermore some types are used by a lot of different users (for example highways) while the use of other types is regulated and controlled (for example runways). Also, some types of asphalt are located stretched out across the total area while others are located compact together.

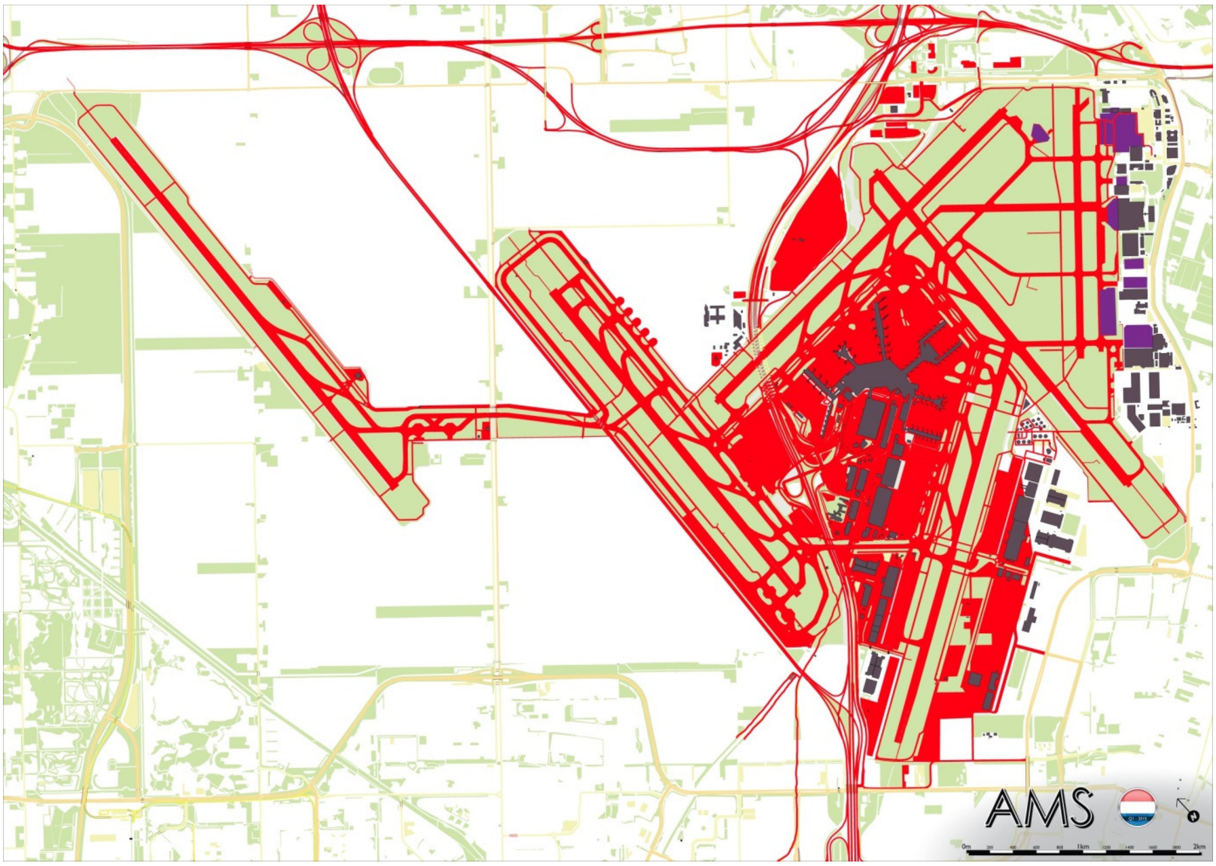
In order to calculate the potential energy gains of the asphalt platforms, a start is made with the surface area of the aprons and the aprons connected to the gate, because the requirements for strength and structure are not the strictest, the use is regulated and controlled and they are located compact together, connected to the terminal buildings. In the continuing of this thesis, the amount of surface area will be:

$$0.40+0.48=0.9 \text{ km}^2$$

The energy potential per surface area can be found in literature. However, this number depends on a lot of aspects, such as depth of the solar collector system, cleanness of the asphalt, colour of the asphalt, wind velocity and other parameters that are involved with solving the heat balance in each layer of the asphalt. That is why the yearly numbers found in literature differ from 0,35 [GJ/m2] to 0,63 [GJ/m2] (Loomans, et al., 2003) (TNO, 2000) (Road Energy Systems®: koude/warmte opslag, 2017).

In order to calculate the amount of heat, the total surface area is multiplied by the different gain factors found. The study of (Loomans, et al., 2003)showed relatively low factors. Aprons are, compared to the sandy asphalt used in this study, clean surfaces of asphalt. Therefore in this research the lowest factor for clean and dark asphalt is used in the calculations, which is 0,4 $GJ/m^2/year$. This comes down to a total thermal potential of 350 TJ per year (30°C).

The total asphalt area of Schiphol airport is marked in red below and is 16,7 km^2 and offers more potential than only the 0,9 km^2 on which the calculation is based at the moment.



APPENDIX XIV: ASPHALT VARIANT PARAMETERS

Variant 2 : Asphalt solar collector			
Warmte: 10,9 GWh			
Ketelrendement	0,9	onderwaarde	
Gas inhoud	31,7	MJ/m3	
Warmtevraag	39240	GJ	
Gasverbruik	1237,9	dam3/jr	
Koude: 17,5 GWh			
Koelmachine rendement	3	[-]	
Elektrische vraag	5,8333	GWh	
Elektra: 34,4 GWh			
Asfalt beschikbare warmte	97,222	GWh	@ 30℃
Warmtepomp COP	4	[-]	
E- WP	24,306	GWh	
Beschikbare warmte	121,53	GWh	@ 55℃
Hydro WP COP	4,2	[-]	
E- hydro. WP	28,935	GWh	
Beschikbare warmte	150,46	GWh	@ 140℃
Rendement centrale_Carnot****	0,31		
Productie	-46,644	GWh	
Vraag	34,4	GWh	
Emissies CO2:			
Totaal biokerosine		kton	
Totaal Gas	1238	dam3/jr	
Totaal elektriciteit	46,8	GWh	
Biok. Equiv.*	3,15	kg/ltr	
Gas equivalent**	1,887	kg/m3	
Elektra equivalent***	0,355	kg/kWh	
Totaal CO2	**24,8**	**kton/jaar**	

* The equivalent of regular kerosene is used as stated by Schiphol. (Royal Schiphol Group, 2014)

** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

*** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

**** $\eta_{Carnot} = 1 - \frac{T_{low}\,[K]}{T_{high}\,[K]}$

APPENDIX XV: GEOTHERMAL VARIANT PARAMETERS

Variant3 : Geothermie		
Warmte: 10,9 GWh		
Beschikbare energie	15,6	GWh
COP energie	40	
Elektrisch t.b.v. verwarmi	0,2725	Gwh
Koude: 17,5 GWh		
AKM COP @ 85℃	0,7	
Resterende warmte	4,7	GWh
Koudelevering AKM	3,29	GWh
Resterende koudevraag	14,21	GWh
Koelmachine rendement	3	[-]
Elektrische vraag	4,73667	GWh
Elektra: 34,4 GWh		
Vraag	34,4	GWh
Emissies CO2:		
Totaal biokerosine	0	kton
Totaal Gas	0	dam3/jr
Totaal elektriciteit	39,4	GWh
Biok. Equiv.*	3,15	kg/ltr
Gas equivalent**	1,887	kg/m3
Elektra equivalent***	0,355	kg/kWh
Totaal CO2	**14,0**	**kton/jaar**

* The equivalent of regular kerosene is used as stated by Schiphol. (Royal Schiphol Group, 2014)

** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

*** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

APPENDIX XVI: BIOKEROSENE EXPECTATION EMISSIONS

The difference between biokerosene and regular kerosene in terms of CO_2 emissions is that biokerosene recycles CO_2 emissions that were emitted previously and subsequently absorbed from the atmosphere during feedstock production. Regular kerosene releases additional carbon that was previously stored in reservoirs.

Since the CO_2 emissions equivalent of biokerosene is not available by reliable sources and there is much research and development ongoing on biokerosene, the equivalents are abstracted from a graph made by TU/delft and BE-basic, published in a report from the government as can be seen in figure 28 (Ministerie van infrastructuur en milieu, 2014). The expected emissions are taken for now, the year 2030 and the year 2050 for the green dotted line (expected emissions without improved technology, operations and infrastructure) and the red line (expected emissions without improved technology, operations and infrastructure and without the use of biofuels). Those are put into a graph (figure 29).

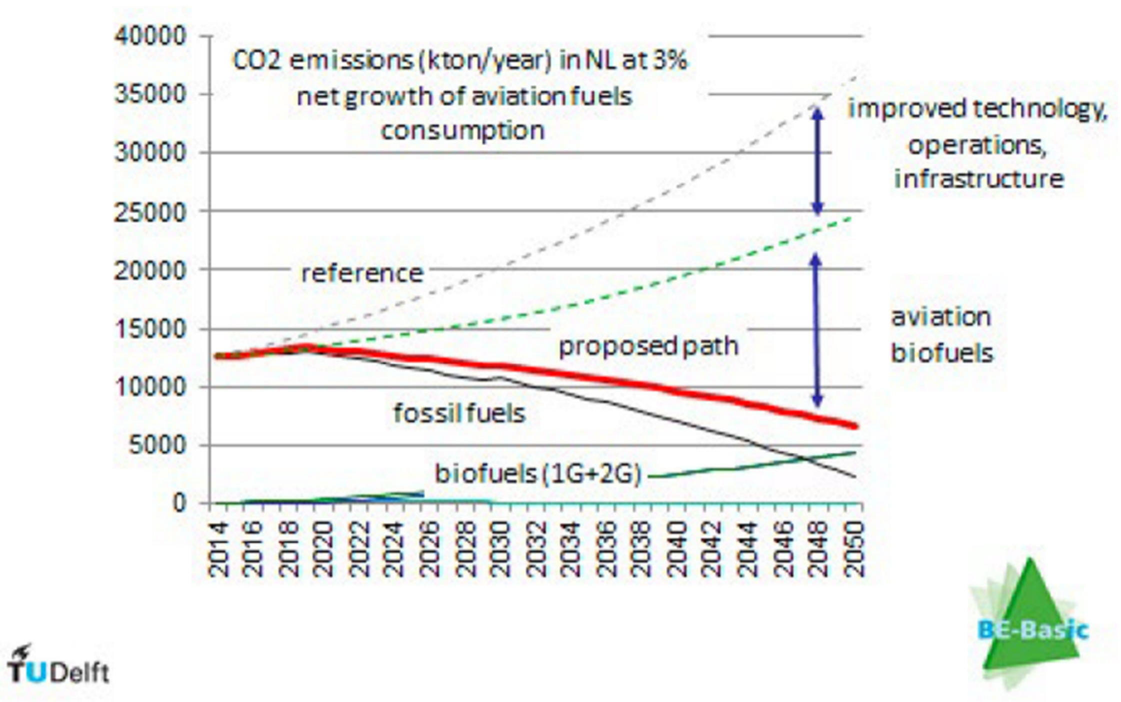


Figure 31 Projected CO2 emissions for the timeframe 2014-2050 in ktons CO2 equivalents per year

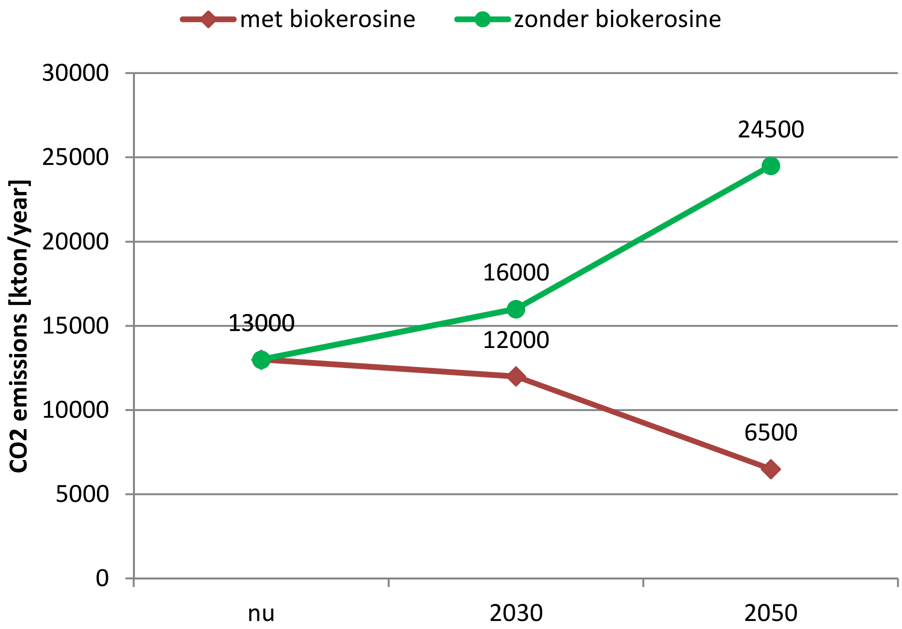


Figure 32 Abstracted data from figure 28 for now, 2030 and 2050

It can be seen that for 2030, emissions are reduced with 25% by making use of biofuels and for 2050 even a reduction of 73% is expected. Assumed is that now, regular kerosene is mainly used with a CO_2 equivalent of 3,15 kg/kg. Taken into account the reductions for 2030 and 2050, the CO_2 equivalents will be 2,5 kg/kg and respectively 0,82 kg/kg.

APPENDIX XVII: (BIO-)KEROSENE VARIANT PARAMETERS

Variant 4a: Kerosene		
Warmte: 10,9 GWh		
Warmtepomp COP	4,0	[-]
E-WP	2,7	GWh
Koude: 17,5 GWh		
WKO koude	8,2	GWh
COP WKO	30,0	[-]
E-WKO	0,3	GWh
Resterende koude vraag	9,3	GWh
COP AKM @ 90℃	0,7	[-]
Benodigde warmte	13,3	GWh
Bio WKK - warmte rendement	0,5	
Bio fuel	29,6	GWh
Bio fuel energie inhoud (ref. biok	42,9	MJ/kg
Bio fuel behoefte	2484182,5	kg
Elektra: 34,4 GWh		
Opwekking WKK	-13,3	GWh
Vraag	34,4	GWh
* Uitgangspunt 45% w armte en 45% Elek. Rendement van WKK		
Emissies CO2:		
Totaal biokerosine	2,5	kton
Totaal Gas		dam3/jr
Totaal elektriciteit	24,1	GWh
Biok. Equiv.*	3,2	kg/kg_kerc
Gas equivalent**	1,9	kg/m3
Elektra equivalent***	0,4	kg/kWh
Totaal CO2	**16,4**	**kton/jaar**

* The equivalent of regular kerosene is used as stated by Schiphol. (Royal Schiphol Group, 2014)

** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

*** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

Variant 4b: Biokerosene		
Warmte: 10,9 GWh		
Warmtepomp COP	4,0	[-]
E-WP	2,7	GWh
Koude: 17,5 GWh		
WKO koude	8,2	GWh
COP WKO	30,0	[-]
E-WKO	0,3	GWh
Resterende koude vraag	9,3	GWh
COP AKM @ 90℃	0,7	[-]
Benodigde warmte	13,3	GWh
Bio WKK - warmte rendement	0,5	
Bio fuel	29,6	GWh
Bio fuel energie inhoud (ref. biok	42,9	MJ/kg
Bio fuel behoefte	2484182,5	kg
Elektra: 34,4 GWh		
Opwekking WKK	-13,3	GWh
Vraag	34,4	GWh
* Uitgangspunt 45% w armte en 45% Elek. Rendement van WKK		
Emissies CO2:		
Totaal biokerosine	2,5	kton
Totaal Gas		dam3/jr
Totaal elektriciteit	24,1	GWh
Biok. Equiv.*	0,8	kg/kg_kerc
Gas equivalent**	1,9	kg/m3
Elektra equivalent***	0,4	kg/kWh
Totaal CO2	**10,6**	**kton/jaar**

* The equivalent of regular kerosene is used as stated by Schiphol. (Royal Schiphol Group, 2014)

** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

*** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

APPENDIX XVIII: ALL-ELECTRIC PV VARIANT PARAMETERS

Variant5 : All-electric PV		
Warmte: 10,9 GWh		
Warmtevraag	10,9	GWh
COP WP	4	
Elektrisch t.b.v. verwarming	2,725	Gwh
Koude: 17,5 GWh		
Koude geladen WKO	8,175	
COP WKO	30	
Elektrisch koeling WKO	0,2725	Gwh
Resterend d.m.v. rev. WP	9,325	Gwh
Koelmachine rendement	3	[-]
Elektrische vraag	3,1083333	GWh
Elektra: 34,4 GWh		
PV opbrengst /m2	135,0	kWh/m2
Aantal m2 dak t3 en pieren	50.885,0	m2
Beleggingsgraad	0,5	
Totaal elektrisch opbrengst	-3,4	GWh
Vraag	34,4	GWh
Emissies CO2:		
Totaal biokerosine		kton
Totaal Gas		dam3/jr
Totaal elektriciteit	37,1	GWh
Biok. Equiv.*	3,15	kg/kg_ker
Gas equivalent**	1,887	kg/m3
Elektra equivalent***	0,355	kg/kWh
Totaal CO2	**13,2**	**kton/jaar**

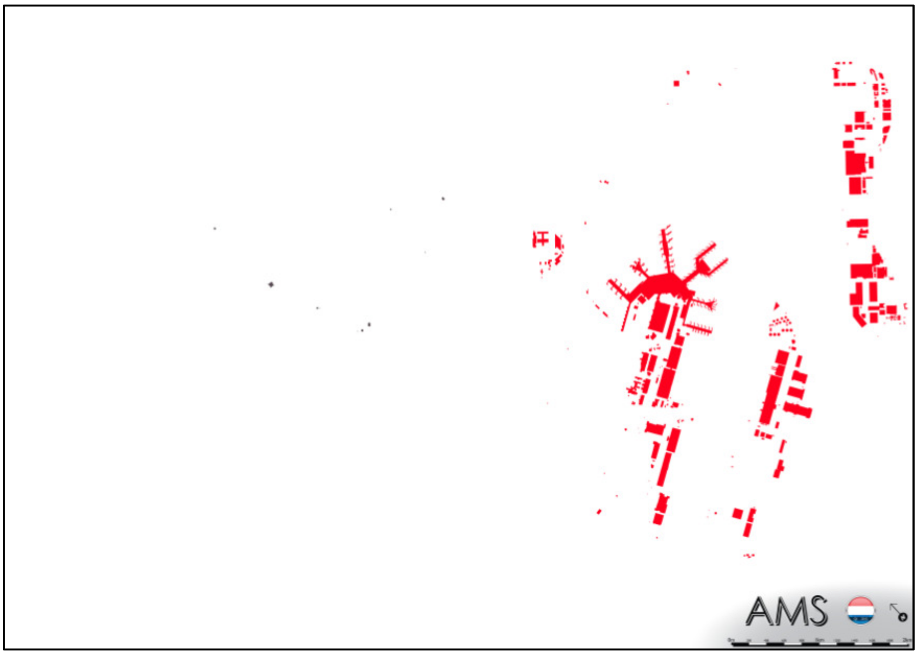
* The equivalent of regular kerosene is used as stated by Schiphol. (Royal Schiphol Group, 2014)

** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

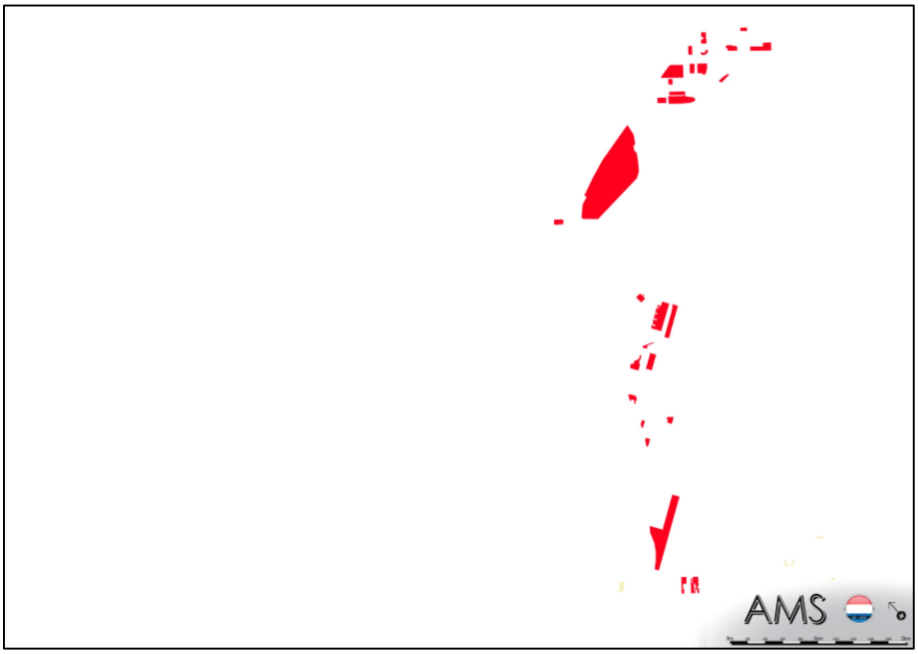
*** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

APPENDIX XIX: PV VARIANT SURFACE AREAS

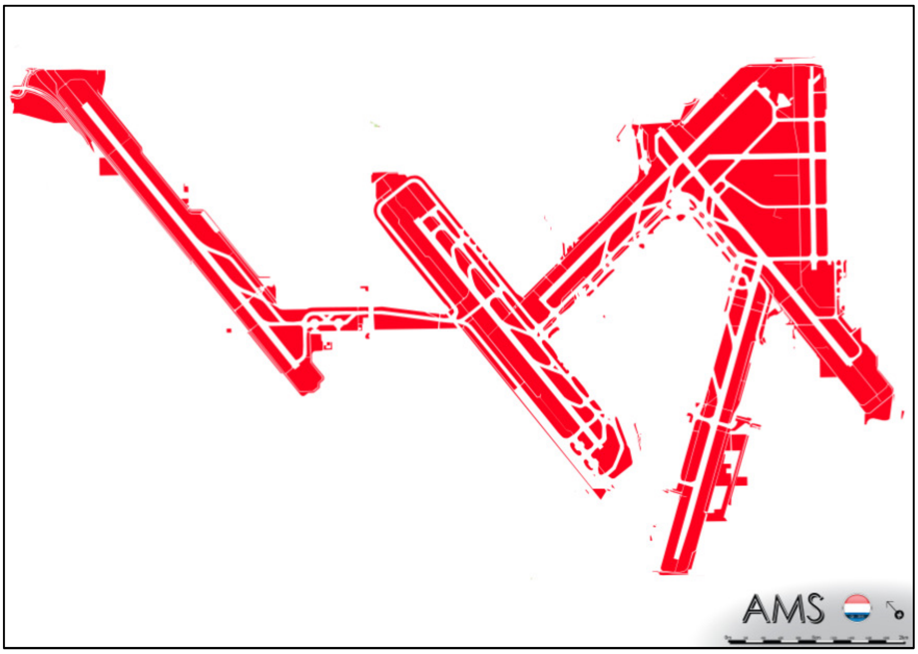
	Surface [m2]	Production [kWh/m2]	Coverage	Total [GWh]
T3 and F + G pier	50.885	135	50%	3
parking area	618.071	135	50%	42
buildings	1.477.942	135	50%	100
grass (farmland excluded)	9.321.974	135	50%	629



Building surface area (red)



Parking surface area (red)



Grass (farmland excluded) surface area (red)

APPENDIX XX: NATURAL COOLING VARIANT PARAMETERS

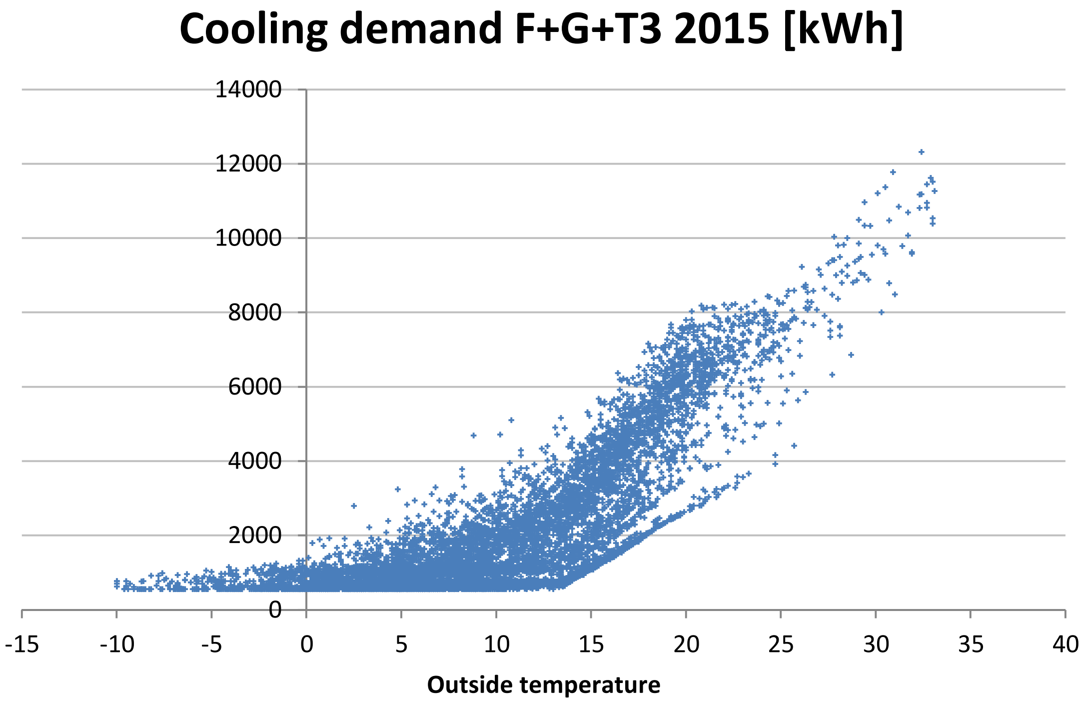
Variant6 : Natural cooling		
Warmte: 10,9 GWh		
Ketelrendement	0,9	onderwaa
Gas inhoud	31,7	MJ/m3
Warmtevraag	39240	GJ
Gasverbruik	1237,85	dam3/jr
Koude: 17,5 GWh		
Vrije koeling, processen	6,6	GWh
COP vrije koeling	40,0	[-]
E-Vrijekoeling	0,2	GWh
Adiabatisch, comfort	7,2	GWh
COP adiab.	50,0	[-]
E-adiabatisch	0,1	GWh
Restkoeling	4,0	GWh
Koelmachine rendement	3,0	[-]
Elektrische vraag	1,3	GWh
Elektra: 34,4 GWh		
Vraag	34,4	GWh
Emissies CO2:		
Totaal biokerosine		kton
Totaal Gas	1238	dam3/jr
Totaal elektriciteit	36,1	GWh
Biok. Equiv.*	3,15	kg/kg_ker
Gas equivalent**	1,887	kg/m3
Elektra equivalent***	0,355	kg/kWh
Totaal CO2	**15,0**	**kton/jaar**

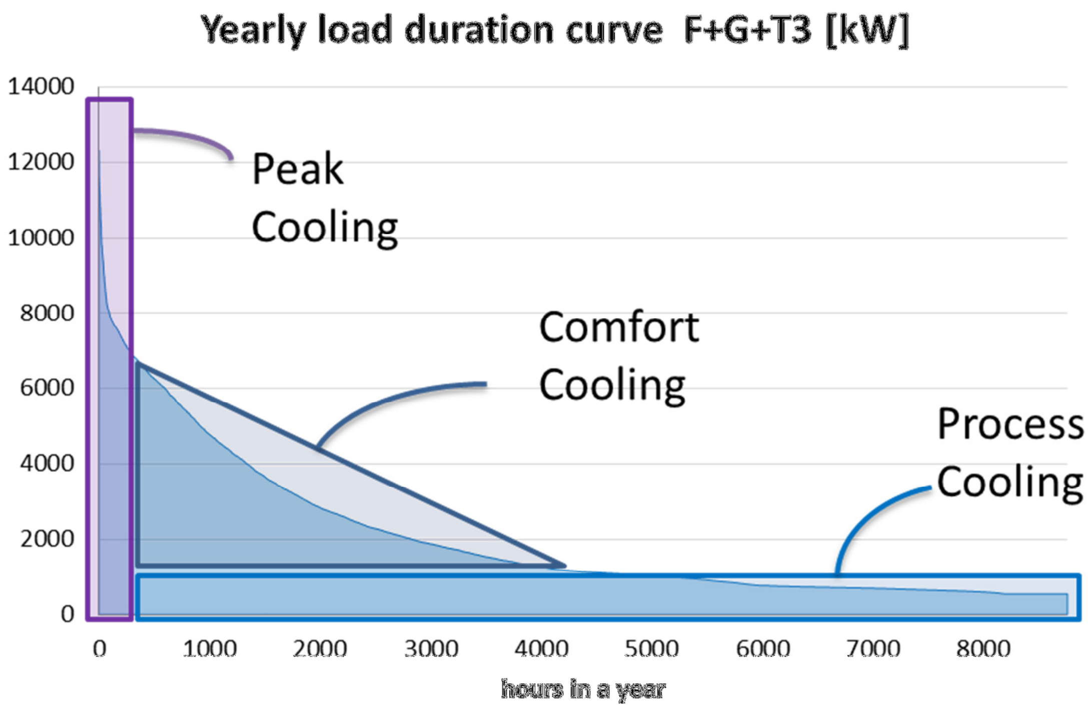
* The equivalent of regular kerosene is used as stated by Schiphol. (Royal Schiphol Group, 2014)

** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

*** (Ministerie van Infrastructuur en Milieu, CO2 emissiefactoren, 2017)

Appendix XXI: Cooling demand versus outside temperature



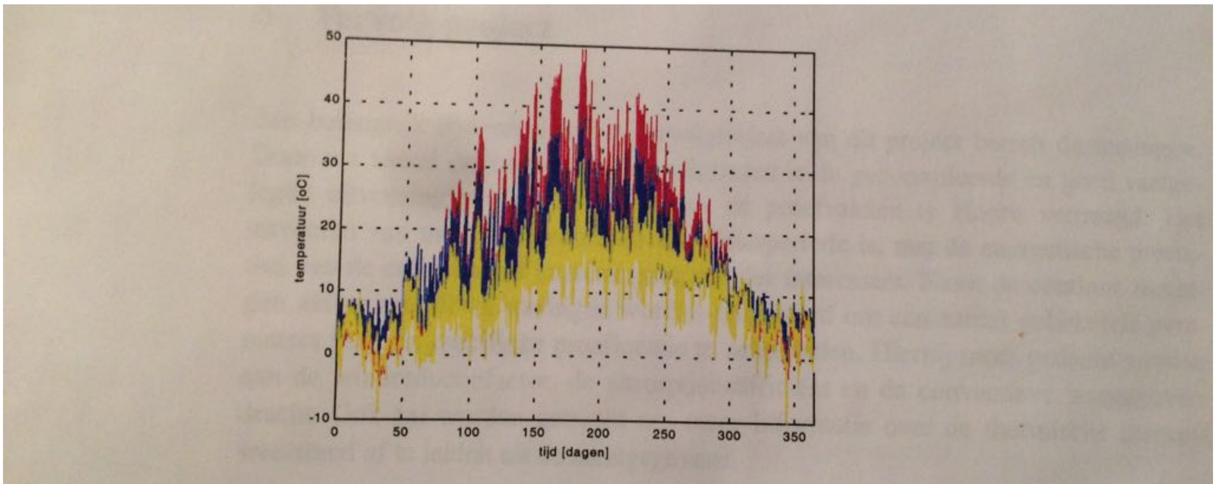


The maximum hourly value for free cooling is set on 1500kW.

APPENDIX XXII: INPUT PARAMETERS FROM TNO ASPHALTCOLLECTOR

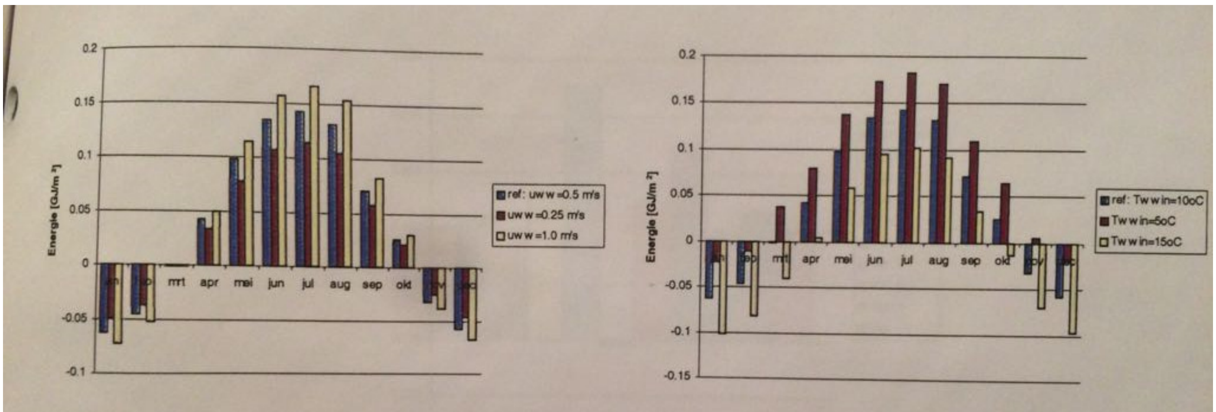
Snelheid doorstroomdebiet	0,5	m/s
Invoertemperatuur warmtewisselaar	10	°C
Contactweerstand	0,5	-
Diepteligging slangen	0,065	m
Absorptiecoefficient asfalt	0,9	

Temperatures of the asphalt (with and without heat exchanger) are shown in the figure below (TNO, 2000). Assumed for this thesis is that in summer the temperature of the asphalt is 30°C and in winter 5°C.



Temperatuurverloop in de asfaltlaag waarin zich de warmtewisselaar bevindt (0.065 m) bij een geactiveerde warmtewisselaar (blauw; referentie) en zonder warmtewisselaar (rood). De gele lijn geeft luchttemperatuur weer.

Energy gains of the asphalt are compared with different parameters in the study of TNO, as can be seen in the figures below. In summer months the potential monthly gains lead up to 0.17 GJ/m^2 and in winter up to 0,10 GJ/m^2. Assumed for this thesis is that in summer the mean potential gains are 0,10 GJ/m^2 per month and in winter 0,05 GJ/ m^2 per month.

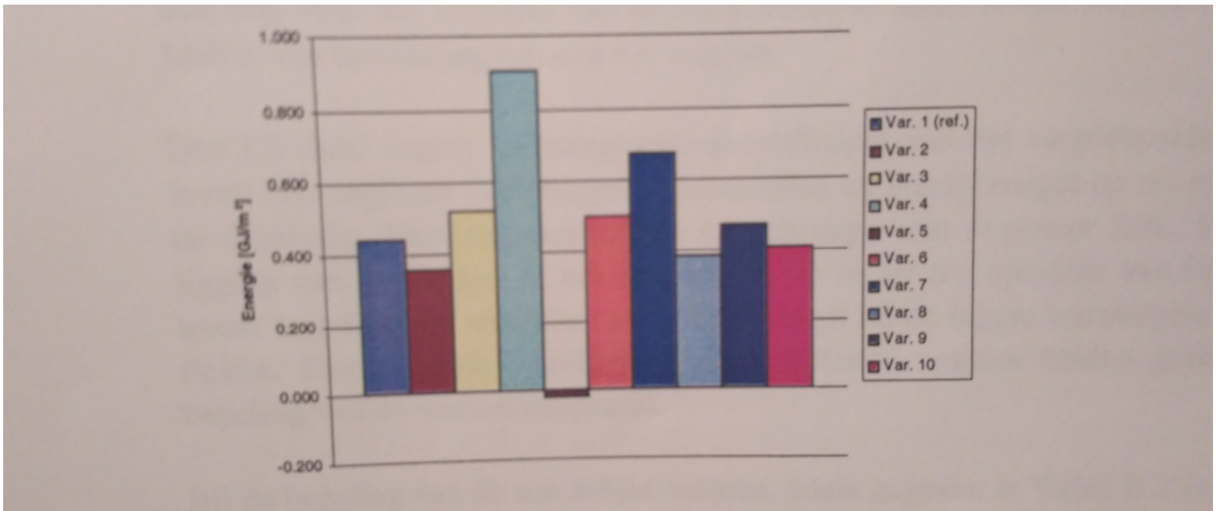


Figuur 4. Invloed van het doorstroomdebiet (u_{ww} [snelheid]) en de toevoertemperatuur (T_{wwin}) op de jaaropbrengst.

Different studies show varying potential gains of the asphalt per m², as can be seen in the table below:

reference country	name	source	GJ/m2/y
Netherlands	1,5D model polluted asphalt	(Loomans, et al., 2003)	0,35
Netherlands	2,5D model polluted asphalt	(Loomans, et al., 2003)	0,40
Netherlands	1,5D model clean dark asphalt	(Loomans, et al., 2003)	0,40
Netherlands	TNO	(TNO, 2000)	*
Netherlands	2,5D model clean dark asphalt	(Loomans, et al., 2003)	0,46
London	reference	(SOLINTEL, 2014)	0,54
Netherlands	Road Energy Systems	(Road Energy Systems®: koude/warmte opslag, 2017)	0,63
London	pipedepth 9 cm	(SOLINTEL, 2014)	0,81
Madrid	reference	(SOLINTEL, 2014)	0,85
London	pipedepth 5 cm	(SOLINTEL, 2014)	0,90
Madrid	pipedepth 9 cm	(SOLINTEL, 2014)	1,20
Madrid	pipedepth 5 cm	(SOLINTEL, 2014)	1,40

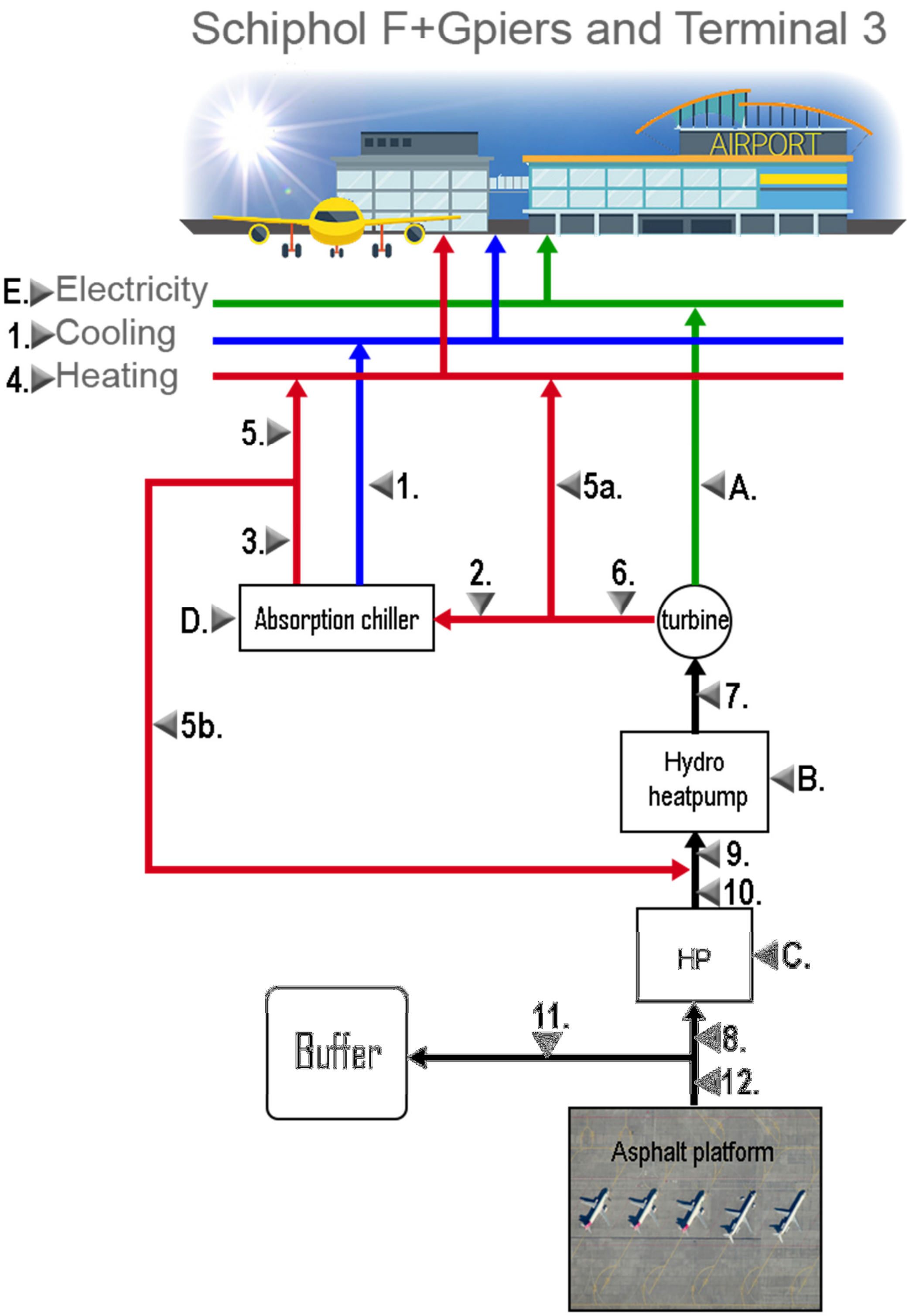
* The study of TNO contained different variants as can be seen in the figure below



Overzicht jaaropbrengst voor verschillende varianten (voor de variantbeschrijving zie Tabel 2).

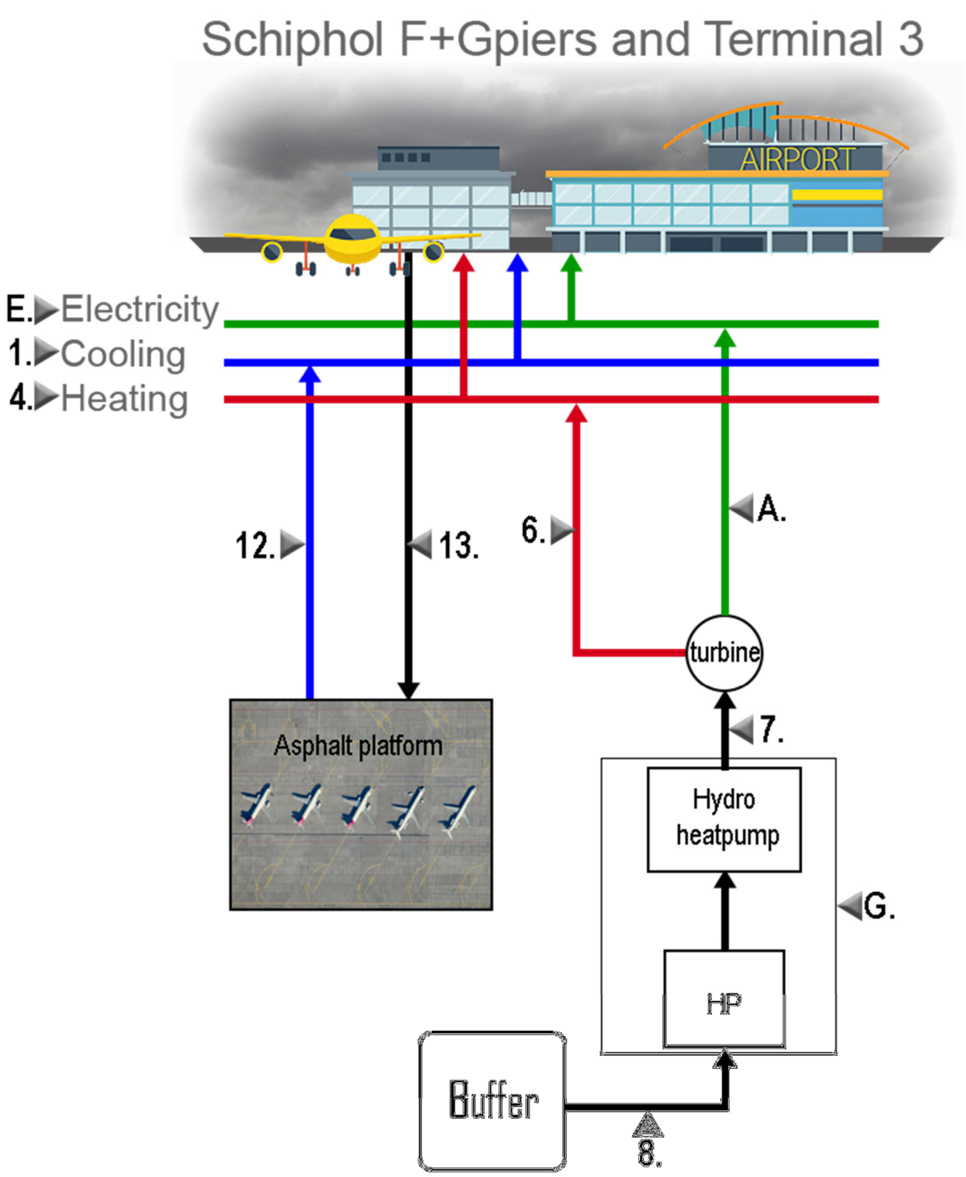
APPENDIX XXIII: CALCULATION ASPHALTCOMBINATION

The letters and numbers in the illustrations represent the calculations which are made in the model.



Asphaltcombination summer

ZOMER			
letter/cijfer	formule	omschrijving	T [ºC]
1.	*dagelijkse waarde*	*koude thermisch naar gebouw*	
2.	2 = 1 / n(k,akm)	thermisch in AKM	90
3.	3 = 2 - 1	thermisch uit AKM	70
4.	*4 = 5 + 5a*	*warmte thermisch naar gebouw*	
5.	5 = 4 - 5a	thermisch uit AKM naar gebouw	70
5a.	5a = 4 - 3	thermisch uit turbine naar gebouw	90
5b.	5b = 3 - 4	thermisch uit AKM naar WP2	70
6.	6 = 5 + 2	thermisch uit turbine	90
7.	7 = 6 + A	thermisch naar turbine	140
8.	8 = 10 / n(copWP1)*(n(copWP1)-1)	thermisch naar WP 1	35
9.	9 = 7 / n(copWP2)*(n(copWP2)-1)	thermisch naar WP 2	60
10.	10 = 9 - 5b	thermisch uit WP 1	60
11.	11 = 12 - 8	thermisch naar buffer	35
12.	opwekking uit asfalt		35
A.	6*n(tur)	Elektriciteitsopwekking uit turbine	
B.	(7/n(copWP2))	Elektriciteitsvraag WP 2	
C.	(10/n(copWP1))	Elektriciteitsvraag WP 1	
D.	1 / n(e,akm)	Elektriciteitsvraag AKM	
E.	*E.*	*Elektriciteitsvraag gebouw*	



Asphaltcombination winter

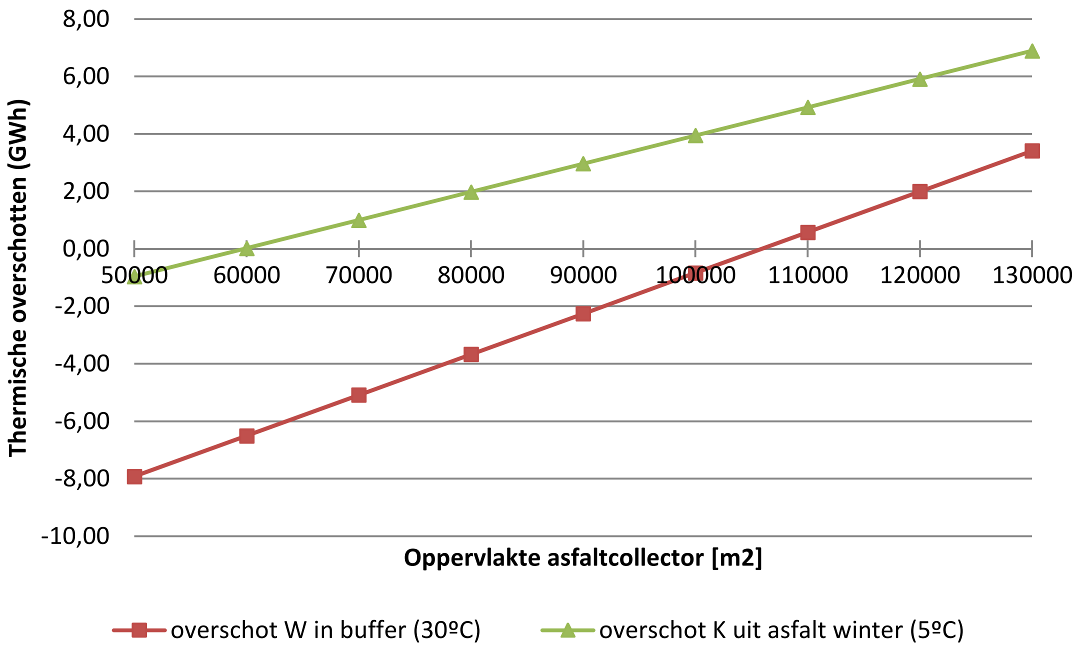
WINTER			
letter/cijfer	formule	omschrijving	T [℃]
1.	*dagelijkse waarde*	*koude thermisch naar gebouw*	
4.	*dagelijkse waarde*	*warmte thermisch naar gebouw*	
6.	6 = 4	thermisch uit turbine	90
7.	7 = 6 + A	thermisch naar turbine	140
8.	8 = 7 / n(coptotaal)*(n(coptotaal)-1)	thermisch naar WP 1 (uit buffer)	35
12.	12 = 1 - F	opwekking uit asfalt	5
13.	-	thermisch naar asfalt	20
A.	6*n(tur)	Elektriciteitsopwekking uit turbine	
E.	*E.*	*Elektriciteitsvraag gebouw*	
F.	F = 1/n(wtw)	Elektriciteitsvraag WTWasfalt	
G.	G = 8 / n(coptotaal)	Elektriciteitsvraag WP totaal in serie	

	waarde
COP beide WPs in serie	2,6
COP hydroWP2	4,2
COP WP1	5,0
COP AKM e	20
Carnot turbine zomer	0,12
COP buffer	30
COP AKM k	0,8
Carnot turbine winter	0,12
n asfalt	20

ZomerOpbrengst GJ/m2	0,1	GJ/m2/mnd
ZomerOpbrengst kWh/m2/dag	0,93	kWh/m2/dag
WinterOpbrengst GJ/m2	0,05	GJ/m2/mnd
WinterOpbrengst kWh/m2/dag	0,46	kWh/m2/dag

Zomer start	1-5-2015
Winter start	1-10-2015

With these input parameters, a surface area of 105,950 m2 should be provided with the asphalt collector system to provide terminal 3 and the F and G piers of heat and cold. This means that in winter there is a surplus of cold. In case of an asphalt collector area larger than 105,950 m2, a surplus of heat in the buffer occurs. This can be seen in the figure below.



However, since a surplus is not necessary in this research, the overall efficiency of the system is calculated based on a surface area of 105950 m2.

Opp Asfalt	**105.950**	m2
som e in tbv systemen	**9,1**	GWh
som e uit tbv systemen	**2,9**	GWh
benodigde som e in tbv system	**6,3**	GWh (e)
benodigde w uit asfalt	**15,0**	GWh (th)
benodigde k uit asfalt	**6,4**	GWh (th)