THE IPORT PROJECT: ENERGY CONCEPT CALCULATIONS

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ABSTRACT

The aviation industry, accountable for 3% of worlds GHG-emissions in 2013, is a fast growing industry (+/- 5% per year). The emitted GHG-emissions in this industry are not only emitted during flight but also during flight preparations, also referred as aircraft handling. The iPort, a rotating building at which aircrafts are handled, is a new aircraft handling concept designed to be more energy efficient in aircraft handling than current concepts. However, no solid calculations were made to support this assumption. This thesis presents an assessment of the energy use of aircraft handling at an iPort-concourse versus the energy use of aircraft handling at a traditional concept, represented by the C-concourse at Schiphol Airport Amsterdam. A material and energy flow analysis was used to quantify the energy use per case. The differences were analyzed through a comparative case study analysis. The energy use per turnaround[1] at an iPort-concourse and at the C-concourse was calculated at 2,1GJ and 5,1GJ respectively. The related GHG-emissions were calculated at 224kg CO_2 per turnaround and 304kg CO_2 per turnaround for respectively the iPort-concourse and the C-concourse. This implies that the iPort-concourse has the potential to reduce the required energy demand per turnaround with 3,0GJ and the potential to reduce the related CO_2 emissions with 80kg per turnaround. This resulted in a potential reduction of 216TJ per year with a related reduction of 5.760 ton of CO_2 emissions per year when multiplied with the, case-study related, amount of turnarounds in 2013 (72.007).

[1] A turnaround is the period of time beginning when a flight arrives at an airport and ending when the aircraft takes off again.

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Before you start to read my thesis, I want to take this opportunity to thank several people for making this project a success.

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LIST OF ABBREVATIONS

F_∞	Thrust (N)
ρ_x	Density of material x (kg/m^3)
ω_y	Rotational velocity in situation y (rad/s)
μ_i	Energy density of i (MJ/kg)
A	Area (m^2)
APU	Auxiliary Power Unit
B737	Boeing 737 aircraft
C_d	Coefficient of Drag
C_F	Coefficient of Friction
CM	Caster Mode
CO	Carbon-monoxide
CO_2	Carbon-dioxide
E_j	Energy use per turnaround for equipment j (MJ)
F	Force (N)
FF_j	Fuel Flow of equipment j in mode k (MJ/min)
FPU	Fixed Power Unit
g	Gravitational constant of 9.81 m/s^2
GHG-emissions	Greenhouse Gas emissions
GPU	Ground Power Unit
GSE	Ground Service Equipment
H_2O	Water
HC	Hydro Carbons
HTS	Hovercraft Transportation System
I	Moment of inertia (kg * m^2)
ICAO	International Civil Aviation Organization
LTO	Landing and Take-Off
m	Mass (kg)
m_d	Mass of disbalance (kg)
MEFA	Material and Energy Flow Analyses
Mtoe	Million ton of oil equivalent
n	Amount of molecules in the gas
η	Efficiency
NO	Nitrogen-oxide
NO_2	Nitrogen-dioxide
NO_x	Nitrogen Oxides
O_3	Ozone
p	Pressure (Pa)
P	Power (W)
PCA	Pre-Conditioned Air
PM	Particle Matter
P_T	Power to overcome the friction caused by tilt (W)
R	Gas constant of 8.314462175 J / (mol*K)
r	Radius (m)
SO_2	Sulfur-dioxide

SO_x	Sulfur Oxides
t	Time (s)
T	Turnaround
TF_j	Total Fuel used by equipment j given in (MJ/yr)
TIM_j	Time in Mode for equipment j in mode k (min)
TM	Tarmac Mode
TT_j	Total Turnarounds whereby equipment j is used (yr^{-1})
v	Velocity (m/s)
V	Volume per turnaround (m^3)
$v_{av,s}$	The average velocity of the sealing (m/s)
W	Work per turnaround (J)
y	Depth (m)

1. INTRODUCTION

The passenger demand in air traffic showed an increase of 5.2% for 2013 compared to 2012, thereby maintaining the annual growth rate of 5% over the last 30 years [1]. This growth in the aviation industry is expected to continue in the coming years [2]. The growth in the aviation industry is accompanied with an increased energy demand to provide the air transportation services. Along with the increase in energy used by the aviation industry increased environmental impacts are assumed [3]. Currently the aviation industry accounts for 3% of human GHG-emissions [4]. The environmental impacts from aircrafts are organized in two categories: emissions during the landing and take-off phases (LTO cycle) and during the non-LTO phases [5]. About 10% of aircraft emissions are produced during the LTO cycle [6]. Much energy related studies have been conducted within the aviation industry with goals like:

- Reducing fuel use of aircrafts [7].
- Reducing the turnaround[2] time of aircrafts[8], [9].
- Understanding the effects of aircraft emissions in higher atmosphere [10].
- Increasing the air quality at airports [11].

However, there are other activities that also have an impact on the environment and have not been thoroughly studied. An example is aircraft ground services. Aircraft ground services, also referred to as aircraft handling, are the services to an aircraft required before the take off. These services are refueling, (de-)loading and cleaning. At a regular airport multiple aprons[3] can be occupied and handled at the same time, resulting in parallel flows of goods, people, energy, water, food and waste. Currently the services are transported to the aircraft. Aircraft landing and departing, on the other hand, are sequential processes. See Figure 1 for visual representation of four aircrafts (located at aprons) being handled parallel and the sequential departure of the aircrafts. The building that connects with the aircrafts, via gates, is called a concourse.

Concourse: parallel
Multiple aircrafts can be handled at the same time at the concourse.

Runways: sequential
Only one aircraft can make use of the runway at any moment in time.

(A) **(B)**

Figure 1: Pictures of (A) the parallel handling processes at a regular concourse and (B) the sequential departure of aircrafts

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[2] A turnaround is the period of time beginning when a flight arrives at an airport and ending when the aircraft takes off again.

[3] An apron is the parking place of an aircraft.

Due to the high sequence of incoming and outgoing aircrafts it might be favorable to swift to sequential aircraft handling instead of parallel aircraft handling[4]. The concept of sequential aircraft handling consists of the idea of bringing the aircrafts to the different handling processes instead of bringing handling processes to the aircraft, like with parallel aircraft handling. Thereby condensing many parallel flows to a few sequential flows. The idea of sequential aircraft handling is developed and embodied in the so called iPort concept. The iPort-concourse is expected to be more efficient than an actual concourse. A rough expectancy foresees that this concept cuts the airport energy use and GHG-emissions by 50%. It should also result in 60% less team personnel and 85% less equipment [12].

The iPort-concourse is conceived to be a building on a rotating platform where aircrafts are handled after landing and immediately prepared for departure (see Figure 2). The departure lounges and catering facilities are located on the ground floor while the supporting processes take place in the basement, out of passengers' sight. The building will contain five floors each with own purposes. A regular concourse is a fixed building of two floors mentioned to handle the passenger streams. The supporting processes are not in this building because the supporting processes are transported to the aircrafts.

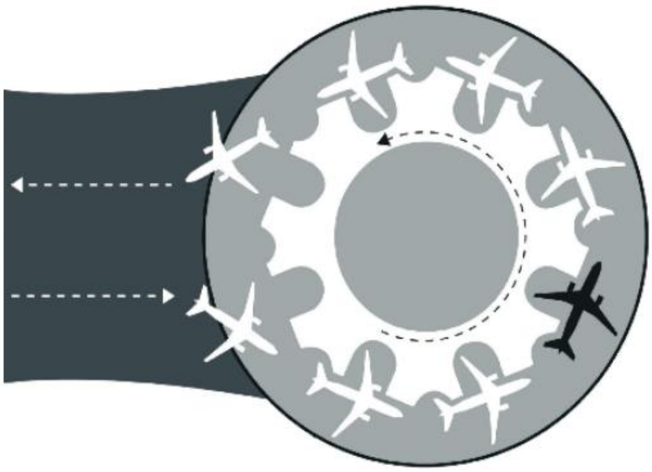

Figure 2: A schematic representation of the principle of the iPort concept

1.1. PROBLEM DEFINITION

The iPort concept turns the distributed parallel handling processes into located sequential ones. By turning the distributed parallel processes into located sequential processes reduction of energy, and thereby reduction of GHG-emissions, can be achieved. However, the assumption for energy- and GHG-emissions reduction is based on the fact that fewer aprons are needed, in comparison with an actual concourse. No solid calculation is made yet to support these estimations. There is a need to assess the energy use and GHG-emissions related with aircraft handling of the iPort-concourse versus an actual concourse.

[4] A sequential process is more like an assembly line. Assembly lines are in favor with economy of scale due to higher efficiencies.

1.2. AIM

The aim of this research is to make an assessment of the differences in energy use and related GHG-emissions of aircraft handling by using an iPort-concourse instead of an actual concourse.

1.3. RESEARCH QUESTION

How does the energy use of the iPort concourse compares with the energy use of a conventional concourse regarding the ground handling services?

To give an answer to this question the following sub-questions need to be answered:

- Which services are involved in aircraft handling?
- What are the process-chains for all the different ground handling services?
- What are the energy use, and the related GHG-emissions, of the different processes involved in aircraft handling in both situations?

1.4. THESIS OUTLINE

This thesis is organized in 8 chapters. Chapter 1 gave the motivation for the work performed in this thesis and presented the research questions. Chapter 2 presents a general background in the energy use of the aviation industry. For completeness of Chapter 2 a general background of problems with energy use and aviation industry development are presented as well. Chapter 3 presents the approach taken and the tools used. Chapter 4 and Chapter 5 present the results of the case studies. Chapter 6 presents the comparison of the results found in both case studies. Chapter 7 discusses the significance of the results and the uncertainty in the research approach. Finally, Chapter 8 is devoted to the main conclusions of this thesis and suggestions for future research.

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2. BACKGROUND

2.1. ENERGY PROBLEM

Energy plays a key role in present society. It is used for demands as lightning, heating, labor and transport. The development of our society has been based on the use of energy. However, the energy use is grown to a scale where unwanted impacts cannot be neglected anymore [13]. Figure 3 shows the worldwide fuel consumption from 1965 till 2010. The worldwide fuel consumption grew with 0.14 Mtoe per year in the second half of the 20th century and this tendency seems to prevail in the first half of the 21th century [14]. Most of this energy is gained from fossil fuels as coal, oil and gas.

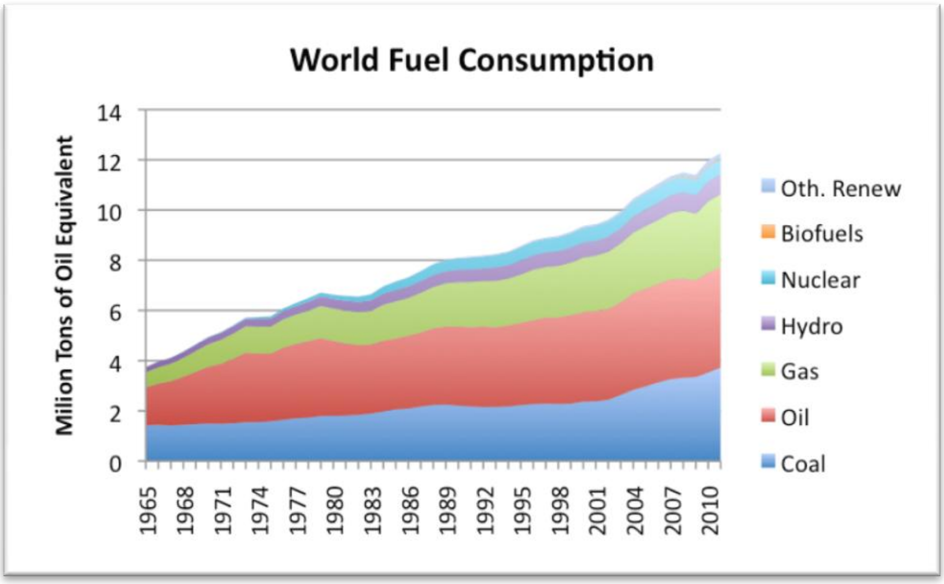

Figure 3: Historical overview of the worldwide energy consumption [14]

Even if fossil fuels have helped in the development of the industrialized world, its use has also caused some environmental –and social- problems. Section 2.1.1 and 2.1.2 describe these problems.

2.1.1. FOSSIL FUEL DEPLETION

First, fossil fuels are used much faster than they are formed[5] [15]. Therefore fossil fuels are not a sustainable source of energy. Several authors discuss the debate over the world's fossil fuel reserves. The discussion concerns not the possibility of a peak in fossil fuel production, the discussion concerns when this peak will be and if the peak will cause major social and economic problems [16] and [17]. The debate is generally framed into 'pessimists', who foresee a problematic peak in fossil fuel production [18], versus 'optimists', who expect market forces and innovation to make limitations of fossil fuel reserves irrelevant [19]. Shafiee and Topal calculated the fossil fuel depletion time to be around 35, 37 and 107 years for oil, gas and coal,

[5] Decomposed organic material that was buried under layers of mud, rock and sand formed fossil fuels during millions of years.

respectively. This calculation is based on an increasing worldwide energy demand. In contrast, if the world continues to consume fossil fuels at rates of 2006 reserves of oil, gas and coal will last a further 40, 70 and 200 years, respectively [20]. Moreover, these depletion rates are based on economically viable fossil fuel reserves. Technological improvements combined with increasing fossil fuel prices will increase the economically viable reserves [16]. In a recently published article BP stated that at current production rates the world only has 53,3 years of oil left [21]. Although it is likely that new reserves will be found, it will only delay the run out of fossil fuels. A fact is that the supply of fossil fuels is limited.

2.1.2. POLLUTION

Second, by the combustion of fossil fuels waste products are generated. These waste products have negative effects as pollutants on the environment. These environmental impacts can be local and global. The combustion of fossil fuels in cars, power plants or machines produces waste products with negative environmental impacts. These waste products are NO_x, SO_x, CO, CO_2, O_3, H_2O, Particulate Matter (PM) and unburned fuel (HC's). A brief description of the effects of the different waste products is given below. Furthermore, an overview of the waste products of fossil fuel combustion is given in Figure 4. For each waste product the related atmospheric processes, environment effects on global and local scales and effects on human health are given. For more information see [22] and [23].

NO_x

The emission of NO_x refers to emissions of NO and NO_2. NO is a relatively harmless gas, but it rapidly oxidizes to NO_2. NO_2 is a poisonous gas. That is why this particle is treated as a pollutant. It can cause adverse health effects such as nose and throat irritations, coughing, choking, headaches, nausea, stomach or chest pains, and lung inflammations (e.g., bronchitis, pneumonia) [24]. NO_2 also helps the formation of acid rain and hampers the growth of plants [25].

SO_2

Sulfur dioxide (SO_2) is formed when fuel containing sulfur (typically coal and oil) is burned. The physical effects of SO_2 include temporary breathing impairment, respiratory illness, and aggravation of existing cardiovascular disease [24]. SO_2 also helps the formation of acid rain.

CO

Carbon monoxide (CO) is an odorless, colorless gas that is highly toxic. It is formed by the incomplete combustion. The health effects associated with exposure to CO are related to its affinity for hemoglobin in the blood. At high concentrations, CO reduces the amount of oxygen in the blood, causing heart difficulties in people with chronic diseases, reduced lung capacity, and impaired mental abilities [24].

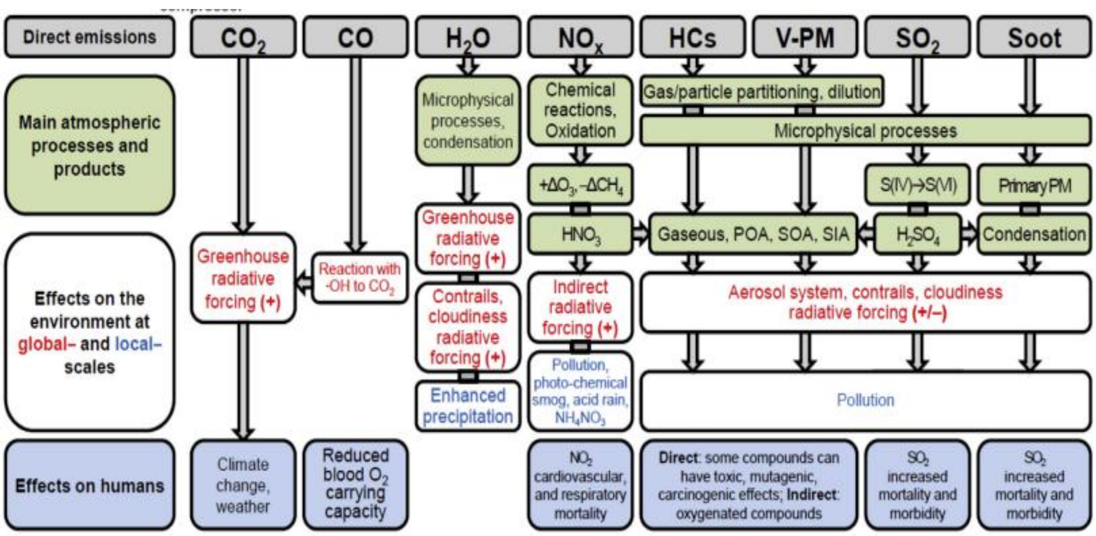

Figure 4: Products of combustion of fossil fuels and the related atmospheric processes, products, environmental effects and human health effects. [23]

H_2O

Water vapor is a greenhouse gas and an increase in concentration tends to warm the Earth's surface. However, the emissions of water vapor are low compared to the fluxes of the natural hydrocyanic cycle and thus the emissions of water vapor are not consider relevant as pollution to human health [26].

HCs (Hydrocarbons)

Unburned hydrocarbons are emitted due to inefficient combustion. Part of the unburned hydrocarbons evaporates easily. A few of these have health effects as eye, nose, and throat irritation. Headaches, loss of coordination, nausea, damage to liver, kidney, and central nervous system are also health effects of some HC's [23].

O_3

Ozone (O_3) forms as a result of HCs, CO and NO_x reacting in the presence of sunlight in the atmosphere. Ozone is known to damage lung tissue and reduce lung function. Ozone can cause health effects such as chest discomfort, coughing, nausea, respiratory tract and eye irritation, and decreased pulmonary functions [24].

PM

Particulate matter (PM_{10}) and fine particulates ($PM_{2.5}$) consist of solid and liquid particles of dust, soot, aerosols, and other matter small enough to remain suspended in the air for a long period of time. PM_{10} consists of particulate matter with an aerodynamic diameter less than or equal to 10μm and $PM_{2.5}$ consists of particulate matter with an aerodynamic diameter less than or equal to 2.5μm. Inhalation can effect morbidity and is significantly associated with mortality and to a substantial reduction in life expectancy [23].

CO_2

CO_2 normally exists in the air and is vital to plant life. It is a heavy, colorless, and odorless gas, and it is at normal concentrations essential in all life processes. At higher concentrations however (10 to 100 times higher than normal), it can accelerate human breathing and increase the effects of poisonous gases. Excessive CO_2 produces the so-called greenhouse effect which appears to have a Global Warming Effect [27]. Due to the high levels of CO_2 emissions the CO_2 concentration on the earth's surface has increased and is still increasing. These higher CO_2 concentration cause enhanced global warming, thereby increasing the average surface temperature on earth. For more information about global warming see [28] and [29].

2.2. ENERGY CONSUMPTION WITHIN AVIATION INDUSTRY

Worldwide energy use can be split into 4 main categories: Industrial, residential, commercial and energy used for transportation [30]. Within the transportation sector air transportation accounts for 8% of the used energy [31]. Aviation shows an ongoing increase in demand and supply and is thereby expected to increase its environmental impacts. Besides, the aviation industry is already the fastest growing source of GHG-emissions [32]. Therefore, this thesis focuses on the impacts of the aviation industry.

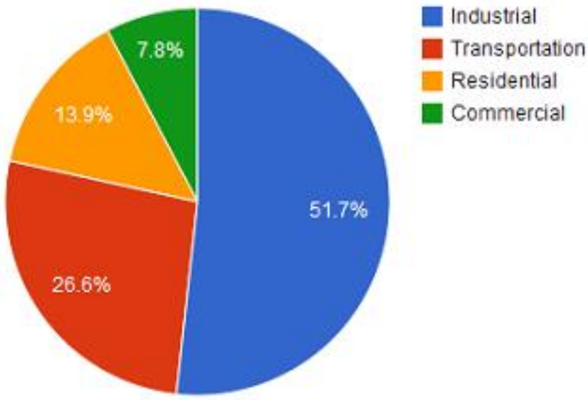

Figure 5: Overview of the world energy consumption by sector in 2012 [30]

2.2.1. DEVELOPMENT OF AVIATION INDUSTRY

17 December 1903 is often called as the day when the 'flight' was born. On this day the brothers Wilbur and Orville Wright flew their 8km long flight with the first sustained, controlled and powered flight using a machine heavier than air[6]. After this event the aircraft technology made rapid developments in World War I and World War II [33]. When World War II finished, the aviation industry boomed mostly relying on aircrafts used in the war. Nowadays, the aviation industry is one of the most influential industries worldwide. It provides major direct and indirect employment, it facilitates the expansion of the world trade and it provides opportunities for tourism and travel [34]. Figure 2 shows the development of the delivered passenger

[6] Before 1903 there already were successful attempts to fly with balloons (using helium) or with kites (using the wind)

kilometers over the past 62 years. The worldwide demand is expected to continue growing at a growth rate of 5% per year in the period 2014-2034 [1], [35] and [36].

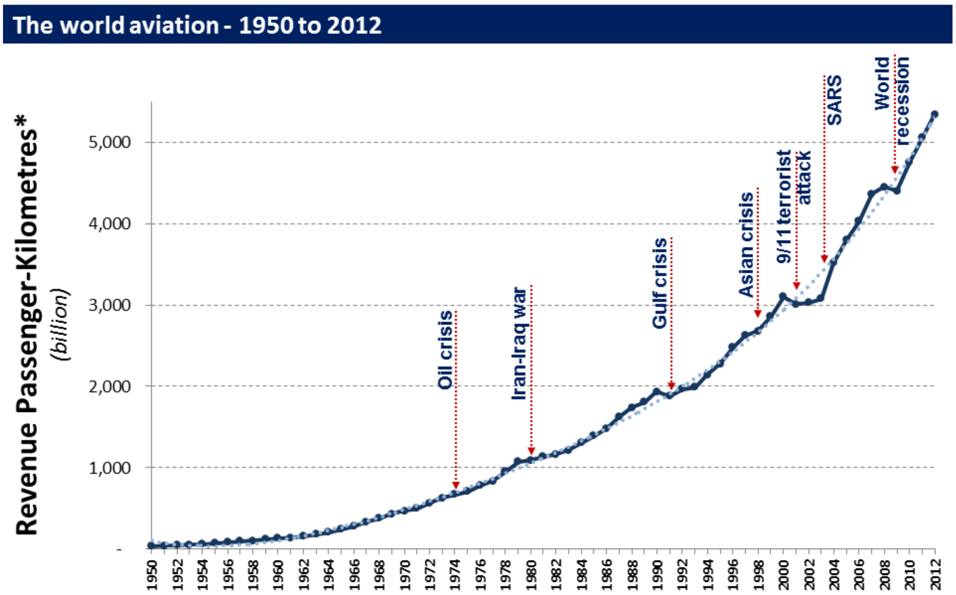

Figure 6 : The historical growth of the aviation industry [35]

2.2.2. CURRENT SITUATION OF THE AVIATION INDUSTRY

According to the Airport Council International more than 79 million aircraft movements transported 5,7 billion passengers between 1.598 airports in 2012 [37]. These airports differ in productivity from a few flights per week till a flight every few minutes. The Federal Aviation Administration divides airports into five categories based on the number of commercial passengers: Large hubs, Medium hubs, Small hubs, non-hubs, and commercial service airports. Table 1 gives an overview of the different categories with the corresponding requirements per category.

Table 1: Classification of airports according to the FAA [38].

Airport Classifications		Percentage of annual passengers boarding	Name
Commercial Service: Publicly owned airports that have at least 2.500 passenger boardings each calendar year and receive scheduled passenger service	**Primary:** Have more than 10.000 passenger boardings each year	[1% ; 100%]	**Large Hub**
		[0,25% ; 1%]	**Medium Hub**
		[0,05% ; 0,25%]	**Small Hub**
		< 0,05%	**Non-hub Primary**
	Non-primary	**[2.500 ; 10.000] passengers**	**Non-primary Commercial Service**

Due to the increase in demand for air transportation the tendency is to develop towards larger Hub-airports. The future growth of the aviation industry is expected to lead to a growth in airline fleets and a growth in airport capacity, not a significant growth in the amount of airports [23].

2.2.3. AIRCRAFT ENERGY USE

The global aircraft fuel use for scheduled flights was at 187 million tons of jet fuel in 2006 [39]. This jet fuel accounted for 30% of the operational costs [40], making fuel costs an important economical factor for airlines. Traditionally, the energy use, with the accompanied emissions, of aircrafts has been addressed in two categories. On the one hand there are aircraft emissions causing pollution on local scale. This energy use, with accompanied emissions, is embodied by the landing and take-off cycle (LTO cycle). On the other hand there are the non-local emissions of aircraft. These emissions are caused due to energy use above the mixing height altitude (non-LTO emissions) [41].

2.2.3.1. LTO cycle

The LTO emissions (30% of the aircraft emissions) are emissions emitted at ground levels, till 914 meter of height. The LTO cycle consists of four phases. In the first phase the aircraft descends from cruising height towards the runway and lands at the airport (Approach). After landing the aircraft enters the ‘idle’ phase in which it proceeds at low speeds to and from the gate (Taxiing). The third phase is the take-off phase in which the aircraft accelerates and leaves the ground. At last the aircraft will switch to the climb-out phase. Figure 7 gives a graphical representation of these four phases. The distance that the aircraft needs to fly has no influence on the emissions within the LTO cycle.

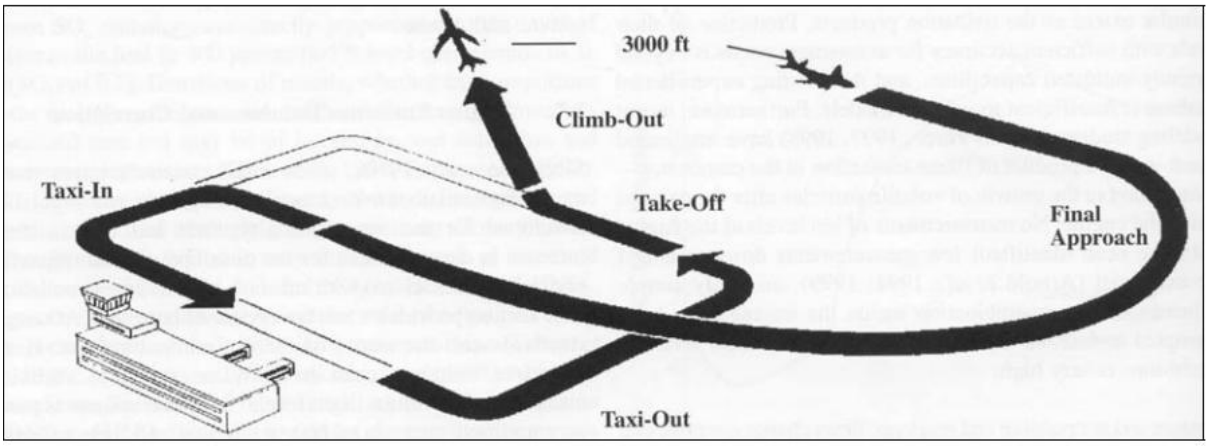

Figure 7: A graphical representation of the four stages in the LTO-cycle.

In each LTO phase the aircraft operates under a different engine thrust (F_{∞}). Table 2 gives the four LTO phases and the accompanied time and thrust within each phase according to the International Civil Aviation Organization (ICAO) with the fuel flow of a typical Boeing 737 new generation aircraft. The ICAO assumes that the approach-phase last for 4,0 minutes with the engines at 30% F_{∞}. The taxi-phase is assumed to be 26 minutes at 7% F_{∞} , the take-off phase is at 100% F_{∞} and lasts 0,7 minutes and in climb-phase takes 2,2 minutes in which the engines are set back to 70% F_{∞}. For the fuel flows [kg/s] and emission data of other aircraft engines see [42].

Table 2: The four stages of the LTO-cycle. The time in operating mode and fuel flows of a CFM56-7B22 engine[7] are given according to the ICAO [42].

Operating Mode	Thrust setting [F_∞]	Time in operating mode [min]	Fuel flow [kg/s]
Take-off	100 %	0,7	1,021
Climb	85 %	2,2	0,844
Approach	30 %	4,0	0,298
Taxi/ground idle	7 %	26,0	0,105

2.2.3.2. Non-LTO cycle

The non-LTO cycle or cruise mode is defined as all the activities within aviation that take place above 914 m (3.000 ft). The emissions emitted in the non-LTO cycle are all emitted above the mixing height altitude, the so called inversion height [43] and [44]. Therefore the emitted particles maintain a longer period of time in the atmosphere compared to ground level emissions. Although early research showed that 90% of the emissions were non-LTO emissions [6], recent research showed that nowadays only 70% of the emissions are emitted above the inversion height [36]. This change is mainly explained by technological developments and change in flight patterns.

Apart from the energy used by the aircraft, other activities are present at airports that contribute to the total energy consumption of the aviation industry. The most important activities are the energy use of the buildings at the airport and the energy use of the ground service equipment (GSE) [24].

2.2.4. GROUND SERVICE EQUIPMENT

''The equipment used in supplying the services to aircrafts is called ground service equipment (GSE)'' [9]. The GSE are strictly linked to airport operations. So, the vehicle fleet is expected to increase with an increasing amount of aircraft operations. The equipments differ for different aircraft sizes and at all airports the equipments have different engines installed, different quality of fuel injected and a different equipment age. Therefore, there are no common characteristics for GSE and does the ICAO databanks do not include any information about GSE energy use or emissions [23]. Nevertheless, assessments of GSE fleet have been conducted. See Appendix A for the different powered vehicles in GSE fleets of American airports.

Research indicated that the energy use of aviation related operations on the ground is 3% of the energy use of aircrafts [39] and [45]. This is equivalent to the worldwide use of 5.6 Million tons of diesel in 2006[8]. Despite this significant energy use only few studies have investigated the emissions caused by the ground service equipment.

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[7] Boeing 737 new generation series are equipped with engines from the CFM56 series [42].

[8] Ground related operations mostly run with diesel engines. The energy density of diesel and jet fuel is comparable (about 43 MJ/kg) [57].

Some studies indicate that GSE contribute a major fraction of the total airport emissions. A study carried out at the McCarran airport in Las Vegas reported that approximately 60% of the total airport emissions are related to GSE [23]. The NO_x concentrations at Zurich airport were affected by emissions from ground support vehicles (see Figure 8) [46], while impact of GSE emissions on ozone and $PM_{2.5}$ concentrations at the Hartsfield–Jackson Atlanta International airport were estimated smaller and more locally compared to the impacts of aircrafts [11].

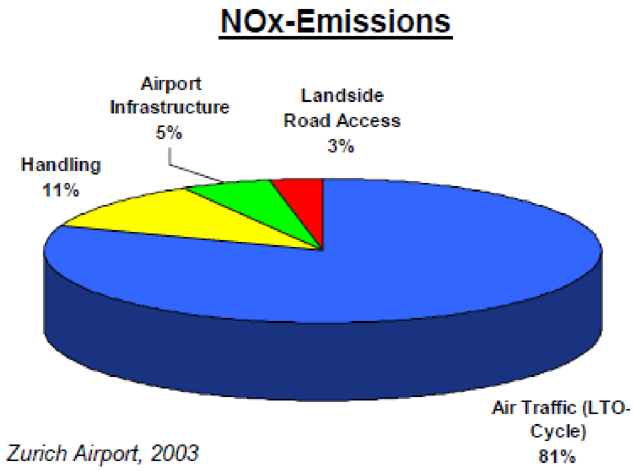


Figure 8: NOx emissions at Zurich Airport with the source of emission.

The emissions caused by GSE differ a lot over several studies. The figures vary from a few percent till 60% of the total emissions. Variations in emissions are expected due to differences in GSE fleets in numbers, age, engine types and sizes. But differences of a few percent till 60% are too much to be explained by this argument. The variation in GSE emissions is caused by boundary differences. In some studies the vehicles used by the passengers to arrive to the airport (cars, busses) are also accounted as GSE. Since these vehicles are equipment in supplying the service of delivering the passengers to the aircraft. While other studies stated that GSE is the equipment used in supplying the services to aircrafts at airside. This difference is the main cause of the huge variation in environmental impacts of GSE. The system boundaries need to be the same by comparing different studies and therefore the results of previous named studies are incomparable. The next section describes the services delivered to aircrafts. This will help understand the purposes of the GSE.

2.2.5. AIRCRAFT HANDLING

Aircraft handling services are the services delivered to the aircraft to prepare it for the next flight. The goal of aircraft handling is to deliver the services as fast as possible. The timeframe in which all these services are delivered to the aircraft is called the turnaround time [9]. A shorter turnaround time results in more flights per aircraft, which has large economical benefits. The definition of turnaround ground handling services is: *'all the handling activities taking place in and around an aircraft between the moment the aircraft comes to a complete standstill at the aircraft stand (blocks-on) till the aircraft is push-back from the gate for departure (blocks-off)'* [47].

The following activities can be distinguished as service supplied to the aircraft (split into services above the wing and below the wing): [9]

Above the wing:

- Connecting passenger bridge(s) and/or boarding stairs
- De-boarding
- Catering service
- Cabin cleaning
- Cabin security check
- Cabin check
- Boarding
- Disconnecting passenger bridge(s) and/or boarding stairs

Below the wing:

- Supply of electricity by: connecting Ground Power Unit (GPU) or Fixed Power Unit (FPU)
- Placing the wheel chocks at the landing gears
- Unloading baggage/freight
- Water service
- Toilet service
- Fuel service
- Placing/removing safety cones
- Loading baggage/freight
- Removing the wheel chocks at the landing gears
- Push-back handling

De-icing is a service delivered to an aircraft to prevent the aircraft from freezing, this service is only required when it is freezing and it is delivered before take-off on a different location than the apron.

Figure 9 shows a precision timing schedule for a Boeing 737 adopted by an Australian carrier for domestic turnaround operations in Australia [8]. All processes are required to be finished by the 'latest finish times' to prevent causing knock-on delays on following processes. This schedule is missing water services, toilet services, electricity supply, de-boarding and push-back handling but it gives an overview of the way handling services are planned.

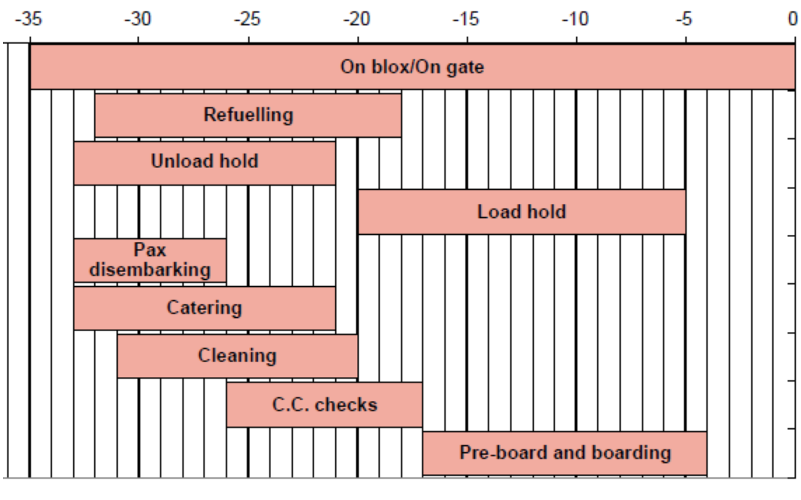


Figure 9: A precision timing schedule for a Boeing 737-800 for domestic operations in Australia

Research within aircraft handling usually focuses on reducing the turnaround time [9], [48] and [49]. The main reason is the economical driver behind this parameter. Other studies focused on the local environmental impacts of aircraft handling. However, the interests in the energy use of the GSE are not evident. All the previous research towards the performances of GSE is focused on the emissions and not on the energy use. While the underlying cause of emissions is the use of energy. The next chapter describes the method used in this research to compare the energy use, with accompanied emissions, of aircraft handling in two different concepts.

3. METHOD

In this research project the consequences in energy use in aircraft handling were calculated for substitution of a traditional concourse by an iPort (the new design). In Chapter 1 a new concourse design was discussed. This design was developed to increase the energy efficiency of aircraft handling. Chapter 2 provided background knowledge of the aviation industry and ground services. Here it became clear that generalization of energy use of the GSE is nearly impossible due to the high diversity among the equipment over different airports. This research was performed through case studies considering the difficulties with generalization. In both cases a Material and Energy Flow Analysis (MEFA) of the handling processes was conducted in order to compare the energy use of the ground handling services. Section 3.1 briefly describes the used samples. Section 3.2 describes the used tools and in Section 3.3 is the sequence of steps taken that allowed comparing the energy use of the samples found. Finally, in Section 3.4 are the project boundaries listed.

3.1. SAMPLES

In this research two cases were compared:

- Case 1: An actual traditional design embodied by the C-concourse at Schiphol
- Case 2: A hypothetical iPort-concourse at Schiphol.

Figure 10 shows the geographical maps of both case 1 and case 2. In case 2 the iPort-concourse substituted the C-concourse. Both concourses have the same capacity. The C-concourse has 12 aprons with a capacity of one turnover per hour (turnaround time plus planning buffer time). The iPort-concourse has 8 aprons with a capacity of one turnover per 40 minutes (turnaround time plus additional rotation time).

(A)

(B)

Figure 10: A geographical map of: (A) the C-concourse case and (B) the iPort case applied to Schiphol

3.2. USED TOOLS

3.2.1. CASE STUDY ANALYSIS

Case study research is a useful mean of contributing to the base of knowledge through improved understanding of phenomena. Detailed case specific studies serve as single experiments that contribute to a developing body of science. At its essence, case study research is a way of investigating a research topic by systematically following a set of predetermined methods [50].

Plenty of literature is available regarding case study methodology, for more information see [51], [52], [53] and [54].

3.2.1.1. Comparative case study

With comparing case 1 with case 2 not the whole cases were observed but only the part of the cases where the cases differ. After all, observing the complete cases given in Figure 10 would be a tremendous task that misses the goal of this research. Within this comparative case study analysis approach additional focus was given to the system boundaries. Only the differences between both cases should be within boundaries. Also, both cases needed to have the same boundaries in order to make a fair comparison. Therefore the physical boundaries of the case studies are: In case 1 the C-concourse and in case 2 the iPort-concourse.

3.2.2. MATERIAL AND ENERGY FLOW ANALYSIS (MEFA)

MEFA is based on two scientific principles, system approach and mass balance. System approach is a method where situations are viewed as a system composed of interconnected parts and related to other systems. Mass balance is an input-output methodology where inputs must meet outputs on account of the laws of nature. An MEFA system consists of the system boundary, processes, flows, and stocks. The basis for any MEFA is a model or scheme for the system examined, containing all relevant process steps and the material and energy flows between them [55].

3.3. THE STEPS TAKEN

This section presents the sequence of steps that allowed comparing the energy use of handling services among both the iPort concept and the actual concept**.** Figure 11 gives an overview for the steps followed in this research.

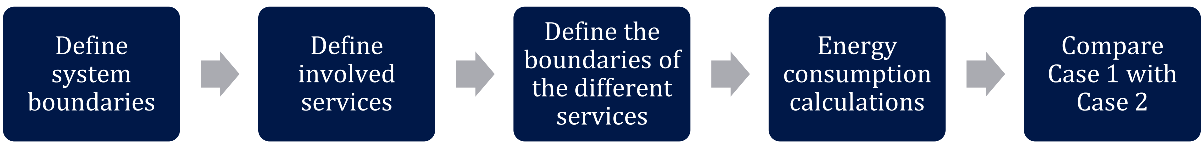


Figure 11: Schematic presentation of the process steps of the research project

3.3.1. DEFINE SYSTEM BOUNDARIES

The research started with defining the system-boundaries of the comparative case study analysis (see Section 3.2.1.1). These boundaries are the physical boundaries[9] wherein case 1 and case 2 differ.

3.3.2. DEFINE INVOLVED SERVICES

Next, the different aircraft ground handling services that took place in the system boundaries were observed.

[9] Physical boundaries are area restricted boundaries. This research concerns the energy use of the services delivered to the aircraft within in this physical boundary.

3.3.3. DEFINE THE BOUNDARIES OF THE DIFFERENT SERVICES

Thereafter, the requirements to deliver the services involved in the ground handling of aircrafts were investigated. All the requirements per service are called the process-chain per service[10]. This was to investigate all the differences in activities caused by the substitution of the C-concourse by the iPort-concourse. The boundary of each process-chain per service is where the process-chain for delivering the service is the same in both cases. Due to this approach all the differences in activities, with related energy demand, in aircraft services between the cases lay within the boundaries of the research.

For defining the ground handling services with associated process-chain personal observations, expert interviews and literature research were used. Figure 12 gives a schematic overview of the physical system under study and its boundaries. The boundaries included the processes and its energy use in transporting the flows of materials to and from the system under study.

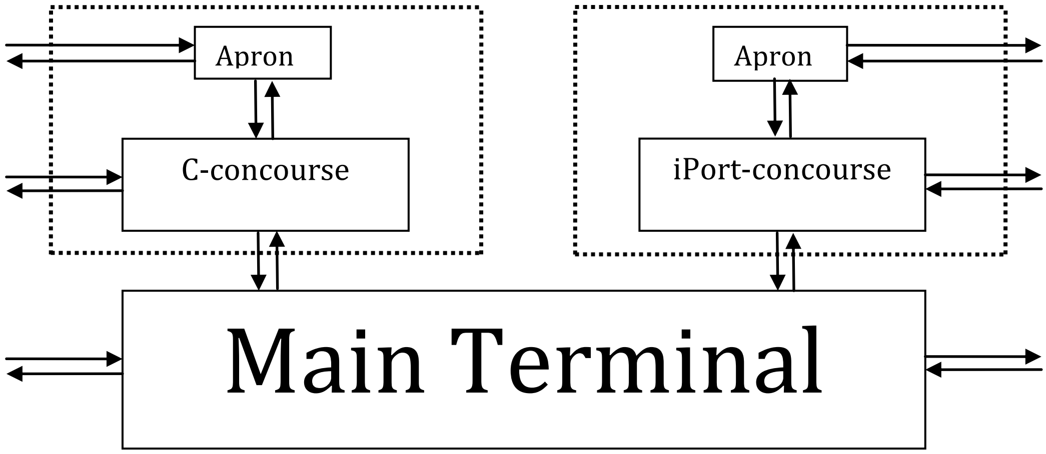


Figure 12: A schematic overview of the physical system boundaries of the MEFA for both situations. The dashed lines are the system boundaries and the arrows are material and flows entering or leaving the system.

3.3.4. ENERGY CONSUMPTION CALCULATAIONS

Once both the physical as processes-chain boundaries were defined and the system scheme was made, the material and energy flows related to the different processes needed to be found.
For case 1 this information was gained by observations and contact with an airliner and Schiphol. Data was:

- Machinery Involved in the delivering of the different ground services
- Average fuel consumption of the machinery
- Average workload per machinery (machinery can be used for different tasks)
- Tank-data
- Amount of turnarounds per year

The average energy use per turnaround was given by Eq. 1 or Eq. 2 (depending on the nature of the information gathered):

[10] The process-chain of a service is the activities at Schiphol required to deliver a specific (handling) service to an aircraft.

$$E_j = \sum TIM_{jk} * FF_{jk} \qquad \text{Eq. 1}$$

$$E_j = \frac{TF_j}{TT} \qquad \text{Eq. 2}$$

Where:

E_j = energy use per turnaround for equipment j given in MJ
TIM_j = Time in Mode for equipment j in mode k given in minutes
FF_j = Fuel Flow of equipment j in mode k given in MJ per minute
TF_j = Total Fuel used by equipment j given in MJ per year[11]
TT_j = Total Turnarounds whereby equipment j is used given in per year

The sum of the energy use per turnaround of all equipment will give the energy needed per turnaround ($E_{tot} = \sum E_j$).

For case 2 the information was gained by interviews with the architects of iPort. Because the iPort concourse is a hypothetical case no actual data could be found. Therefore assumptions were used within this concept. Literature research combined with the assumptions was used to predict the energy consumption for the different services within this concept using equation 1. Assumptions were different TIM's and comparable energy use of the equipment used in the iPort concourse with the values found in the literature.

3.3.5. COMPARE CASE 1 WITH CASE 2

The results of the case 1 and case 2 are presented in a Sanky diagram. A Sankey diagram[12] presents the results in an understandable way, making the results available for a wider audience. The diagrams were constructed using the software on SankeyMatic.com [56] inserting the values of the energy flows. The energy consumptions were converted to emissions using measured data gained from Schiphol and standard values of 'Stichting Klimaatvriendelijk Aanbesteden & Ondernemen' [57]. The values of case 1 and case 2 were compared to each to get a better understanding of the energy use of the iPort-concourse and of a conventional concourse regarding the ground handling services.

3.4. PROJECT BOUNDARIES

- This project only focused on energy used by the aircraft handling processes caused by the processes that take place within the defined system. So the energy use of the equipment used was taken into account. And not the energy used for manufacturing of the equipment.
- The comparative case study analysis focused on narrow-body aircrafts because narrow-body aircrafts are handled in amounts high enough to supply the iPort-concourse. More specifically: Boeing 737-800. For this reason was the C-concourse selected, because mostly Boeing 737-800 aircraft's are handled at this concourse.
- The ground services were conducted by one specific ground handling company
- Aircraft taxiing of 5 minutes before and after the turnaround is included in the case studies.

[11] Within this approach it is important to know the fuel fraction used for the activity under study.
[12] For more information about Sankey diagrams see [88].

4. CASE 1: C-CONCOURSE

As discussed in Chapter 3, the C-concourse is the concourse representing the standard. This Chapter follows the methods as described in Chapter 3 in order to retrieve the energy use per turnaround. Section 4.1 describes the case of the C-concourse. Section 4.2 elaborates the flow diagram of the C-concourse. Section 4.3 describes the involved services with its corresponding process-chain. Finally, Section 4.4 gives the energy use, with related GHG-emissions, of system under study.

4.1. CASE DESCRIPTION

Schiphol airport Amsterdam is the largest Dutch and an important European airport. It is located 14km southwest of Amsterdam. It is the world's fourteenth busiest airport with 52,6 million passengers in 2013 [58]. The needed facilities to board and de-board passengers from an aircraft are located in a building called ´main terminal'. Within the main terminal passengers purchase tickets, go through security and deliver or receive their baggage. The main terminal is in contact with different concourses. These concourses provide access to the aircrafts through gates. So, a concourse is an extension of a terminal.

An aircraft that lands at Schiphol Airport is transported to an apron, a standing place for the aircraft. Here a connection is made with a gate and then the aircraft is handled. See Figure 13 for an overview of Schiphol Airport.

Figure 13: A schematic overview of Schiphol airport with terminology of the buildings included. Adjusted from [59]

At the apron the aircraft is prepared for the next flight. These preparations are referred to as ground services. These services are conducted by different actors. Schiphol airport is the owner of the area and the buildings. The airlines pay Schiphol Airport to land at Schiphol Airport and they also pay for the ground services. Schiphol Airport subcontracts the ground equipment services. The maintenance of these equipments is done by a different actor. Table 3 shows the actors that interact within the boundaries of this research.

Furthermore, the C-concourse has 12 aprons. A turnaround took 50 minutes in 2013 and an additional 10 minutes planning buffering time was counted, resulting in a production of one turnaround per hour per apron.

Table 3: An overview of the actors at Schiphol Airport within the research boundaries.

Schiphol Airport		
Airlines	**Ground services**	**GSE maintenance**
• Coredon • KLM • Transavia • Vueling	•Aero Groundservices B.V. •Aviapartners •KLM ground sevices	

4.2. FLOW DIAGRAM C-CONCOURSE

The physical boundaries for the C-concourse case are graphically shown in Figure 12 (Section 3.3.3). The analysis was focused on turnarounds of aircrafts at aprons at the C-concourse in 2013. The material and energy flows are calculated per turnaround. An apron at the C-concourse had the material and energy flows per turnaround as given in Figure 14. From the runway an aircraft is transported to the apron bringing luggage, water, consumables, kerosene and passengers with it (arrow 5). Form the apron to the runway (arrow 6) the same aircraft leaves with new luggage, fresh water, new consumables, extra kerosene and new passengers. Passengers (H) leave the apron through the C-concourse. A new set of passengers (G) enters the apron through the C-concourse. These flows consume electricity to fulfill their own transport from and to the apron. The flows from and to the apron from aircraft GSE facilities are consuming electricity and diesel (arrow 3 and arrow 4). An aircraft taxiing from and to the apron consumes kerosene. The consumption of diesel and kerosene goes with direct emissions to the environment. The box with the dashed lines gives the boundaries of this research.

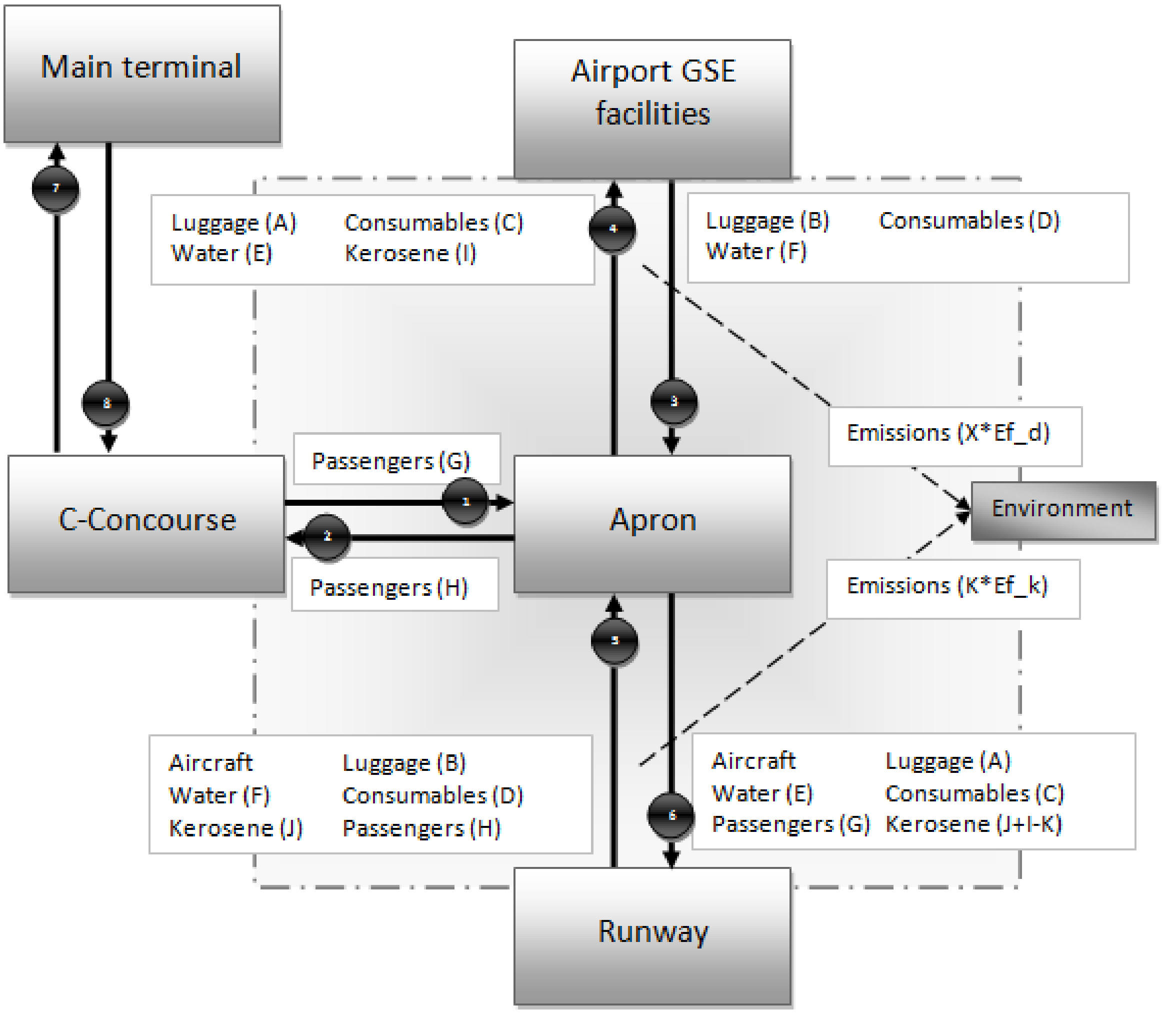


Figure 14: The Material and energy flow diagram of an apron at the C-concourse.

4.3. HANDLING SERVICES

To keep the turnaround time as short as possible all services are conducted immediately after the landing of the aircraft. So, the apron is prepared before the aircraft arrived by the set up of the GSE. After the landing of an aircraft the aircraft transports itself to the apron. Right away, the aircraft is set 'blocks on' and is connected to a ground power unit (GPU). From this moment most of the ground services are delivered using the already prepared equipment. The observed ground services delivered to a Boeing 737-800 aircraft at the C-concourse are given in Figure 15. The coming sections describe each service with the related process-chains. The findings are based on personal observations and interviews with experts.

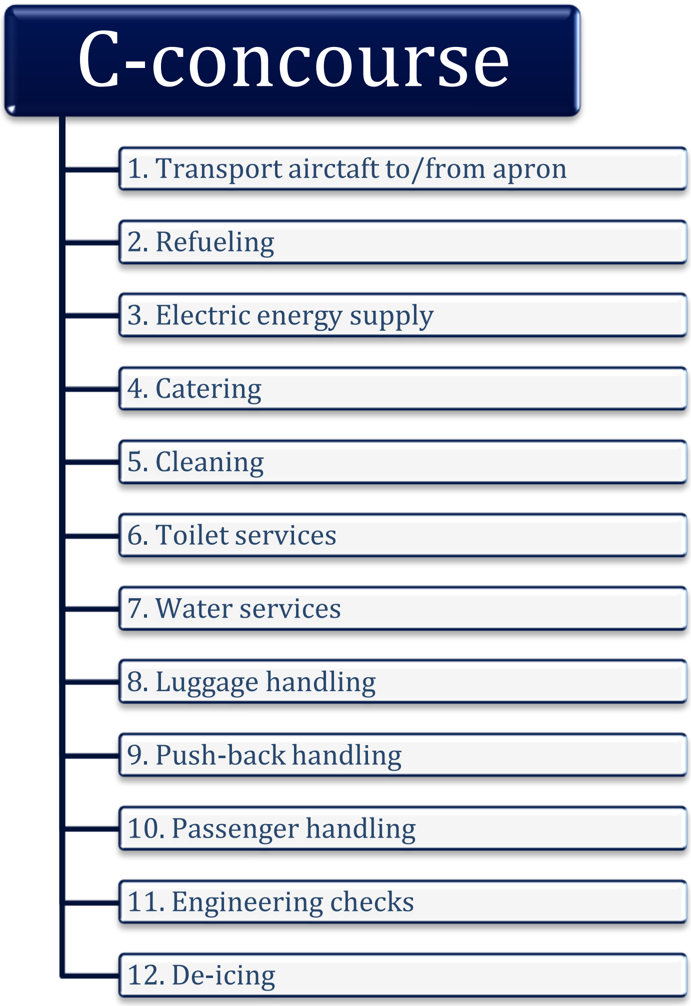
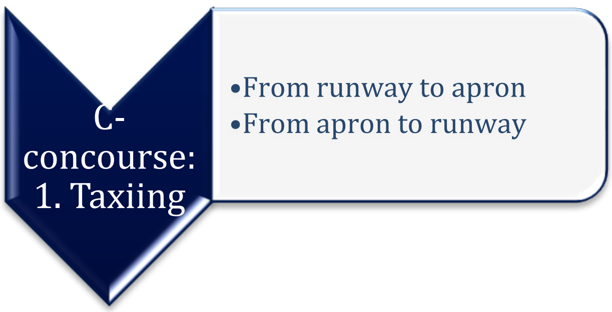


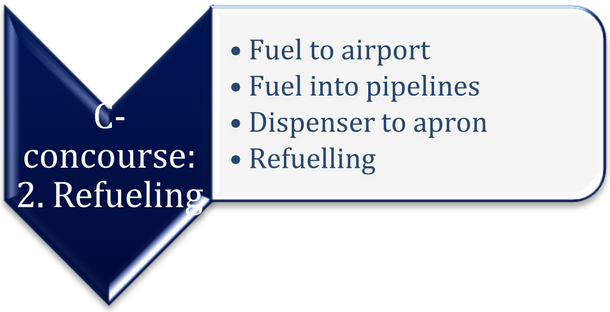
Figure 15: The observed services delivered to a Boeing 737-800 aircraft at the C-concourse

4.3.1. TRANSPORT AIRCRAFT TO/FROM APRON



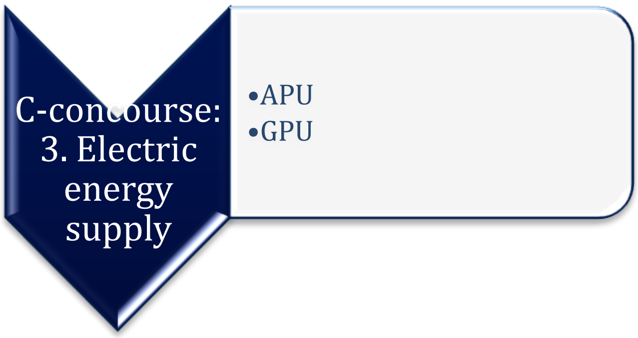
After landing the aircraft needs to be transported to the apron for aircraft handling. This transport is realized by taxiing the aircraft to the apron using aircraft engines. Taxiing is driven by one of the two aircraft engines. The same processes are used by transporting the aircraft from the apron to the runway.

4.3.2. REFUELING



Aircraft fuel, kerosene, is supplied to Schiphol airport by pipelines from the Port of Rotterdam and/or Amsterdam. The kerosene is stored in tanks that are connected with an underground network of pipelines. The fuel is pumped into these pipelines and pressurized. By refueling the aircraft a dispenser is transported to the apron. The dispenser makes a connection between the pipelines and the fuel tank of the aircraft. The kerosene is moving through this dispenser to the fuel tank of the aircraft due the pressure in the pipelines. The dispenser lowers the speed of the moving kerosene to prevent damage to the fuel tank of the aircraft. The energy using equipments are the dispenser and the system used to pressurize the pipelines.

4.3.3. ELECTRIC ENERGY SUPPLY



The controlling systems of an aircraft, running on electricity, may not be shut-down due to long start-up times of the systems (in order of an hour). A flying aircraft produces electricity with engine driven generators. The engine driven generators do not deliver the required power when an aircraft is landing. Therefore an auxiliary power unit (APU) is turned on to deliver the electricity (400Hz – 16A). The APU runs on jet fuel. After the aircraft arrives at the apron a ground power unit (GPU), running on diesel, is connected to the aircraft to deliver the electricity for the onboard systems. Therefore the APU can be turned off. GPU’s are standing at every apron of the C-concourse. The energy using equipments are the GPU and APU.

4.3.4. CATERING SERVICES

C-concourse: 4. Catering

- Truck prepaired
- Exchange of old with new
- Deloading the truck

Catering services deliver consumables as food, drinkables and blankets to the aircraft. Catering services also take the (remains of) the previous consumables with them. Per aircraft two catering trucks are prepared at a specific building. These trucks transport to the apron and connect with the aircraft, as seen in Figure 16. This connection allows the exchange of new consumables with the (remains of) the previous consumables. The energy using equipments are the catering trucks and the equipment used to prepare the catering trucks.

Figure 16: The catering truck (almost) connected to an aircraft

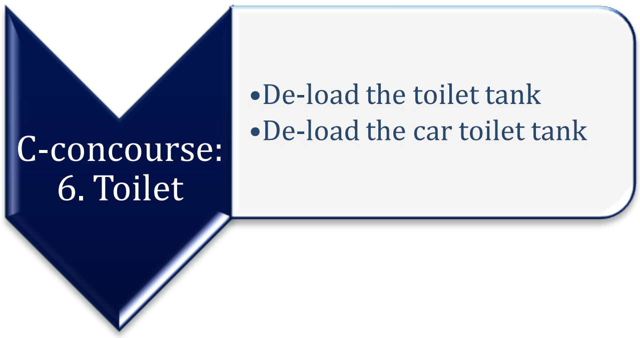
4.3.5. CLEANING SERVICES

C-concourse: 5. Cleaning

- Transport cleaners to aircraft
- Cleaning
- Transport to other aircraft

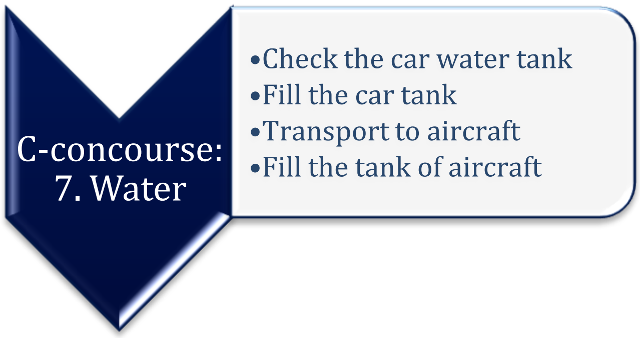
During a turnaround an aircraft is cleaned from the inside. The cleaners are transported to the aircraft by car and enter the aircraft from the backside entrance. Cleaning services happens in the period while passengers de-board until boarding of the new passengers. The energy consuming equipments are the cars used for transport and some of the cleaning equipment.

4.3.6. TOILET SERVICES



The toilet-tank, filled with diluted water, is emptied after each flight. A car supplied with an additional tank drives to the aircraft and de-loads the tank using gravitational forces. The car drives to a diluted water depot to de-load the water there. Energy using equipments are the car and the water cleaning facilities.

4.3.7. WATER SERVICES

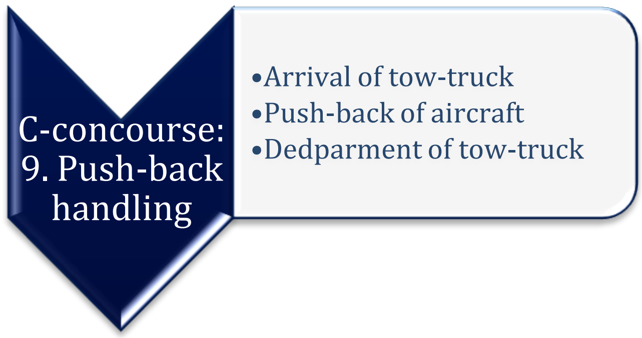


Drinking water is supplied to the aircraft by a water-truck. This is a simple car with an additional water-tank. The water is tanked in a specific building. To ensure that the water is not infected the water tanks are often checked and cleaned with hydrogen peroxide. The energy using facilities are the water-truck, the cleaning facilities, the testing facility and pumps to fill the tanks.

4.3.8. LUGGAGE HANDLING

The luggage is handed-in by the passengers at the check-in desk. Then the luggage is sorted by a complex luggage-system. In the end the luggage that needs to be on the same aircraft is concentrated to one of the luggage basements. The luggage is loaded into trolleys and these trolleys are transported, by tractors, to the apron. After arrival of the aircraft the old luggage is unloaded and the new luggage is loaded. The unloaded luggage is transported, in trolleys by tractors, to the luggage system in the basements and from there delivered to the arrival halls. The energy using equipments are the tractors, (un)loading equipment and the conveyors of the luggage system.

4.3.9. PUSH-BACK HANDLING

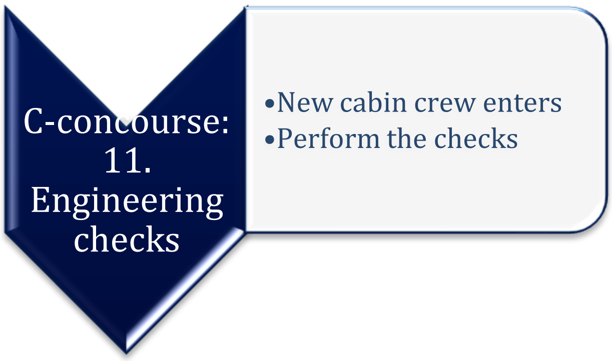


Push-back handling service is the service of pushing the aircraft back from the apron on the runway. The aircraft is thereby pushed back on the runway by a tow-truck. An aircraft is able to drive backwards itself but damages the buildings with the forces that are released by this action. Also noise is a reason the use the push-back handling service. The tow-truck has a standing place at the apron.

4.3.10. PASSENGER HANDLING

Passenger handling starts at the moment that passengers arrive at Schiphol. The passengers check in at Schiphol Airport thereby delivering their luggage. After checking-in the passengers and their hand-luggage undergo a security check. Once the security check is finished the passengers arrive in the shopping area to spend some time. Later the passengers check-in at the correct gate at the correct concourse. Then they arrive in a lounge-room with only passengers that are on the same aircraft. When the aircraft arrives, the aircraft connects with an electric passenger bridge. The on-board passengers leave the aircraft though this bridge. The off-board passengers will enter the aircraft afterwards. The energy using equipment is the electric passenger bridge.

4.3.11. ENGINEERING CHECKS



Engineering checks are performed according to the safety protocol. This means that the most important system values are checked. The APU needs to be on to generate the needed air flow required for the start-up of the engines. When the engines are started the system values can be checked.

4.3.12. DE-ICING SERVICES

When the temperature is around freezing temperature or lower, an aircraft is supplied with de-icing services. Therefore the aircraft is transported to a qualified area where it is de-iced. De-icing means a treatment with chemicals in order to reduce the formation of ice on the aircraft. After treatment the aircraft is transported to the runway ready for take-off

4.4. ENERGY USE WITHIN THE C-CONCOURSE

The energy use of different activities in a turnaround at the C-concourse are given in Figure 17, all numbers are given in MJ. For further elaboration of the given data see Appendix B. Appendix C gives the input data for the Sankey diagram. The total energy use of the system under study is 5,1GJ[13] per turnaround at the C-concourse. Most of this energy is used to taxi the aircraft from and to the apron and to power the APU. Most of the diesel is used to power the GPU. Also the amount of electricity used is almost negligible compared to total energy use per turnaround. The correlated CO_2 emissions (a total of 304 kg CO_2 per turnaround) are given in Table 4 using the emission factors given in appendix F.

[13] 1 GJ equals 1.000 MJ

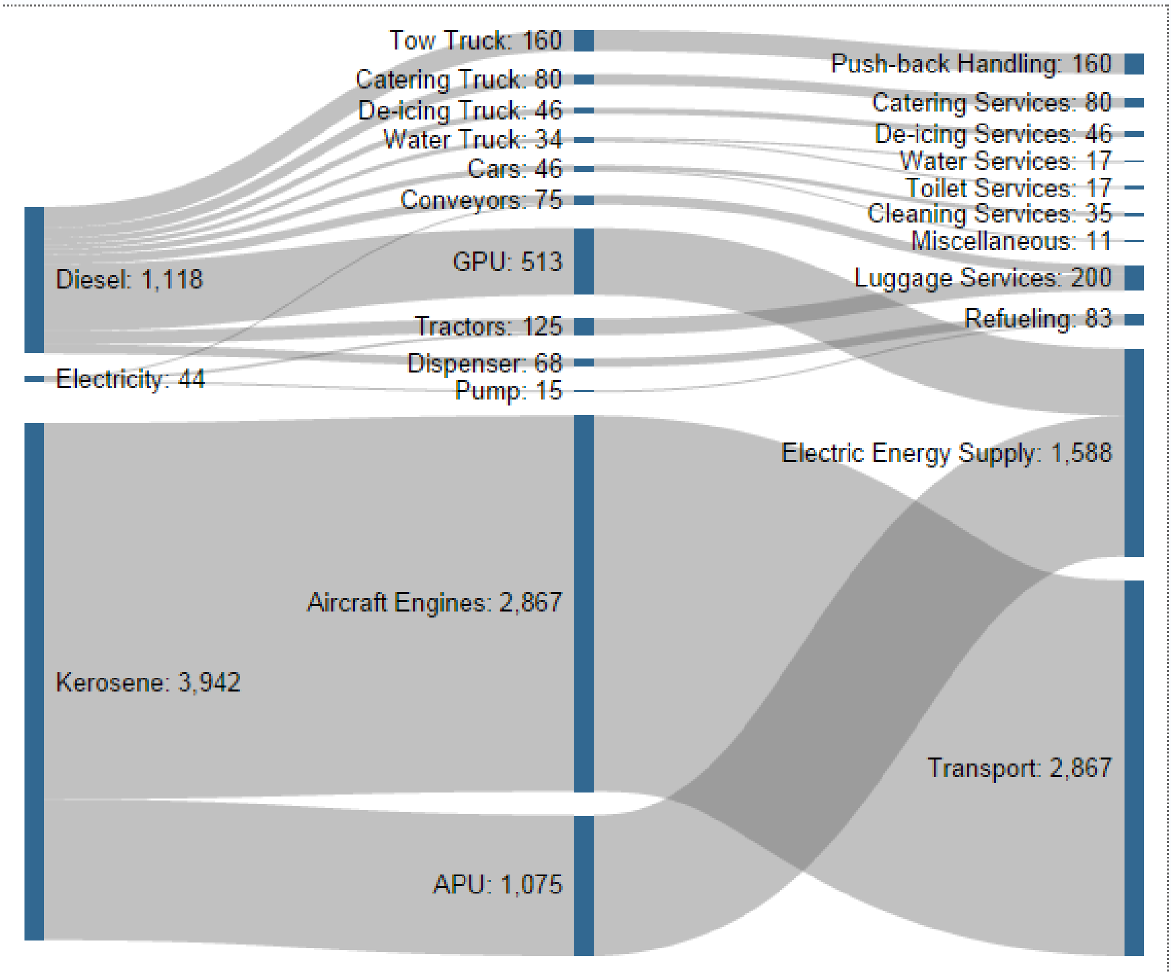


Figure 17: The energy flows per turnaround at the C-concourse

Table 4: The CO_2 emissions per turnaround for the C-concourse

	MJ	g CO_2 / MJ	g CO_2
Electricity	44	126,4	5.562
Diesel	1.118	60,5	67.639
Kerosene	3.942	58,6	231.001
Total	5.104	-	304.202

5. CASE 2: THE IPORT-CONCOURSE

As explained in Chapter 1, the iPort-concourse represents the concept of sequential aircraft handling. This Chapter follows the methods described in Chapter 3 in order to find the energy use per turnaround. Section 5.1 describes the main elements of the iPort-concourse. Section 5.2 elaborates the flow diagram of the iPort-concourse. Section 5.3 describes the involved services with its corresponding process-chain. Finally, section 5.4 gives the energy use, with related GHG-emissions, of the system under study.

5.1. CASE DESCRIPTION

The iPort concourse is a hypothetical case. This hypothetical case comprises the iPort-concourse at Schiphol Airport on the location of the C-concourse (see Figure 18). A case description of Schiphol Airport is found in Section 5.2. The iPort concourse is devised to have 8 aprons with a turnaround time of 25 minutes and an additional rotation time of 15 minutes, resulting in a production of one turnaround per 40 minutes per apron.

Figure 18: A schematic overview of Schiphol airport with the iPort-concourse replacing the C-concourse.

The iPort-concourse is conceived to be a building of seven levels split up in two parts: 'the rotating part of the iPort' and the 'stationary part of the iPort'. Figure 19 gives a schematic overview of all the seven levels. Level -2 is a corridor under the rotating part of the iPort-concourse. This corridor is conceived to be used as transportation pathway for all the needs in a turnaround. Level -1 consists of a stationary part (the center) and a rotating part (the ring). The rotating part is conceived to be a caisson floating on water holding the apron. This caisson is hollow and holds all technical installations for supplying aircraft handling services as refueling and supply of water. The stationary center is used to supply the material and energy flows to the apron. Level 0 (ground level) consists of rotating gates and a stationary center used to supply passengers to the gates. The aircraft connects with the rotating gates while standing on the rotating apron. After 1 round the aircraft leaves the apron of the iPort-concourse resulting in that every aircraft enters and leaves exactly the same way (as seen in Figure 20). Level 2 and 3 are stationary levels used for needs of passenger and as entrance. Level 4 is the roof. Figure 21 gives a cross-section of the building with the rotating parts highlighted in red. For more information about the working principle of the iPort concept see [60].

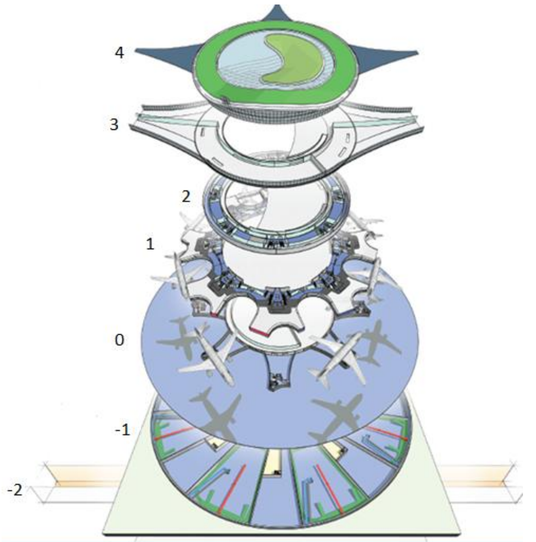


Figure 19: An overview of the iPort-concourse building with each level highlighted [61].

Figure 20: The iPort concept as it is conceived to be looking [61].

The iPort concept comes with a special transportation system, the hovercraft transporting system (HTS). The HTS was developed to overcome the problem of entering a rotating plate by an aircraft. Because the aprons are rotating and the aircraft needs to enter the rotating platform the aircraft would experience forces where it was not developed for[14]. The HTS lifts the aircraft and it is therefore not affected by a moving underground. More information about the HTS is given in section 6.3.1. When the aircraft has completed its 'round' on the iPort it will be transported from the iPort using the HTS.

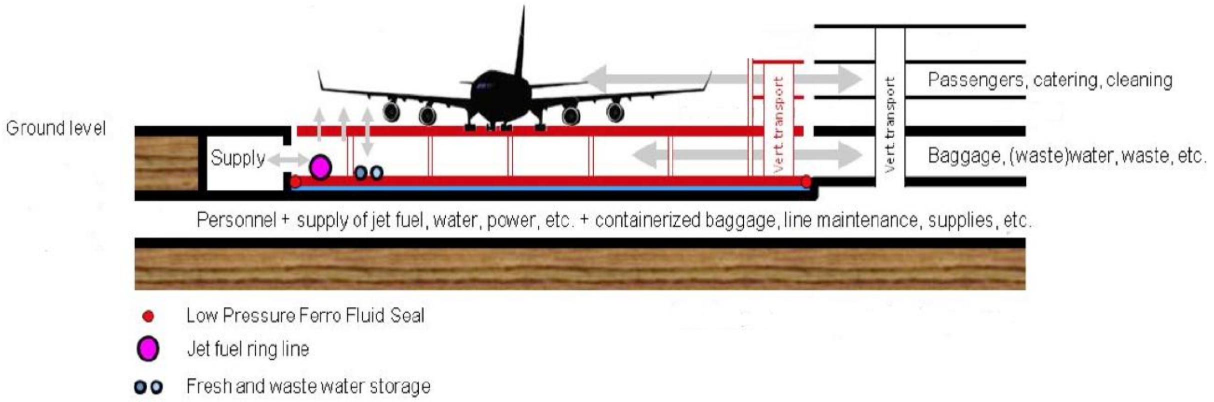


Figure 21: A cross section of the iPort-concourse where the physical pathways of the material flows are presented [61].

5.2. FLOW DIAGRAM OF THE IPORT-CONCOURSE

The physical boundaries for the iPort-concourse case are graphically shown Figure 12. The analysis was focused on turnarounds of aircrafts at aprons at the iPort-concourse. The material

[14] According to an interviewed expert it is likely that the aircraft could withstand the forces but the financial risks are way too high to try the concept.

and energy flows are calculated per turnaround. An apron at the iPort-concourse had the material and energy flows per turnaround as given in Figure 22. From the runway an aircraft is transported to the apron by the HTS bringing luggage, water, consumables, kerosene and passengers with it (arrow 3). Form the apron to the runway (arrow 4) the same aircraft leaves with new luggage, fresh water, new consumables, extra kerosene and new passengers transported by the HTS. All the supplies needed in a turnaround are delivered through the iPort-concourse (arrow 1). All the 'waste flows' of a turnaround are drained via the iPort-concourse (arrow 2). These flows consume electricity to fulfill their own transport from and to the apron. The flows from and to the iPort-concourse from aircraft GSE facilities are consuming electricity and diesel (arrow 5 and arrow 6). The consumption of kerosene goes with direct emissions to the environment. The box with the dashed lines gives the boundaries of this research.

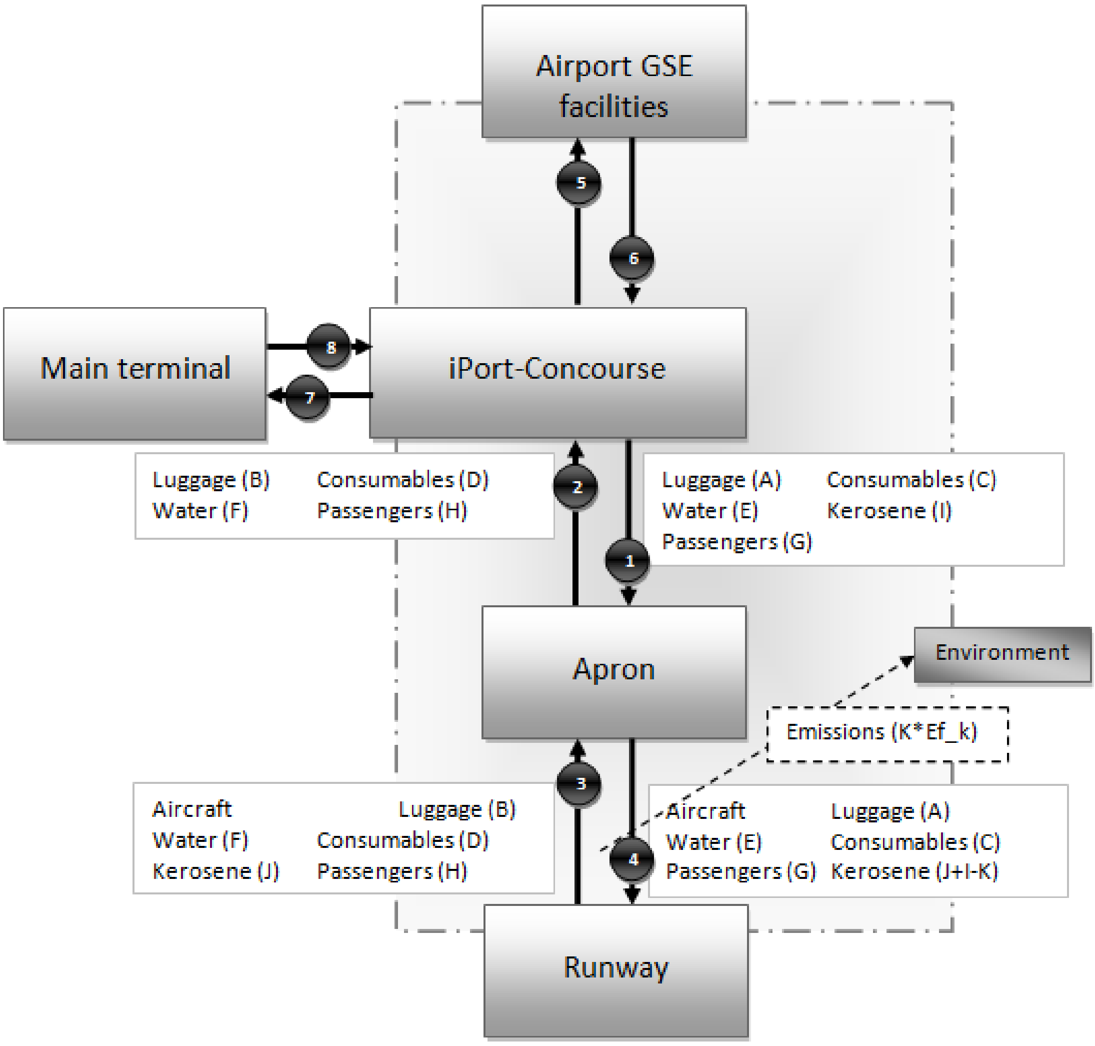


Figure 22: The Material and energy flow diagram of an apron at the iPort-concourse.

5.3. HANDLING SERVICES

The first service in the iPort concept is the HTS. After landing the aircraft is picked up by the HTS. The HTS is conceived to transport the aircraft to the parking position at the apron. When the aircraft is parked (blocks on) the handling services start. Each apron is installed with fixed electrical equipment to deliver the handling services. Personal is entering the aircraft through the gates via routes specially designed to keep personal and passengers separated. The needed ground services are given in Figure 23. The coming sections describe each services with the related process-chains. The descriptions are based on interviews with experts and internal documents related to the iPort-concept.

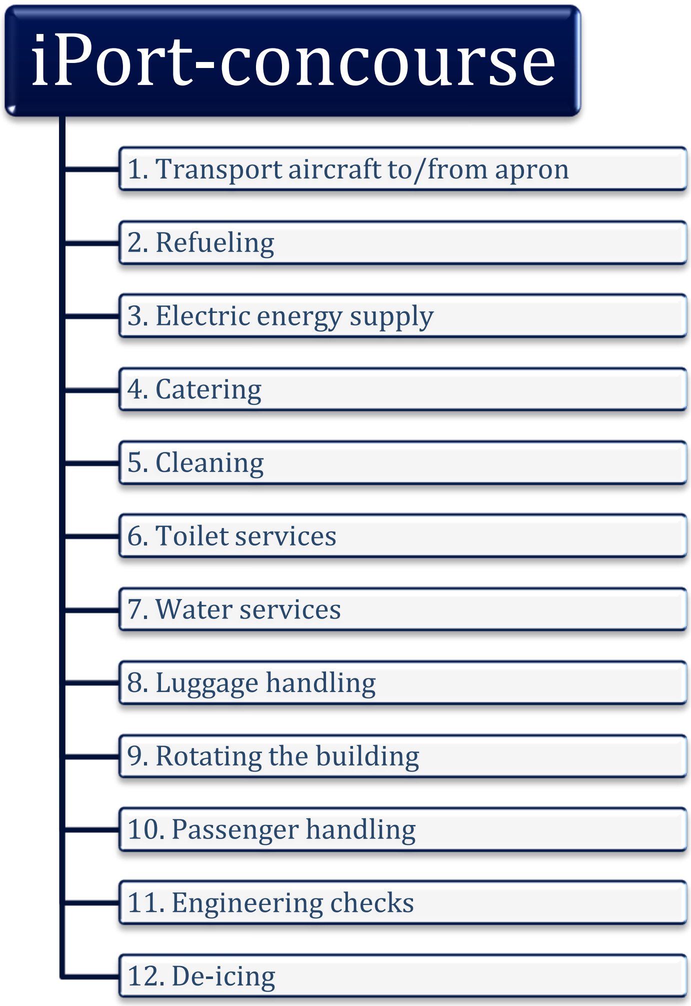
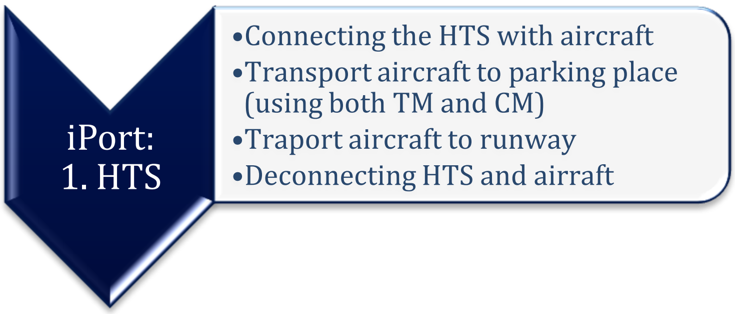


Figure 23: The observed services delivered to a Boeing 737-800 aircraft at the iPort-concourse

5.3.1. HOVERCRAFT TRANSPORTATION SYSTEM (HTS)



The HTS consists of three vehicles with a total lift capacity of 180 ton. The goal of the HTS is to position the aircraft on the parking position at the platform. The framework of the HTS is provided with batteries, engines, 400Hz and PCA supply. The HTS has two different modes namely the tarmac mode and the caster mode. In “tarmac mode” (TM) the HTS propulsion takes place by wheels. When the platform is reached, the HTS switches to “caster mode” (CM). In the caster mode the HTS propulsion takes place by air casters (see Figure 24). The energy using equipment is the HTS.

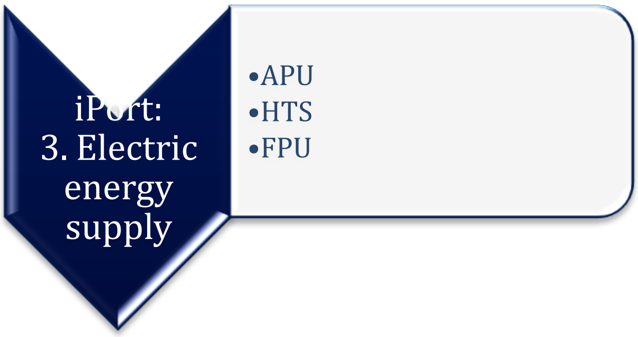
Figure 24: Air casters as conceived to propel the HTS using air pressure to 'fly' as a hovercraft.

5.3.2. REFUELING

The iPort connects with the current fuel-network at Schiphol. The pipelines will connect to the iPort and the fuel transports into the storage system of the turning iPort. The jet fuel storage facility has a buffer capacity of 2000 m^3 and is replenished with a robotic system which has an automatic on and off- latching system (see Figure 25). This system is divided into 4 to 8 points on the outer edge of the platform. As part of this system, an automatic wind / unwind device is integrated in the fixed outer wall of the platform. The energy using equipments are the fueling system, the system used to refuel the storage tank and the pumps used to pressurize the original pipeline network at Schiphol.

Figure 25: A photograph of the tanking system conceived to be used to fuel the iPort-concourse [61]

5.3.3. ELECTRIC ENERGY SUPPLY



An aircraft consumes electricity. This electricity is produced by an APU at ground level, see Section 4.3.3 for more information. The HTS is mounted with a battery to immediately deliver electricity (400Hz, 16A, 115V) to an aircraft after landing. Therefore the APU can be turned off. The aircraft will be connected to a fixed power unit (FPU) when it is set 'block on' after its arrival at the apron of the iPort-concourse. The FPU takes electricity from iPort-concourse.

5.3.4. CATERING SERVICES

Catering services deliver consumables as food, drinkables and blankets to the aircraft. Catering services also take the (remains of) the previous consumables with them. The supplies for catering services are delivered to the iPort-concourse using the corridor of level -2. The supplies are delivered to the apron through a special route through the gates at level 1. The supplies are vertically transported with an elevator. The old consumables are brought down to the lowest level and are gathered here. The energy using equipments are the elevator, and the truck delivering the supplies to the iPort-concourse and taking the old consumables.

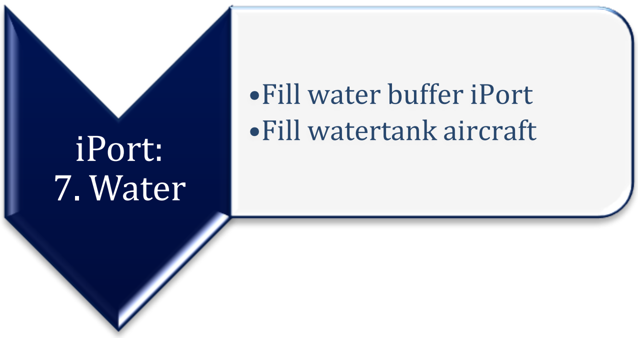
5.3.5. CLEANING SERVICES

During a turnaround an aircraft is cleaned from the inside. The cleaners are transported to the aircraft by elevator and enter the aircraft from both backside and frontside entrance. Cleaning services happens after de-board and until boarding of the new passengers. The energy consuming equipments are the elevator used for transport and some of the cleaning equipment.

5.3.6. TOILET SERVICES

The toilet-tank, filled with diluted water, is emptied after each flight. To facilitate the discharge of the wastewater from the aircraft, sanitary installations, buffer tanks, induction pipes and sewage pumping installations are installed inside the platform. These buffer tanks will automatically empty following the principle of a “waste water basement” which is realized with a free drainage from the rotating platform to the fixed outer wall or is realized in the basic floor. The capacity is determined by the buffer capacity required in an emergency of 400 m^3. The energy using equipments are the pumping installations required to discharge the wastewater tank of the aircraft and the wastewater depot in the iPort-concourse.

5.3.7. WATER SERVICES

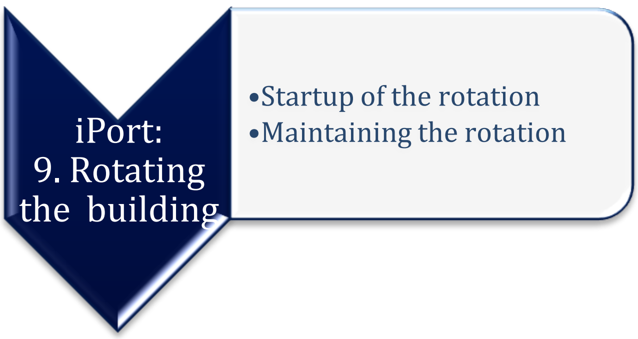


Provide water for the aircraft’s freshwater needs buffer tanks, induction pipes and pump installations installed into the platform. These buffer tanks will automatically replenish following the principle of a “clear-water reservoir” which is realized with an outlet from the fixed outer wall to the rotating part of the platform. The capacity of the reservoir is 400 m^3.

5.3.8. LUGGAGE HANDLING

The luggage is handed-in by the passengers at the check-in desk. Afterwards the luggage is sorted by a complex luggage-system. In the end the luggage that needs to be on the same aircraft is concentrated to one of the luggage basements. The sorted luggage is transported to the iPort-concourse using conveyors via the corridor under the building. An integrated containerized logistic system distributes these in between a specific location inside the iPort-concourse and the main terminal. From this specific location the luggage is transported to the different aprons.

5.3.9. ROTATING THE BUILDING

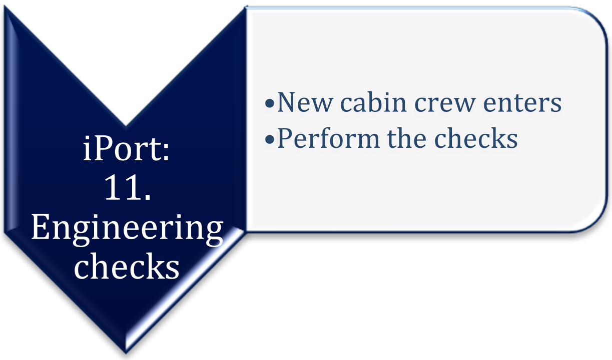


The rotational part of the iPort-concourse needs to rotate else the iPort principle does not work. The building is build upon a layer of water using sealing's to prevent the water from escaping. The water under the building is pumped to a certain velocity. The kinetic energy transferred, by friction, from the moving water to the building causes the building to rotate.

5.3.10. PASSENGER HANDLING

Passenger handling starts at the moment that passengers arrive at Schiphol. The passengers check in at Schiphol Airport thereby delivering their luggage. After checking-in the passengers and their hand-luggage undergo a security check. Once the security check is finished the passengers arrive in the shopping area to spend some time. Later the passengers check-in at the iPort-concourse. Then they arrive in a shopping area with lounge-rooms. Just before arrival of the aircraft the passengers check-in at the gate entering a new lounge room. When the aircraft arrives, the aircraft connects with an electric passenger bridge. The on-board passengers leave the aircraft though this bridge. The off-board passengers will enter the aircraft afterwards. The energy using equipment is the electric passenger bridge.

5.3.11. ENGINEERING CHECKS



Engineering checks are performed according to the safety protocol. This means that the most important system values are checked. The APU needs to be on to generate the needed air flow required for the start-up of the engines. When the engines are started the system values can be checked.

5.3.12. DE-ICING SERVICES

When the temperature is around freezing temperature or lower, an aircraft is supplied with de-icing services. Therefore the aircraft is transported to a qualified area where it is de-iced. De-icing means a treatment with chemicals in order to reduce the formation of ice on the aircraft. After treatment the aircraft is transported to the runway ready for take-off.

5.4. ENERGY USE WITHIN THE IPORT-CONCOURSE

The energy flows of different activities needed for a turnaround at the iPort-concourse are given in Figure 26, all numbers are given in MJ. For further elaboration of the given data see Appendix D. Appendix E gives the input data used for constructing the Sankey diagram. The total energy use of the system under study is 2,1GJ per turnaround at the iPort-concourse. Most of this energy is used for the transportation and electric energy supply. The correlated CO_2 emissions (a total of 224 kg CO_2 per turnaround) are given in Table 5 using the emission factors given in appendix F.

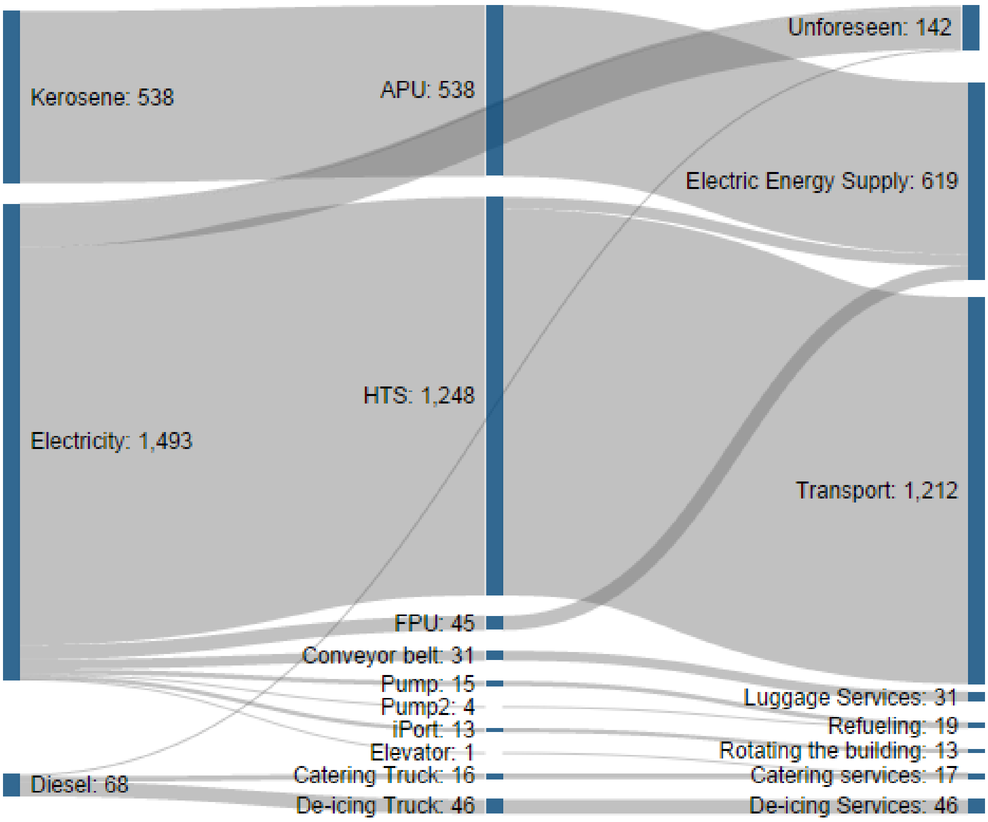


Figure 26: The Energy flows per turnaround at the iPort-concourse

Table 5: The CO_2 emissions per turnaround for the iPort-concourse

	MJ	g CO_2 / MJ	g CO_2
Electricity	1.493	126,4	188.715
Diesel	68	60,5	4.114
Kerosene	538	58,6	31.537
Total	2.099	-	224.356

6. COMPARISON BETWEEN THE C-CONCOURSE AND THE IPORT-CONCOURSE

The growth in the aviation industry is accompanied with an increased energy demand to provide the air transportation services. This research project focused on energy use in aircraft handling in two concourses: the C-concourse at Schiphol Airport and a new theoretical design called the iPort-concourse. In Chapter 4 a MEFA of the C-concourse is presented. Chapter 5 presents the MEFA of the iPort-concourse. This chapter presents a comparison of the energy use per turnaround between both cases. First a general comparison is made in Section 6.1 Second, the energy flows are split-up into two different categories: i) The energy flows between 'blocks on' and 'blocks off' and ii) the energy flows of taxiing. This comparison gives a good understanding of the differences in energy consumption in both systems. Section 6.2 discusses the energy flows between 'blocks on' and 'blocks off' and Section 6.3 discusses the energy flows of taxiing.

6.1. COMPARISON

The total energy consumption of aircraft handling at the C-concourse was 5,1GJ per turnaround[15]. The total energy consumption of aircraft handling at the iPort-concourse was calculated at 2,1GJ per turnaround (see Figure 27 for the energy flows). Therefore switching to the iPort concept saves 3,0GJ per turnaround. The emissions are reduced from 304 kg CO_2 to 224 kg CO_2 per turnaround. At the C-concourse most CO_2 is emitted with the use of kerosene used by transport processes described in Section 4.3.2. At the iPort-concourse most of the CO_2 is emitted due to electricity use corresponding to transport processes described at Section 5.3.2. Table 5 presents the energy consumption in both cases with corresponding CO_2 emissions. With the combustion of diesel and kerosene respectively 3.135 g CO_2 and 3.128 g CO_2 is emitted per Liter. For electricity the emission factor is 444 g CO_2 per kWh (for a detailed calculation of the emission factors of kerosene, diesel and electricity see Appendix F).

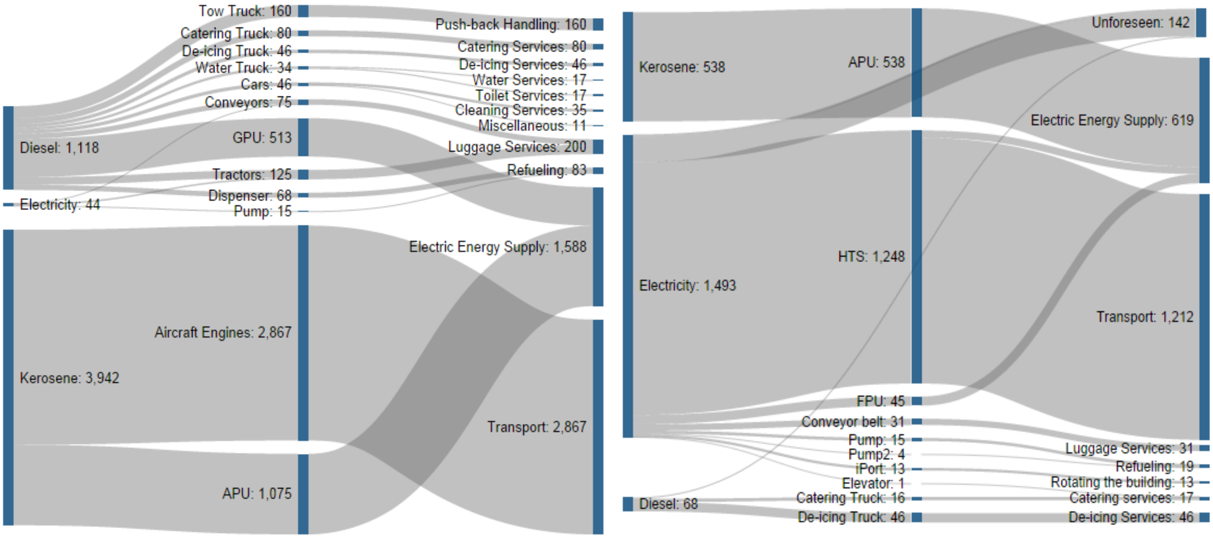


Figure 27: The Sankey diagrams of the all the energy flows per turnaround of (left) the C-concourse and (right) the iPort-concourse. All flows are given in MJ per turnaround.

[15] 1 GJ equals 1.000 MJ

At the C-concourse aircraft handling energy demand is mostly supplied by kerosene followed by diesel, while most aircraft handling energy demand at the iPort-concourse is supplied by electricity. To get a good understanding of the differences in energy consumption in both systems the energy consumption is split into two categories:

- The energy consumption between 'blocks on' and 'blocks off' (Section 6.2)
- The energy consumption of aircraft taxiing (Section 6.3)

Table 6: The energy use and CO_2 emissions per turnaround for both cases

	C-concourse		iPort-concourse	
	MJ	g CO_2	MJ	g CO_2
Electricity	44	5.562	1.493	188.715
Diesel	1.118	67.639	68	4.114
Kerosene	3.942	231.001	538	31.537
Total	5.104	304.202	2.099	224.356

6.2. ENERGY CONSUMPTION BETWEEN 'BLOCKS ON' AND 'BLOCKS OFF'

The energy flows per turnaround between 'blocks on' and 'blocks off' are presented in Figure 28 for both cases with Sankey diagrams. At the C-concourse the energy consumption was 1,7GJ per turnaround. At the iPort-concourse the energy consumption per turnaround was 0,7GJ. Table 7 gives the breakdown of the energy flows per fuel type with corresponding CO_2 emissions. The total CO_2 emissions in the C-concourse case were 105kg CO_2 per turnaround and the emissions in the iPort-concourse case were calculated at 51kg CO_2 per turnaround. The result is a CO_2 reduction of 54kg CO_2 per turnaround.

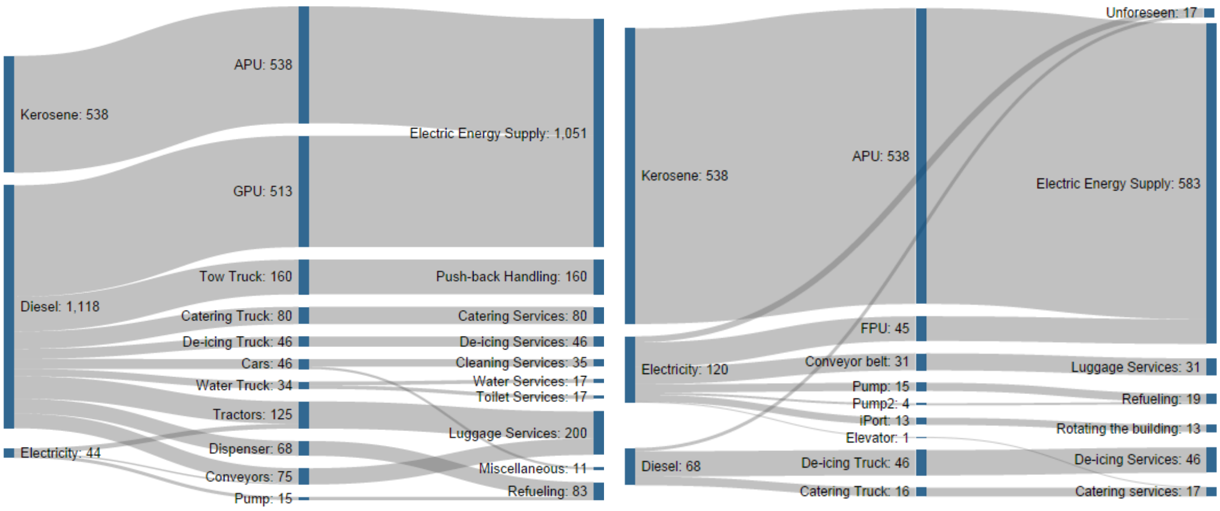


Figure 28: Sankey diagrams of the energy flows between 'blocks on' and 'blocks off' of (left) the C-concourse and (right) the iPort-concourse. All flows are given in MJ per turnaround.

With aircraft handling at the C-concourse most of the energy use between 'blocks on' and 'blocks off' was used for electric energy supply. This service was delivered using the APU and the GPU. Theoretically the APU can be shutdown when the aircraft is connected with the GPU but during the case study the APU appeared to run for an average 5 minutes after connection with the GPU and an average 5 minutes before disconnection. The start of the APU before disconnection with the GPU is part of the starting procedure. The shutdown of the APU 5 minutes after connection is caused by the reaction time of the pilots. Furthermore, push-back handling (160 MJ/T) and luggage services (200 MJ/T) are energy intensive services as well.

With aircraft handling at the iPort-concourse the assumption was made that pilots have the same reaction time, of 5 minutes, for shutting down the APU after connection to a GPU/FPU as in the C-concourse case. Also the APU is started 5 minutes before disconnecting with the FPU. The shutdown and startup of the APU is conceived to happen while the aircraft is being transported by the HTS but to make both cases comparable this energy use is included in the analysis between 'blocks on' and 'blocks off'. There is no supply of Pre-Conditioned Air (PCA) because the time that the APU is shutdown happens to short enough so no PCA is needed. In the iPort-concourse case the assumption is made that the iPort operates at 100% capacity. Therefore the energy required for continuously rotation of the building is only 13MJ per turnaround. However, if the iPort would run at 50% capacity this energy flow would double because the energy for rotating the building does not depends on the amount of turnarounds. It depends of the velocity of rotation with the corresponding resistance.

All the energy savings between ´blocks on´ and ´blocks off´ are in the benefit of the airport. The energy flows of Schiphol Amsterdam for aircraft handling drop from 1,2GJ to 0,2GJ per turnaround. This energy reduction is accompanied with a CO_2 emission reduction from 54kg CO_2 per turnaround to 19kg CO_2 per turnaround (see Table 7). The kerosene required by the APU stayed the same[16], so the airlines do not save energy in this phase.

Table 7: The CO_2 emissions per turnaround for both cases between 'blocks on' and 'blocks off'

	C-concourse		iPort-concourse	
	MJ	**g CO_2**	**MJ**	**g CO_2**
Electricity	44	5.562	120	15.168
Diesel	1.118	67.639	68	4.114
Kerosene	538	31.529	538	31.529
Total	1.700	104.730	726	50.811

6.3. THE ENERGY CONSUMPTION OF AIRCRAFT TAXIING

The energy flows corresponding for taxiing in both cases are presented in Figure 28 with Sankey diagrams. The C-concourse had a taxi time of 10 minutes in total. At iPort-concourse the hovercraft transportation system (HTS) transports the aircraft. The HTS had a taxi time of 10 minutes in tarmac mode (TM) and an additional 6 minutes in caster mode (CM). See appendix D.1. and Section 5.3.1 for more information regarding the different modes of the HTS system. The energy used for taxiing an aircraft in the C-concourse was 3,4GJ. The energy used for taxiing an aircraft in the iPort-concourse was calculated at 1,4GJ. As a consequence, the energy use for taxiing reduces with 2,0GJ. Switching to the iPort-concourse also results in a CO_2 emissions reduction from 200 kg CO_2 per turnaround to 174kg CO_2 per turnaround (see Table 8).

[16] The time that the APU runs, while the aircraft is connected to an external electricity source (GPU/FPU), is kept constant in both cases. This is because a change in running time of the APU while being connected to a GPU or FPU is a procedural change and not a technical change. And this research focuses on the technical change of switching to the iPort-concourse.

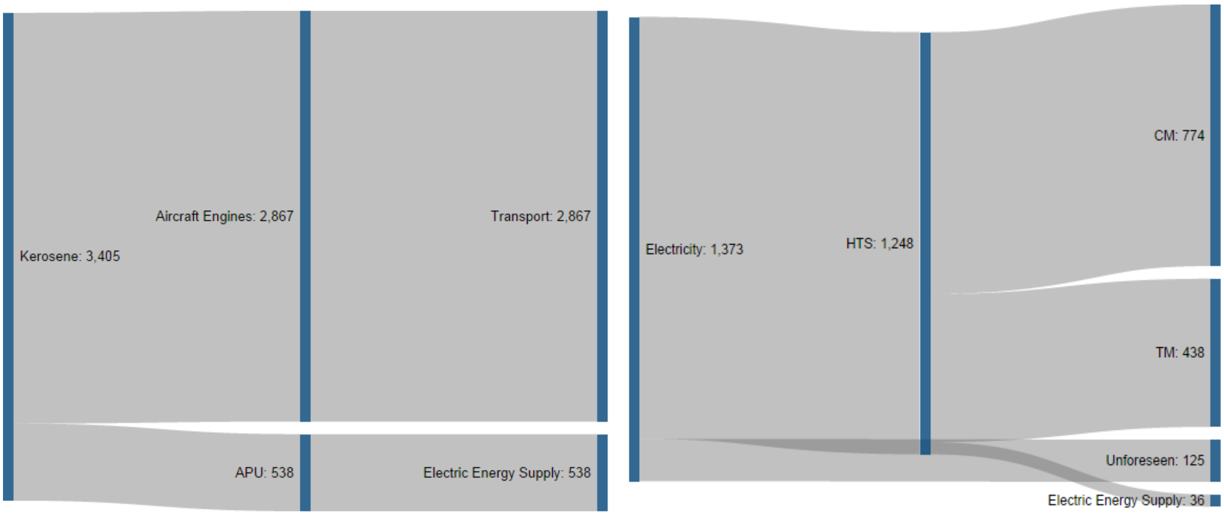


Figure 29: Sankey diagrams of the energy flows of taxiing at (left) C-concourse and (right) iPort-concourse. All flows are given in MJ per turnaround.

In the C-concourse most of the energy used while taxiing is used for transport. 0,5GJ of the 3,4GJ are used for electricity supply. The rest is used for taxing using a single aircraft engine. In the iPort-concourse the energy use for electricity supply while taxiing is brought down to 36 MJ per turnaround due to the use of external electricity supply from the HTS. The energy use for transport, represented by the TM, was calculated at 0,4GJ. The energy use to place the aircraft into and out to parking position was calculated at 0,8GJ. This is thereby the most energy consuming process of taxiing the aircraft. The relatively large energy savings of 2,0GJ (59%) did not result in large CO_2 emissions reduction due to the swift to electricity. Electricity is generated by power plants using fossil fuels. Due to the conversion efficiency, the CO_2 emissions per MJ electricity are higher than the CO_2 emission per MJ kerosene (see Appendix F). This implicates that a reduction in energy demand does not necessary means a reduction in CO_2 emissions if the energy source changes.

Table 8: The CO_2 emissions per turnaround for both cases for aircraft taxiing only.

	C-concourse		iPort-concourse	
	MJ	g CO_2	MJ	g CO_2
Electricity	0	0	1.373	173.547
Diesel	0	0	0	0
Kerosene	3.405	199.533	0	0
Total	3.405	199.533	1.373	173.547

7. DISCUSSION

This thesis was set out to assess the energy use and GHG-emissions related with aircraft handling at the iPort-concourse versus an actual concourse. This chapter discusses the results of the research in Section 7.1. The reliability of the results is discussed in Section 7.2. Finally, the implications of this research on the body of knowledge are discussed in Section 7.3.

7.1. THE RESULTS

The results in this thesis quantify that a turnaround[17] at the iPort needs 3,0GJ of energy less, and emits 80kg of CO_2 less, compared to a turnaround at the C-concourse. Section 7.1.1 discusses the total impacts of these results and Section 7.1.2 put the results into broader context.

7.1.1. THE TOTAL IMPACT

In 2013 there were 72.007 narrow-body aircraft handlings at Schiphol Airport Amsterdam from the airliner under study. If all these aircraft handlings were performed at the iPort-concourse instead of at the C-concourse a total of 216.021GJ of energy and 5.761 ton of CO_2 emissions would have been saved. An average Dutch household consumes 109GJ per year [62] and it emits 8 ton of CO_2 per year [63] by using energy in house and for transportation. Thus, the energy savings are equal to the energy consumption of 1.982 Dutch households. The CO_2 reduction equals the emissions of 725 Dutch households. The impacts of the iPort-concourse could even be higher. Because, according to its design, at 100% capacity the iPort-concourse can handle 105.000 aircrafts per year.

7.1.2. CONTEXT OF THE RESULTS

The aim of this research was to find the differences in energy consumption, with related GHG-emissions, regarding aircraft handling at the iPort-concourse or at a conventional concourse. The C-concourse represented the conventional concourse in this research. This section discusses the impact on the results due to the choice of the C-concourse as reference situation. The C-concourse was selected due to the similarities in characteristics as capacity and type of aircrafts capable of handling (see Section 3.4). The next paragraphs discuss some findings of a turnaround at the C-concourse.

Discussion of the C-concourse as typical concourse

The diesel consumption per turnaround found at the C-concourse was around 32 liter per turnaround. The car used for tanking the water had a fuel consumption of 0,5 liter diesel per turnaround. This vehicle is a simple car and it is basically used for transport of water. On average, a typical sedan auto can drive 10km using 1 liter of diesel. This means that the diesel consumption of the 'water car' is equivalent to '5km driving in a passenger car' per turnaround. This might sound as high fuel consumption. But this is explained by a large travel distance (~4-5 km/T) that needs to be covered by the GSE. Schiphol Airport Amsterdam is a complex system where vehicles are used for multiple aircraft handlings at different locations. Schiphol Airport

[17] A turnaround is the period of time beginning when a flight arrives at an airport and ending when the aircraft takes off again.

Amsterdam developed a road network in order to secure successful transport of the flows of goods and services.

The energy flows per minute (MJ/sec) between the different electrical energy supply sources differ widely. An APU consumes 54MJ/min, the GPU consumes 10MJ/min and a FPU consumes 2 MJ/min for delivering the same service. For the discussion about why these differences are so large, see Appendix G. The equipments used for electric energy supply at the C-concourse were GPU's. These use more energy for the same service as FPU's. Also, the GSE needed to travel large distances due to the airport lay-out, which comply with strict safety regulations. These reasons may result in higher energy consumptions per turnaround, at the C-concourse, than a turnaround at a concourse somewhere else. Although there are no references available, exclusively from the energy point of view, to compare these results with it seems reasonable to assume that the C-concourse is not one of the most energy efficient concourses in the world. This thesis has selected two cases as a part of a bigger project: develop more energy efficient airports. Although the limitations of such exploratory research are widely accepted and understood [64] the results are considered to provide an indicative platform of knowledge to inform the final design of the iPort, allowing for variations in industrial and national circumstances and practices. The conclusions and recommendations provided by this thesis are made with these limitations and cautions in mind. Besides, even when a turnaround at another location consumes 50% less diesel per turnaround, it does not change the conclusion that the iPort-concept is a more energy efficient concept.

7.2. RELIABILITY OF THE RESULTS

7.2.1. IPORT-CONCOURSE

The fact that the iPort-concourse does not exists (yet) implies that the energy use in this concept was calculated instead of measured. The calculations predicted the energy consumption of a turnaround at the iPort-concept and prediction comes with uncertainties. To increase the reliability of the energy use calculations two strategies were chosen:

- i) The split-up of different activities, and the thereby associated independent calculations, increased accuracy and therefore resulted in an increased reliability.
- Ii) The energy flow 'unforeseen' was added to cover any miscellaneous energy use. This flow was set at 10% of the calculated energy flows.[18]

These strategies resulted in valid and reliable results.

7.2.2. C-CONCOURSE

For the quantification of the energy use for a turnaround at the C-concourse the data of the year 2013 was used. Diesel supply to GSE was gathered over a year and added up per vehicle. The total energy use per equipment was divided over the total narrow-body aircraft handlings in 2013 resulting in the average energy use per equipment per turnaround for narrow-body aircrafts. Some GSE's were used for both narrow-body and wide-body aircraft handlings. To subtract the energy used for narrow-body aircraft handlings, of the total energy used, economical data was used. The energy use is based on the invoices of energy use for the GSE for

[18] The energy use of the aircrafts APU was set equal with the C-concourse. Therefore this flow was not included in the calculation for unforeseen

narrow-body aircraft handling. This results in a high reliability of the calculated energy use of the different GSE's.

Another point to take into account is that Schiphol Airport Amsterdam is a dynamic environment. Procedures change and improvements are made thereby affecting the energy use of the GSE. Currently a program runs for electrifying the GSE. Also, there is the plan to reduce the turnaround time from 50 to 45 minutes in 2014.[19] These changes are expected to decrease the energy consumption per turnaround thereby reducing the profits gained by switching to an iPort-concourse. However, these changes do not change the outcome of this thesis: switching to an iPort-concourse reduces the energy use and CO_2 emissions.

7.3. IMPACT ON THE FIELD OF KNOWLEDGE

As far as understood, there is no general data about energy consumption in aircraft handling. Several studies have been conducted regarding this topic (see Section 2.2.4). However, non-matching boundaries and low transparency in boundary settings make it difficult to compare results between studied cases. But, literature stated that aviation related operations on the ground uses 3% of the energy use of aircrafts (see Section 2.2.4). That is equivalent to an energy use of 3,0 GJ per turnaround[20], whereby the energy use of the aircraft was not included. The C-concourse used 1,2 GJ per turnaround without including the energy use of the aircraft, during a turnaround. These energy consumptions have the same magnitude, but the boundaries of the energy use found in the literature are unknown. This thesis used a clear format for boundary setting. It also provides a robust (consist and coherent) method to calculate material and energy flows at any given concourse at any given airport. Furthermore, the results are presented is such a way that they can be made comparable with future studies, thereby contributing to the field of knowledge.

[19] A reduced turnaround results in a reduced use of the GPU. So, a reduction of 5 minutes reduces the energy use of the GPU with 51 MJ/T.

[20] 187 million tons of jet fuel (Section 2.2.3) * 0.03 * 43 MJ/kg / 79 million flights (Section 2.2.2) = 3 GJ/T

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8. CONCLUSION

The iPort-concourse represents the concept of sequential aircraft handling. This concept is designed to be less energy intensive than the conventional parallel aircraft handling concepts. However no solid calculations were made yet to support this claim. This thesis assesses the energy use and related GHG-emissions with aircraft handling of the iPort-concourse versus an actual concourse. It has also calculated the difference in energy use, with the related GHG-emissions, between the C-concourse at Schiphol Airport Amsterdam and an iPort-concourse. In both cases a material and energy flow analysis (MEFA) was used to quantify the energy use. The differences were analyzed through comparative case study analysis. Section 8.1 presents the results to the research questions. Then, Section 8.2 presents the limitations of this study. Thereafter, the suggestions for further research are presented in Section 8.3. Finally, the final remarks are presented in Section 8.4.

8.1. ANSWER TO THE RESEARCH QUESTIONS

This study sought to answer the following (sub) question(s):

Which services are involved in aircraft handling?

The aim of this sub-question was to indentify all the services delivered to an aircraft during a turnaround. The supply of these services requires the use of energy. Twelve services were observed during turnaround at the C-concourse and at the iPort-concourse. These aircraft handling services delivered to the aircraft were almost identical in both cases, only the push-back service was only required at the C-concourse and the rotational movement of the building was only required at the iPort-concourse. For the other services see Figure 15 and Figure 23.

What are the process-chains for all the different ground handling services?

The aim of this sub-question was to indentify all the steps needed in order to deliver the services. The process-chain per service is all the activities needed to deliver the specific service. At the C-concourse most services were transported by vehicles to the apron. At the iPort-concourse most services are conceived to be automatic, so vehicles are not needed anymore. For details about these process-chains see section 4.3 and 5.3 for the services at respectively the C-concourse and the iPort-concourse

What are the energy use, and the related GHG-emissions, of the different processes involved in aircraft handling in both situations?

When the steps needed for the services are known a precise and solid calculation was made to quantify the total energy use per turnaround. Each individual energy consuming step was calculated. For the results of the C-concourse and the iPort-concourse see Appendix B and Appendix D respectively. This thesis quantified the energy flows per turnaround with the accompanied GHG-emissions of both cases. A turnaround at the C-concourse required a total energy of 5,1GJ accompanied with 304kg of CO_2 emissions. A turnaround at the iPort-concourse required a total energy of 2,1GJ accompanied with 224kg of CO_2 emissions. Most of this energy was used to deliver the services 'transport of the aircraft' (2,9GJ and 1,2GJ) and 'electrical energy supply' (1,6GJ and 0,6GJ).

As presented in Chapter 6, the iPort-concept can be divided into two concepts: i) the aircraft handling concept (the principle of the building) and ii) the aircraft transportation concept (the HTS-system).

i) The energy use of the airport per turnaround between 'blocks on' and 'blocks off' of the C-concourse and the iPort-concourse were 1,1GJ (73kg CO_2) and 0,2GJ (19kg CO_2) respectively. Also the airlines consumed 0,5GJ per turnaround to fuel the APU.[21]

ii) The energy use of the airport per turnaround for taxiing at the C-concourse and the iPort-concourse were 0GJ and 1,4GJ (174kg CO_2) respectively. At the C-concourse the airlines consumed 3,4GJ (200kg CO_2) per turnaround and the airlines did not consume anything at the iPort-concourse due to the HTS-system.

***Main Question**: How does the energy use of the iPort concourse compares with the energy use of a conventional concourse regarding the ground handling services?*

This thesis quantified the differences in energy use of aircraft handling at the C-concourse and the iPort-concourse at 3,0GJ per turnaround. The differences in CO_2 emissions were quantified at 80kg CO_2 per turnaround less in the case of the iPort-concourse compared to the C-concourse. In 2013 there were 72.007 narrow-body aircraft turnarounds conceived. This results in a CO_2 reduction of 5.800 ton CO_2 per year.[22] This calculated CO_2 reduction shows large potential in CO_2 reduction (equivalent of 725 households). Therefore the iPort-concept has the potential of CO_2 reduction.

8.2. LIMITATIONS OF THE STUDY

8.2.1. GENERALIZING PROBLEM

The results of the case studies provide energy use and emissions data from concourse-specific aircraft handling. A limitation of this approach is that this approach only provides information from one concourse at one airport. Hence, generalizing goes with a particular uncertainty [64]. As an example to strengthen this statement: at Schiphol Airport Amsterdam the aircraft handling service of preconditioned air (PCA) is not delivered to narrow-body aircrafts due to the short period of time in which the aircraft does not run its APU[23] and the favorable climatological circumstances. In warmer or colder climates the service of PCA is needed when the APU is shutdown. Also literature review stated that generalizing emissions data of GSE goes with high uncertainties due to the differences is GSE facilities (Section 2.2.4). The result of this research is that the iPort-concourse would reduce the CO_2 emissions of narrow-body aircraft handling with 80 kg (3,0GJ) per turnaround at Schiphol Airport Amsterdam, when the iPort-concourse would replace the C-concourse. Nevertheless, the expectations are that similar results will be found for replacement of a concourse at another airport by an iPort. Furthermore, this thesis presents a robust method that can be applied to calculate the energy needs per at other concourses at other airports.

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[21] Due to the boundary issue the energy consumption of the APU is counted between 'blocks on' and 'blocks off' for both situations. While in the actual situation the same energy consumption of the APU is conceived to be during taxiing.

[22] 72.007 turnarounds per year should mean that the iPort-concourse operates at the capacity of 69%

[23] An APU delivers both electricity and an air flow. This air flow is used for climate control in the aircraft.

8.2.2. EMISSIONS

In this research the GHG-emissions were represented by CO_2 emissions. The use of kerosene and diesel results in local emissions of CO_2 and other pollutants as SO_x, NO_x, HC's and PM. These other pollutants were not taken into account in this research because they are no GHG-emissions, but these emissions do occur. Furthermore, there are no local emissions caused by the use of electricity, the emissions occur delocalized. In other words, no local emissions are observed. The emissions of the electricity are emitted at other locations depending on the way the electricity was generated. Currently, most of the electricity is generated by coal- and gas power plants resulting is CO_2 emissions at the power plant. In this research there were no difference made in where the CO_2 was emitted. At Schiphol Airport Amsterdam there are regulations to measure and goals to decline the local emissions of all the pollutants (see Section 2.1.2 for these pollutants). The use of electricity instead of diesel or kerosene reduces the local emissions of pollutants. Therefore has the use of electricity as power source positive effects on the local environment, but we should remember that pollutants might be emitted elsewhere. These effects are not taken into account in this research.

8.3. RECOMMENDATIONS FOR FURTHER RESEARCH

1) **Increase the amount of cases:** The C-concourse represented the actual concourse in this research. More energy assessments of turnarounds at different concourses on different airports could result in a database of energy consumption in aircraft handling. These calculations of such a database could be useful for other studies in this field of study.
2) **Energy use within the building**: This research focused on the energy use needed for a turnaround, thereby neglecting the energy used within the building. A research to compare the energy use inside a conventional concourse with the energy use inside the iPort-concourse should supplement this research. Nadine Catz [65] started a research as parallel work in this research. As she pointed out: the difficulty with this research would be that the iPort-concourse provides much more facilities and services to the passengers than a conventional concourse.
3) **Effect on the local environment**. As mentioned in Section 8.2.2, this thesis did not study the effects on the local environment caused by the substitution of the C-concourse by an iPort-concourse. The effect of this substitution on the local environment supplements this thesis.
4) **HTS or no HTS**: The hovercraft transportation system (HTS) was developed to overcome the 'problem' of the aircraft entering the rotating disk. However, the speed at the outside of rotational disk is only 0,28m/s. The landing gears of aircrafts were developed to withstand the forces that are released on it during landing. The forces acting on the gear by entering a rotating disk are probably significantly smaller. It is worth investigating for several reasons if an aircraft is able to safely enter the rotating disk without using the HTS: i) The 'caster mode' of the HTS is energy intensive and ii) The caster mode comes with problems as discussed in the discussion section.

8.4. FINAL REMARKS

The research aimed to make an assessment of the differences in energy use and related GHG-emissions of aircraft handling by using an iPort-concourse instead of an actual concourse. Solid calculations were made for calculating the energy use per turnaround for both the C-concourse and the iPort-concourse. This thesis demonstrated that the iPort-concept has the potential to reduce the energy consumption and related GHG-emissions within aircraft handling. With ideas like this we hope to realize a fascinating efficient world to live.

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APPENDIX A: GENERAL GSE TYPES AND FUNCTIONS

Table 9 gives an overview of general GSE types and functions subdivided in five categories. The types of GSE are limited to "powered" GSE and do not include non-motorized equipment such as baggage carts, fuel carts, mobile storage tanks, etc [66].

Table 9: Different GSE types with given functions.

Category	Category Description	GSE	GSE Description
Ground power/air conditioning	Used to help start the engines, operate instruments and provide for passenger comfort (e.g., lighting, air conditioning while an aircraft is on the ground.	Air starter 	Vehicle with a built-in engine which, when aircraft engines are started, provides air for the initial rotation of a large engine.
		Ground power unit (GPU) 	Mobile generators that provide power to parked aircraft when an aircraft's engines are not in use. Typically not used when an airport has gate power systems [i.e., 400 Hertz (Hz)]. Can also be used to start aircraft engines.
		Air conditioning units 	Also referred to as air carts, these units provide conditioned (i.e., cooled and heated) air to ventilate parked aircraft. At some larger airports, individual packaged assemblies or centralized electrical-powered pre-conditioned air (PCA) systems are used.
Aircraft movement	Although an aircraft's engines are capable of moving an aircraft in reverse, this is not typically done for aircraft with jet engines due to the resulting "jet blast" that would occur at the back of the aircraft. For this reason, and others, pushback tugs/tractors are used to maneuver aircraft away from (i.e., out of) gates.	Pushback tugs/tractors 	Used to move an aircraft out of a gate when a pilot is given clearance to taxi to a runway. May also be used to move an aircraft to various locations on an airport (e.g., maintenance hangars). There are two types of pushback tugs/tractors: (1) conventional and (2) towbarless. Conventional tugs use towbars that are connected to an aircraft's noise wheel. Towbarless tractors scoop up the noise wheel and lift it off the ground.
Aircraft service	Aircraft service activities include replenishing supplies and aircraft refueling.	Catering truck 	Typically owned and operated by airlines and companies that specialize in airline catering (e.g., preparing and supplying packaged food). Services provided include removal of unused food/drinks and loading of these items for the next flight.
		Cabin service vehicles 	The main cabin service activities are cleaning the passenger cabin and replenishing items such as soap, pillows, and blankets.
		Lavatory service vehicles	Used to flush aircraft lavatory systems. Small commuter and regional aircraft used for short flights may not be equipped with

			on-board lavatories.
		Portable water truck/cars 	These trucks provide drinkable water to an aircraft.
		Aviation fuel trucks, hydrant dispenser trucks/carts  	Two methods are used to fuel aircraft. The first dispenses fuel from a fuel truck/tanker directly to an aircraft's tank(s). The second method of dispensing fuel is used at airports with underground fueling systems and employs hydrant trucks/carts as "connectors" between the underground fueling system and aircraft.
		Hydrant pit cleaners 	Used at airports with underground fueling systems. Flushes and cleans hydrant pits.
		Maintenance vehicle 	Various types of vehicles are used to provide aircraft maintenance service. These vehicles are used by airport and/or airline employees to travel to/from maintenance facilities and an aircraft in need of repair.
		De-icers 	Vehicles that are used to transport, heat, and spray deicing fluid on an aircraft prior to departure.
Passenger loading/ unloading	Methods vary depending on airport, aircraft, and available airport equipment/facilities. Two methods are used to board passengers onto large aircraft—boarding stairs and jet bridges.	Boarding stairs 	Whether towed, pushed into position, or fixed to a truck, boarding stairs provide a means of loading and unloading passengers at hardstands (i.e., remote parking positions) and in the absence of jet bridges.
		Buses 	On the airside of a large airport, buses may be used to transport passengers and employees from terminal to terminal (or aircraft). Referred to as "people movers," "mobile passenger lounges," and "moon buggies."
Baggage/cargohandling	Passenger baggage/some cargo must be transferred to/from gates and from gate to gate. Cargo-only aircraft typically have one or more large doors to facilitate loading/unloading	Baggage tugs 	Most recognizable type of GSE at an airport. These vehicles are used to transport luggage, mail, and cargo between an aircraft and the airport terminal and/or processing/sorting facilities.
		Belt loaders	Used to load and unload baggage and cargo into/from an aircraft.

	of goods.		
		Cargo/container loaders 	Used to load and unload the cargo on an aircraft that is within a container or on a pallet.
		Cargo transportation/ tractors 	Used to load and unload cargo but are primarily used to move cargo from one airport location to another.
		Forklifts 	Cargo is moved primarily by forklifts within airport cargo handling facilities.
		Conveyors	At larger airports, there has been a recent trend to move baggage between concourse collection areas and to/from the concourse collection areas and the terminal baggage claim areas using conveyor systems. Installation of such conveyor systems can significantly reduce the run time for baggage tugs and/or reduce the number of baggage tugs at an airport.
Airport service	Various types of GSE are used by ground crews (airline and/or airport) to service airports.	Snow removal equipment 	Airports use snow removal equipment to keep runways, taxiways, and ramp areas free of snow and ice. Can include snowplows, snow sweepers, and snow blowers. Snow sweepers, typically used in areas with low snow tolerance (i.e., runways), use brushes to remove thin layers of snow from pavement services. Snow blowers are sometimes used instead of snowplows. This type of vehicle uses spinning blades that force the snow out of a “funnel” on the top of the blower.
		Foreign object debris (FOD) removal 	The removal of FOD can be accomplished using mechanical systems (power sweeper trucks, vacuum systems, and jet air blowers) and non-mechanical systems (e.g., tow-behind trailers equipped with brushes, magnetic bars).
		Bobtail trucks	A bobtail is an on-road truck that has been modified to tow trailers and equipment. Bobtails are also used at some airports to plow snow.
		Miscellaneous equipment	Includes the non-road equipment used by an airport’s ground crew to maintain the airport airside environs. This GSE includes generators and lawn mowers. Select on-

			road equipment such as tow trucks (pictured) can also fall into this category.

APPENDIX B: ENERGY FLOW CALCULATIONS FOR C-CONCOURSE

The data in the green cubes of Table 10 is data from the actor who tanks all the vehicles. The fuel supplied to all these vehicles is added to a total fuel use over 2013 per vehicle. Then all the energy use of vehicles used for narrow body aircraft handling per category are added up to a total. This total is divided over the total narrow body aircraft handlings in 2013 resulting in the average energy use per equipment per turnaround for narrow body aircrafts.

For the conversion of liters or kilograms fuel per turnaround to energy (MJ) per turnaround the conversion constants of $43 MJ/kg_{Diesel}$, $830 g_{Diesel}/L$ and $43\ MJ/kg_{Kerosene}$ were used. The conversion factors were adapted from [67].

Table 10: The energy flows per turnaround for all equipments used in the C-concourse.

Equipment (j)	Mode (k)	TF_j (L/yr)	TT (yr^{-1})	E_j (MJ/T) [24]
Dispenser	-	138.066	72.007	68,43 (diesel)
GPU	-	1.035.495	72.007	513,24 (diesel)
Catering truck	-	161.077	72.007	79,84 (diesel)
Cars	-	69.127	72.007	34,26 (diesel)
Miscellaneous	-	23.042	72.007	11,42 (diesel)
Toilet car	-	34.516	72.007	17,11 (diesel)
Water car	-	34.516	72.007	17,11 (diesel)
Tow truck	-	322.154	72.007	159,67 (diesel)
De-icing facilities	-	92.169	72.007	45,68 (diesel)[25]
Tractor (luggage)	-	207.099	72.007	102,65 (diesel)
(Un)loading equipment	-	138.066	72.007	68,43 (diesel)
Equipment (j)	**For calculations see:**			**E_j (MJ/T)**
APU	Eq. 3			1.075 (kerosene)
Aircraft engines	Eq. 4			2.866,67 (kerosene)
Fuel pump	Eq. 5 and Eq. 6			14,7 (electric)
Tractors (luggage)	See Section B.1.			22 (electric)
(Un)loading equipment	See Section B.1.			7,35 (electric)
Catering truck facilities				X[26]
Luggage system				X
Testing facility				XX[27]
Pump (water)				XX
Passenger Bridge				XX
VDGS[28]				XX

[24] 'T' stands for Turnaround

[25] This is the average energy per turnaround for de-icing over 2013. The energy use for a single de-icing procedure is much higher because most of the turnarounds could be performed without de-icing.

[26] 'X' These energy consumptions could not be calculated due to lack of data and complexity of the situation. Also these energy consumptions are exactly the same for case 1 and case 2 thereby not influencing the results.

[27] ´XX´ These energy consumptions are highly insecure due to the lack of data. Also the estimated energy uses were negligible compared to the total energy use.

B.1. HYBRID VEHICLES

Equipment used to transport luggage and to (un)load the luggage are hybrid equipments. These equipments can be charged at recharge locations. To identify the electrical energy used by these equipments the energy data of the recharging locations of this equipment over 2013 were obtained. The total electricity use of all equipment in 2013 was 587.069 kWh for narrow body aircraft handling. That is a total energy use of 8,15 kWh per turnaround which is equivalent to 29,35 MJ per turnaround. 75% of this energy use is subscribed to the (luggage) tractors.

B.2. APU

The fuel use of an APU of a Boeing 737-800 aircraft is an average of 75 kg per hour [68]. The APU runs while the aircraft is taxiing (10 minutes). According to an interviewed expert and [69] the APU runs 5 min after 'blocks on' and 5 min before 'blocks off'. The APU is started before 'blocks off' because it is used for system and engine safety tests. The energy use per turnaround is given by Eq. 3:

$$E_{APU} = 75 \frac{kg_k}{h} * \frac{20\,h}{60\,T} * 43 \frac{MJ}{kg_k} = 1075\; MJ/T \qquad \text{Eq. 3}$$

B.3. TAXIING

By calculating the energy requirements for taxing data from [70] was used. At Schiphol Airport all Boeing 737 aircraft taxi with a single engine. This engine uses 400 kg kerosene per hour. In this research only 5 min taxi time is assumed. That adds to 10 min total (from and to the apron). The energy use per turnaround is given by Eq. 4:

$$E_{Engines} = 400 \frac{kg_k}{h} * \frac{10\,h}{60\,T} * 43 \frac{MJ}{kg_k} = 28866{,}67\; MJ/T \qquad \text{Eq. 4}$$

B.4. FUEL PUMP

The fuel pump pressurizes the kerosene in the pipelines. By refueling the dispenser connects to these pipelines and lowers speed of the moving kerosene before it enters the fuel tank of the aircraft. The fuel moves through the dispenser because of the differences in pressure. An average of 20.000 L of kerosene is tanked to a B737-800 aircraft per turnaround.[29] To calculate the energy required to move the fluid the assumption is made that with pressurizing the kerosene its volume does not change. So the energy required per turnaround was calculated using Eq. 5 with $dp = p_i - p_f$ = 100.000 Pa - 800.000 Pa = 700.000 Pa [71] and V = 20 m^3.

$$W_{pump} = dpV = 700.000\; Pa * \; 20^3\; m^3 = 14\; MJ \qquad \text{Eq. 5}$$

Where:

- W = Work per turnaround (J)
- p = Pressure (Pa)
- V = Volume per turnaround (m^3)

---

[28] The Vliegtuig Docking Guidance System (VDGS) consists of a few lamps and pressure sensors in the ground.

[29] The capacity of the fuel tank of a B737-800 is 26.020L [86]

Using a system efficiency of 95% (according to an interviewed expert is the resistance of the pipelines negligible due to the coating used) the calculated energy use is given by Eq. 6.

$$E_{Fuel\ pump} = \frac{W_{pump}}{\eta} = \frac{14MJ}{0.95} = 14.7\ MJ \qquad \text{Eq. 6}$$

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APPENDIX C: INPUT DATA SANKEY DIAGRAM FOR C-CONCOURSE

The software of SankeyMATIC [56] was used to dram the Sankey diagrams, as described in Chapter 3. In this Appendix the raw input data is found for the Sankey diagram of case 1.

Diesel [68.] Dispenser
Dispenser [68.] Refueling
Diesel [513.] GPU
GPU [513.] Electric Energy Supply
Kerosene [1075] APU
APU [1075] Electric Energy Supply
Diesel [80] Catering Truck
Catering Truck [80] Catering Services
Diesel [34.] Water Truck
Water Truck [17.] Water Services
Water Truck [17.] Toilet Services
Diesel [160] Tow Truck
Tow Truck [160] Push-back Handling
Diesel [103] Tractors
Tractors [125] Luggage Services
Diesel [68] Conveyors
Conveyors [75] Luggage Services
Kerosene [2867] Aircraft Engines
Aircraft Engines [2867] Transport
Diesel [46] De-icing Truck
De-icing Truck [46] De-icing Services
Diesel [46] Cars
Cars [35.] Cleaning Services
Cars [11.] Miscellaneous
Electricity [22] Tractors
Electricity [7] Conveyors
Electricity [15] Pump
Pump [15] Refueling

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APPENDIX D: ENERGY FLOW CALCULATIONS FOR IPORT-CONCOURSE

The data in the green cubes of Table 11 is data from the actor who tanks all the vehicles. The fuel supplied to all these vehicles is added to a total fuel use over 2013 per vehicle. Then all the energy use of vehicles used for narrow body aircraft handling per category are added up to a total. This total is divided over the total narrow body aircraft handlings in 2013 resulting in the average energy use per equipment per turnaround for narrow body aircrafts.

For the conversion of liters or kilograms fuel per turnaround to energy (MJ) per turnaround the conversion constants of 43MJ/kg_{Diesel}, 830g_{Diesel}/L and 43 MJ/$kg_{Kerosene}$ were used. The conversion factors were adapted from [67].

Table 11: The energy flows per turnaround for all equipments used in the iPort-concourse.

Equipment (j)	Mode (k)	TF_j (L/yr)	TT(yr^{-1})	E_j (MJ/T)
De-icing facilities	-	92.169	72.007	45,68 (diesel)[30]
Equipment (j)	**Mode (k)**	**For calculations see:**		**E_j (MJ/T)**
HTS	Drive	Eq. 8		438 (electric)
	Fly	Eq. 15		70 (electric)
	Push while flying	See D.1.		704 (electric)
	FPU	See D.4.		36 (electric)
Refueling	iPort pipelines	Eq. 18		4,2 (electric)
	Fuel Pump	Eq. 5 and Eq. 6		14,7 (electric)
APU	(start up)	75 kg/h *43 MJ/h	10 min	537,5 (kerosene)
FPU	-	See D.4.		45 (electric)
Catering truck	-	See D.3.		16 (diesel)
Rotation of building	Start up	Eq. 23		1 (electric)
	Resistance	Eq. 38		12,5 (electric)
Elevator	2 elevators	Eq. 17		1 (electric)
Conveyor system	-	Eq. 40		31 MJ (electric)
Unforeseen[31]	-	(10% of calculated flows)		142(all)
Toilet pump	-			XX[32]
Water pump	-			XX
Testing facility	-			XX
Pump (water)	-			XX
Passenger Bridge	-			XX
Catering truck facilities	-			X[33]
Luggage system	-			X

[30] This is the average energy per turnaround for de-icing over 2013. The energy use for de-icing is higher for a single de-icing procedure because most of the turnarounds could be performed without de-icing.
[31] In 'real life' processes are different than ideal calculated situations. Therefore 'unforeseen' is included in the flow diagram.
[32] ´XX´ These energy consumptions are highly insecure due to the lack of data. Also the estimated energy uses were negligible compared to the total energy use.
[33] 'X' These energy consumptions could not be calculated due to lack of data and complexity of the situation. Also these energy consumptions are exactly the same for case 1 and case 2 thereby not influencing the results.

D.1. HTS CALCULATIONS

DRIVING

The HTS drives 5 min to the apron and 5 min from the apron to the runway. The power required to deliver this services is calculated in Eq. 7.

$$\mathrm{P} = FF_{diesel} * \eta_{engine} * \mu_{diesel} * \mathrm{t} = \frac{1{,}5\mathrm{kg_d}}{\mathrm{min}} * 0{,}5 * \frac{43\mathrm{MJ}}{\mathrm{kg_d}} = \frac{32{,}25\mathrm{MJ}}{\mathrm{min}} \qquad \text{Eq. 7}$$

Where:

P = Power (MJ/min)
μ_{Diesel} = Energy density diesel (MJ/kg)
FF = Fuel Flow (kg/min)
η = Efficiency

Hereby the required power is derived from experimental aircraft taxi systems ([72] and [73]) under the assumption that these systems have the same efficiency as current best diesel engines (efficiency is 50% [74]). This assumption overestimates the power required if the engines used in the experiments had lower combustion efficiencies. These taxi systems were also tested with B747 aircrafts. These aircrafts are larger and heavier then B737-800 aircrafts thereby compensating for the likely additional weight of the HTS compared to the experimental taxi systems. To deliver this power the electricity needs to be converted to work. This efficiency is estimated at 92% [75]. The electricity is delivered from a battery therefore also a battery efficiency of 80% is taken into account. Eq. 8 gives the total power in MJ per minute for the HTS system while taxiing the aircraft. The taxi time is 10 minutes.

$$P_{HTS,drive} = W / \eta_{motor} / \eta_{battery} = 32{,}25 \frac{MJ}{min} / 0{,}92 / 0{,}80 = 43{,}8 \frac{MJ}{min} \qquad \text{Eq. 8}$$

AIRLIFTING CALCULATIONS

The hovercraft system was conceived to be based on the air casters principle [61]. For the working principle see [76]. As reference a type of air casters of AeroGo Inc were used [77]. These air casters can lift 108.000 kg what is enough to lift the aircraft and the HTS. The pressure of the air is 4,5 bar and the airflow is 225 L per second. For calculating the power needed to lift the aircraft with the HTS the ideal gas law was used (see Eq. 9).

$$pV = nRT \qquad \text{Eq. 9}$$

Where:

T = Temperature (K) and is constant
R = Gas constant (8,314462175 J / (mol*K))
n = Amount of molecules in the gas
p = Pressure (Pa)
V = Volume (m^3)

The work is done by the gas. It is assumed that the air behaves as an ideal gas. Eq. 13 shows the work needed by pressurizing a gas from situation A to B. Eq. 13 follows from Eq. 10 and Eq. 9. The mathematical steps taken are shown in Eq. 11 and Eq. 12.

$$W_{A\to B} = \int_{V_A}^{V_B} pdV \qquad \text{Eq. 10}$$

$$W_{A\to B} = nRT \int_{V_A}^{V_B} \frac{1}{V} dV = nRT \ln\left(\frac{V_B}{V_A}\right) \qquad \text{Eq. 11}$$

$$nRT = constant \to p_A V_A = p_B V_B \qquad \text{Eq. 12}$$

$$W_{A\to B} = p_A V_A \ln\left(\frac{p_A}{p_B}\right) = p_B V_B \ln\left(\frac{p_A}{p_B}\right) \qquad \text{Eq. 13}$$

Change the volume to a flow and work changes to power (Eq. 14):

$$P_{A\to B} = \frac{p_B V_B}{\mathrm{t}} \ln\left(\frac{p_A}{p_B}\right) \qquad \text{Eq. 14}$$

Where:

$P_{A\to B}$ = Power needed to pressurize a flow of air (W)
t = Time (s)

The power to lift the HTS with an aircraft is given by Eq. 15 and is 0,155 MW. The air casters were conceived to run for 6 minutes resulting in an energy use of 55,6 MJ. The efficiency of delivering this energy to the engines is the battery efficiency of 80% resulting in an energy supply of 62 MJ.

$$P_{lift} = 450.000\ \mathrm{Pa} * 0.225 \frac{\mathrm{m}^3}{\mathrm{s}} * \ln\left(\frac{100.000\ Pa}{450.000\ Pa}\right) = 154.630\ W \qquad \text{Eq. 15}$$

THRUST

When the aircraft is lifted by the air casters it needs to be pushed to the parking spots by thrust generated by vents. A good vent delivers 800 N using a power 25 kW [78]. The system needs a power to accelerate at 1 m/s^2 therefore 100.000 N is needed. 100.000 N can be generated using 3,125 MW. The system runs for 6 minutes on an average load of 50% resulting in an estimated energy use of 563 MJ.[34] The efficiency of delivering this energy to the engines is the battery efficiency of 80% resulting in an energy supply of 625 MJ.

D.2. ELEVATORS CALCULATIONS:

The elevators are conceived to have a capacity of 1500kg. The iPort has two elevators per apron for the purpose of transporting staff and GSE staff and facilities to the aircraft. The elevators are conceived to have a velocity of 2m/s and the transport the facilities and staff 13 meters

[34] This energy requirement is estimated high because the thrust needs to compensate for the drag force acting on the aircraft due to the wind.

vertically per trip. The energy use for calculating the energy requirements for an elevator is given by Eq. 16: [79] and [80]

$$E_{el} = \frac{P_{rated}}{\eta_{elevator}} * t + P_{standby} * t_{standby} \qquad \text{Eq. 16}$$

Where:

E = Energy (J)
P =Power (W)
Ƞ = Efficiency
t = Time (s)

$$E_{el} = \frac{15.000W^{35}}{0,7} * 14\frac{s}{T} + 50W^{36} * (40\,\text{min} * 60\frac{s}{min} - 14s) = 419.000J \qquad \text{Eq. 17}$$

Eq. 17 shows the energy use per turnaround per elevator. The total energy use of the elevators per turnaround was calculated to be 0,84 MJ.

D.3. CATERING TRUCK

The catering trucks deliver the consumables to the iPort-concourse instead of to the aprons. Therefore the trucks can transport larger quantities per time and drive less often. The energy consumption of the trucks is estimated at 20% of the energy consumption in the C-concourse case because it is estimated that trucks will transport the consumables with 5-6 times higher loads [61]. So, the energy consumption per turnaround is 16 MJ.

D.4. FIXED POWER UNITS

A FPU consumes about 25 kWh (equivalent to 90 MJ) per turnaround (see Table 12). A turnaround takes 50 minutes and will take 25 minutes so the FPU is expected to use 45 MJ per turnaround.

Table 12: Electricity consumption data of two turnarounds at Schiphol using a FPU.

1	Adrescode	Datum/Eindtijd	kW	kWh
1895	VS4-R43 HS455 EAN7138	20-01-2014 17:30	0	0
1896	VS4-R43 HS455 EAN7138	20-01-2014 17:45	18,58974358	4,64
1897	VS4-R43 HS455 EAN7138	20-01-2014 18:00	26,98373017	6,7999
1898	VS4-R43 HS455 EAN7138	20-01-2014 18:15	24,35897436	6,08
1899	VS4-R43 HS455 EAN7138	20-01-2014 18:30	23,71794872	5,92
1900	VS4-R43 HS455 EAN7138	20-01-2014 18:45	1,602564103	0,4
1901	VS4-R43 HS455 EAN7138	20-01-2014 19:00	0	0
1902	VS4-R43 HS455 EAN7138	20-01-2014 19:15	22,43589742	5,6
1903	VS4-R43 HS455 EAN7138	20-01-2014 19:30	32,06349207	8,08
1904	VS4-R43 HS455 EAN7138	20-01-2014 19:45	32,37179487	8,08
1905	VS4-R43 HS455 EAN7138	20-01-2014 20:00	21,47435898	5,36
1906	VS4-R43 HS455 EAN7138	20-01-2014 20:15	0	0

[35] The power is estimated using [79] and [80].
[36] See footnote 35

D.5. PRESSURE PIPELINES IN IPORT

The fuel is supplied to the iPort-concourse using the same power needed as in case 1 for refueling the aircraft at the C-concourse. The fuel is supplied to a tank and the fuel from this tank is used to keep the pipelines in the iPort-concourse under pressure. Therefore the additional energy supplied to this system is calculated using Eq. 5. Only the initial pressure will be higher than the air pressure. The initial pressure is estimated at 600.000 Pa[37]. The total addition work was calculated using Eq. 6.

$$E_{Fuel\ pump,additional} = \frac{W_{pump}}{\eta} = \frac{4MJ}{0{,}95} = 4{,}2\ MJ \qquad \text{Eq. 18}$$

D.6. ROTATING THE BUILDING

Energy use for rotating the building can be divided into two different categories. Starting the building with rotating and maintaining the rotational speed in process.

For starting the rotation of the building the mass needs to overcome its inertia. The formula used to calculate change in kinetic energy of a rotating object is given by Eq. 19.

$$\Delta E_k = \frac{1}{2} I {\omega_f}^2 - \frac{1}{2} I {\omega_i}^2 \qquad \text{Eq. 19}$$

Where:

E_k = Kinetic energy (J)
I = Moment of inertia (see Eq. 20) (kg * m^2)
ω_i = Rotational velocity in initial situation (rad/s)
ω_f = Rotational velocity in final situation (rad/s)

$$I = \frac{1}{2} m (r_{ex}^2 - r_{in}^2) \qquad \text{Eq. 20}$$

Where:

m = Mass (kg)
r_{ex} = External radius (m)
r_{in} = Internal radius (m)

Resulting in Eq. 21:

$$E_k = \frac{1}{4} m (r_{ex}^2 - r_{in}^2) {\omega_f}^2 - \frac{1}{4} m (r_{ex}^2 - r_{in}^2) {\omega_i}^2 \qquad \text{Eq. 21}$$

One rotation is conceived to take 40 minutes. The outer radius of the rotating platform is 107 meter and the inner radius of the platform is 54 meter.[61] The platform weights approximately 70.000.000 kg. By calculating the energy required to let the iPort rotate at the correct speed the assumption that the weight was equally spread was made. This assumption, knowing that the

[37] Due to the transfer of fuel from the pipelines to the tank a slight pressure drop is expected.

inner part of the rotating disk is slightly heavier, gives an energy demand higher then actually needed. The water is going to rotate at the same speed so the mass of water was taken into account as well. The depth of the water was conceived to be 10 cm resulting in a weight of 2.680.700 kg (Eq. 22). The starting energy is the energy required to overcome the inertia is given by Eq. 23:

$$M_w = A * y * \rho_w = (\pi 107^2 - \pi 54^2) * 0{,}1\ m * 1000 \frac{kg}{m^3} = 2.680.700\ \text{kg} \qquad \text{Eq. 22}$$

Where:

M_w = Mass of water (kg)
y = Depth (m)
ρ_w= Density of water (kg/m³)

$$E_k = \frac{1}{4} * 72.680.700kg * (107^2 m^2 - 54^2 m^2) * \left(\frac{2\pi}{60s/min * 40min}\right)^2 = 1.062.700\ J \qquad \text{Eq. 23}$$

The energy consumption for continuous rotation during the operational mode of the platform depends on friction. Thereby the friction of the air, the friction of the water and the friction of the sealing were considered. Also the energy to rotate the mass of the aircraft was taken into account.

ROTATING THE AIRCRAFT

Energy required for rotating the aircraft is given by Eq. 24. The mass of a Boeing 737-800 may not exceed the 80.000 kg. The aircraft rotates about 70 meter from the rotating point and with the same rotational speed as the building.

$$E_{k,a} = \frac{1}{4} * 80.000kg * (70^2 m^2) * \left(\frac{2\pi}{60s/min * 40min}\right)^2 = 672\ J \qquad \text{Eq. 24}$$

Where:

$E_{k,a}$ = Kinetic energy needed to rotate the aircraft (J)

DRAG FORCE BY AIR ON THE IPORT

Figure 30 gives a schematic overview of the iPort-concourse. The top cylinder represents the building with rotating outside and the lower larger cylinder represents the underground rotating caisson. The force of the wind does not act in the rotational direction but acts in linear direction. This force acting on the iPort-concourse (arrow 1) is cancelled by the building. The iPort-concourse is in-grounded therefore the force of the wind cannot move the building. The speed of the wind has no influence on the drag force of the rotational movement.

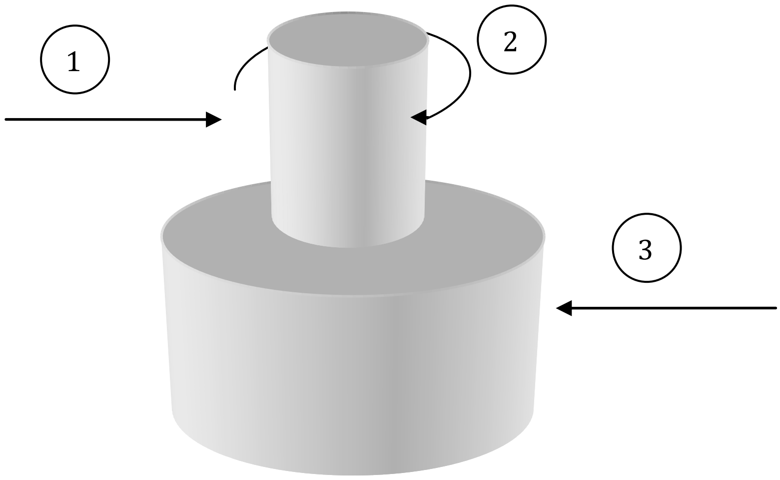


Figure 30: A schematic overview of the iPort with the drag force of the wind (arrow 1) friction from the building (arrow 3) and the moving direction of the aprons (arrow 3). $F_1 = F_2$

So, when the drag of the building was calculated the speed of the wind had no influence. Eq. 25 gives the formula used to calculate the rotation drag friction.

$$P_d = F_d * v = \frac{1}{2}\rho_a v^3 C_d A \qquad \text{Eq. 25}$$

Where:

P_d = Power to overcome the drag friction (W)
F_d = Drag friction (N)
v = velocity (m/s)
ρ_a = density of air (kg/m^3)
C_d = Drag coefficient
A = Area (m^2)

The average speed is 0,21 m/s[38], the area was estimated at 200 m^2, the C_d was estimated at 2 [81][39] and the air density is 1,225 kg/m^3 according to the International Standard Atmosphere [82]. Eq. 26 gives the power required to overcome the drag force by the air:

$$P_d = \frac{1}{2} * 1{,}225 \frac{kg}{m^3} * (0{,}21 \frac{m}{s})^3 * 2 * 200\ m^2 = 2{,}3\ W \qquad \text{Eq. 26}$$

FRICTION CAUSED BY THE WATER

Eq. 27 was used to calculate the power needed to overcome the resistance caused by the viscosity of the water. The viscosity of water is $1{,}002*10^{-3}$ Pa*s at 20 degrees of Celsius[40] [83]. The area is calculated using Eq. 28 with r_{out} is 107 meter and r_{in} is 54 meter.

---

[38] Average speed = Average radius * 2 * π / 2.400 sec per round = 0,21 m/s
[39] This C_d is a high estimation based on the C_d of the Empire State building.
[40] The viscosity of water increased if the temperature decreases. At 0 degrees of liquid water the viscosity is $1{,}792*10^{-3}$ Pa*s resulting in a P_v of 22 Watt. This power is not significant.

$$P_v = F_v * v = \mu A \frac{v^2}{y} = 1{,}002 * 10^{-3} Pa\ s * 26807\ m^2 * \frac{0{,}15^2}{0{,}1} \frac{m}{s^2} = 12\ W \quad \text{Eq. 27}$$

Where:

P_V = Power needed to overcome the friction of viscosity (W)
F_v = Friction caused by viscosity (F)
v = Velocity of the water (m/s)
µ = Viscosity of water (PA *s)

$$A = \pi r_{out}^2 - \pi r_{in}^2 \quad \text{Eq. 28}$$

SEALING

The sealing used to prevent the water from leaking was conceived to be a ferro fluid seal. Ferro fluid is a magnetic fluid attracted to the magnetic seals. The fluid of magnetic particles then forms a barrier that prevents the water from leaving the caisson. Ferro fluid seals can typically withstand an additional 0,2 bar according to Ferrotec. That is why two sealing's were conceived to be used. Because the sealing medium was a fluid, there is virtually no friction between the rotating and stationary components [84]. See Figure 31 for a schematic overview of the working principle of the sealing.

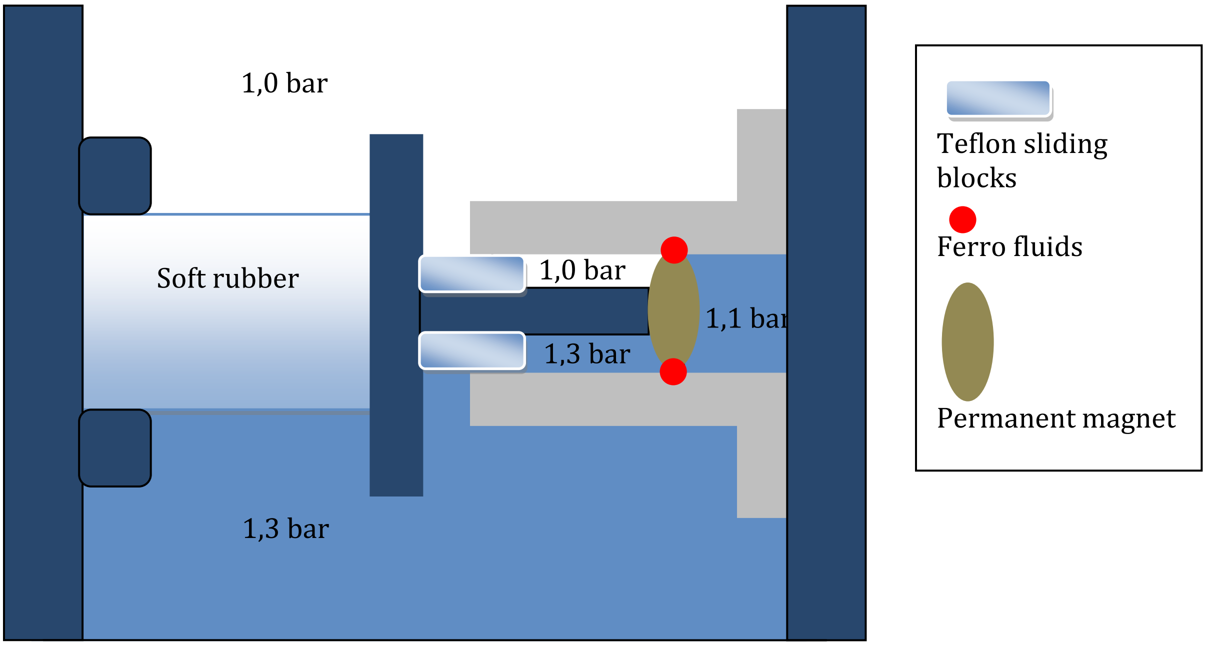


Figure 31: A simplified schematic overview of the working principle of the sealing. The left black bar represents the stationary outer wall of the pit and the right black bar represents the outer part of the rotating iPort-concourse.[41]

The power to overcome friction is calculated using Eq. 29 with C_F = 0 resulting in no losses due to friction.

$$P = F_F * v = F * C_{F,f} \quad \text{Eq. 29}$$

[41] The pressure of the water is calculated as the force caused by the building on the water. The additional force was (70.000.000 kg * 9,81 m/s)/26.807m^2 = 0,3 bar

Where:

$C_{F,f}$ = Coefficient of friction of ferro fluid

The teflon sliding blocks have a friction coefficient of 0,1 [85] and the sliding blocks have a width of 2 cm. The outer sealing has a total contact surface with the sliding blocks of 13,4 m² (see Eq. 30) and the inner sealing has a total contact surface of 6,8 m² (see Eq. 31).

$$A_{s,o} = 2\pi r_{out} * x = 13{,}4\ m^2 \qquad \text{Eq. 30}$$

Where:

$A_{S,O}$ = Area of sliding blocks at outside (m^2)
x = Width of the sliding blocks (m)
r_{out} = Outer radius (m)

$$A_{s,i} = 2\pi r_{in} * x = 6{,}8\ m^2 \qquad \text{Eq. 31}$$

Where:

$A_{S,i}$ = Area of sliding blocks at inside (m^2)
r_{in} = Inner radius (m)

The velocity at the outside is 0,28 m/s (see Eq. 32) and the velocity and the inside is 0,14 m/s (see Eq. 33). The force acting on the sliding blocks is caused by the differences is pressure. Therefore the force is 30.000 N/m².

$$v_o = \frac{2\pi r_{out}}{t} = 0{,}28\ m/s \qquad \text{Eq. 32}$$

Where:

v_o =velocity at the outside (m/s)
t = time per rotation (s)
r_{out} = Outer radius (m)

$$v_i = \frac{2\pi r_{in}}{t} = 0{,}14\ m/s \qquad \text{Eq. 33}$$

Where:

v_i = velocity at the inside (m/s)
t = time per rotation (s)
r_{in} = Inner radius (m)

The total power needed to overcome the friction of the sliding blocks is 14.912 Watt. Eq. 34 was used to calculate this power.

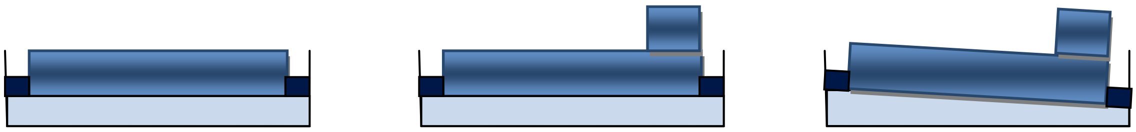
$$P_s = F_s * A_{s,o} * C_{F,s} * v_o + F_s * A_{s,i} * C_{F,s} * v_i \qquad \text{Eq. 34}$$

Where:

P_s = Power needed to overcome the friction of the sliding blocks (W)
F_s = Force acting on the sliding blocks (N/m^2)
$C_{F,s}$ = Coefficient of friction of sliding blocks

DISBALANCE OF ROTATING DISK

A perfect balanced concrete disk floats on water due to the enclosure of sealing (shown in Figure 32A) Figure 32B represents the same situation as Figure 32A only with an added weight at one location. When the sealing is not fixed the disk will find a new equilibrium (Figure 32C) but when the sealing is fixed the additional forces of disbalance act on the sealing. When the disk rotates this additional force increases the friction. The iPort-concourse in conceived to have fixed sealing to prevent tilt of the aprons. The additional weight causing disbalance are mainly the aircrafts entering and leaving the aprons.



(A) **(B)** **(C)**

Figure 32: (A) A 2 dimensional schematic representation of a concrete disk floating on water due to the enclosure of the sealing, (B) an additional weight added to the system and (C) a representation of tilt caused by disbalance of the disk.

The assumption is made that the iPort-concourse is in average disbalanced by one aircraft (80.000 kg). All the forces due to the additional disbalanced weight are absorbed by the sealing. Eq. 37 gives the power needed to overcome the friction. The coefficient of friction is 0.1 [85] and the average velocity is given by Eq. 36.

$$P_T = m_d * g * C_F * v_{av} = 80.000\ kg * 9{,}81 \frac{m}{s^2} * 0{,}1 * 0{,}234 = 18.364\ W \qquad \text{Eq. 35}$$

Where:

P_T = Power to overcome the friction caused by tilt (W)
m_d = Mass of disbalance (kg)
g = gravitational constant of 9,81 m/s^2
C_F = Coefficient of friction

$$v_{av,s} = \frac{2\pi r_{out} * v_{out} + 2\pi r_{in} * v_{in}}{2\pi r_{out} + 2\pi r_{in}} = 0{,}234\ m/s \qquad \text{Eq. 36}$$

Where:

$v_{av,s}$ = The average velocity of the sealing (m/s)

TOTAL FRICTIONAL FORCES

The total energy to overcome per turnaround is 1 KJ of kinetic energy for rotating the aircraft, 2,3 Watt to overcome the drag force of the air, 12 Watt to overcome the viscosity of the water, 14.912 Watt to overcome the friction of the sliding blocks and 18.364 Watt to overcome the friction caused by the prevention of tilt. Each turnaround takes 5 minutes so the total work for continuous rotation per turnaround is 4,5 MJ per turnaround (see Eq. 37). The energy required is the work needed divided by a conversion efficiency of 80% resulting in an energy use of 12,5 MJ (see Eq. 38).

$$W_{T,r} = E_{k,a} + (P_D + P_V + P_S + P_T) * t$$ Eq. 37
$$= 1\,KJ + (2{,}3W + 12W + 14.912W + 18.364) * 5min$$
$$= 10{,}0\,MJ$$

Where

$W_{T,r}$ = Work needed for continuous rotation per turnaround (J)

$$E_{T,r} = \frac{W_{T,r}}{\eta} = 12{,}5\,MJ$$ Eq. 38

Where

$E_{T,r}$ = Energy needed for continuous rotation per turnaround (J)

D.7. CONVEYOR BELT CALCULATIONS

The luggage was conceived to be transported from the luggage basement to the iPort-concourse by conveyor belts. This conveyor belt is 200 meter in length. Then the luggage is transported to the apron and from there to the aircraft. The old luggage follows the same route back (on adjacent conveyor belts. A Boeing 737-800 holds an average of 150 passengers per aircraft [86] with 20 kg of luggage per passenger. The luggage of one aircraft needs to be transported to the iPort-concourse in five minutes. So the capacity must meet 3.000 kg/5min (10 kg/sec). The power of the conveyor belts are based on a reference conveyor belt at Kastrup Airport in Copenhagen [87]. The time used for the conveyor belts from the center of the iPort-concourse to the aircraft is estimated at 11 minutes (10 minutes at 5kg/sec + an additional processing time).

Conveyor belt 1 (to and from the iPort-concourse):
Length = 300 meter
Speed = 2 m/s
Load = 10 kg/sec (250 kg/50 meter)
Time = 300 sec
Power is 5,5 kW per 50 meter. So, 35 kW for the system

Conveyor belt 2 (upwards):
Length 80 meter
Speed = 2 m/s
Load = 5 kg/sec (125 kg/50 meter)
Time = 660sec
Power is 4,5 kW per 50 meter. So, 7,2 kW for the system

Conveyor belt 3 (downwards):
Length 80 meter
Speed = 2 m/s
Load = 5 kg/sec (125 kg/50 meter)
Time = 660sec
Power is 3,5 kW per 50 meter. So, 5,6 kW for the system

Conveyor belt 4 (upwards):
Length 12,25 meter
Speed = 2 m/s
Load = 5 kg/sec (125 kg/50 meter)
Time = 660 sec
Power is 5,5 kW per 50 meter. So, 1,4 kW for the system

Conveyor belt 5 (downwards):
Length 12,25 meter
Speed = 2 m/s
Load = 5 kg/sec (125kg/50 meter)
Time = 660 sec
Power is 5,5 kW per 50 meter. So, 0,9 kW for the system

Conveyor power calculations:
1.500W (no load) [87]. The assumption is made that 5.500W is used at full capacity (250 kg load) with a linear dependency with load. So 125 kg results in 3.500W but the load needs to be transported in height. Therefore the power is estimated at 4.500W (conveyor belt 2) and 5.500W (conveyor belt 4)

The total energy use for the conveyor belts is calculated using Eq. 39:

$$E_{CV} = \sum P_{CV,i} * n_{CV,i} * t_{CV,i} \qquad \text{Eq. 39}$$

Where

E_{CV} = Energy use of the conveyor belts per turnaround (J)
$P_{CV,I}$ = Power of conveyor belt i (W)
$n_{CV,I}$ = Amount of conveyor belts i
$t_{CV,I}$ = Time used per turnaround of conveyor belt i (s)

The total energy use is 31 MJ per turnaround (see Eq. 40)

$$E_{CV} = P_{CV,1} * n_{CV,1} * t_{CV,1} + P_{CV,2} * n_{CV,2} * t_{CV,2} + P_{CV,3} * n_{CV,3} * t_{CV,3} + P_{CV,4} * n_{CV,4} * t_{CV,4} + P_{CV,5} * n_{CV,5} * t_{CV,5} = 31\ MJ \qquad \text{Eq. 40}$$

APPENDIX E: INPUT DATA SANKEY DIAGRAM FOR IPORT-CONCOURSE

The software of SankeyMATIC [56] was used to dram the Sankey diagrams, as described in Chapter 3. In this Appendix the raw input data is found for the Sankey diagram of case 2.

Electricity [15] Pump
Pump [15] Refueling
Electricity [4] Pump2
Pump2 [4] Refueling
Electricity [45] FPU
FPU [45] Electric Energy Supply
Diesel [16] Catering Truck
Catering Truck [16] Catering services
Electricity [1] Elevator
Elevator [1] Catering services
Electricity [13] iPort
iPort [13] Rotating the building
Diesel [46] De-icing Truck
De-icing Truck [46] De-icing Services
Electricity [1248] HTS
HTS [1212] Transport
HTS [36] Electric Energy Supply
Kerosene [538] APU
APU [538] Electric Energy Supply
Electricity [31] Conveyor belt
Conveyor belt [31] Luggage Services

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APPENDIX F: EMISSION FACTORS

The emission factors are based on data gathered from 'Stichting Klimaatvriendelijk Aanbesteden & Ondernemen' [57].

Table 13: Emission factors

	g CO_2 / L	g CO_2 / kg	g CO_2 / kWh	g CO_2 / MJ
Electricity	-	-	455	126,4
Diesel	3.135	2.602	-	60,5
Kerosene	3.128	2.518	-	58,6

For the conversion of g CO_2 emissions per liters or per kilograms fuel to g CO_2 emissions per energy (MJ) the following conversion constants were used [67]:

Diesel:
830 g/L
43 MJ/kg
Kerosene:
805 g/L
43 MJ/kg
Electricity
3,6 MJ/kWh

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APPENDIX G: EXPLANATION OF DIFFERENCE IN ENERGY USE BETWEEN APU/GPU/FPU

The energy flows per minute (MJ/sec) between the different electrical energy supply sources differ widely. An APU consumes 54MJ/min, the GPU consumes 10MJ/min and a FPU consumes 2 MJ/min. In this appendix three arguments are given in order to explain the large difference in energy consumption between the APU, GPU and FPU.

First, an APU consumes kerosene to generate electricity and GPU consumes diesel to generate electricity, while a FPU has electricity as input. The conversion factors of kerosene to electricity (~30%) and diesel to electricity (~50%) partly explain the difference in energy input.

Second, the amount of electricity supplied to the aircraft must at least match the electricity demand. A FPU can exactly match the electricity supply with the electricity demand. An APU and a GPU, on the other hand, cannot exactly match the demand with supply. The electricity supplied by an APU and a GPU always surpasses the electricity demand. This partly explains the difference in energy inputs.

Third, an APU also delivers an air flow. This requires an energy investment thereby reducing the efficiency for electricity generation of the APU.