ZÜRICH AIRPORT

Aircraft Ground Energy Systems

at Zurich Airport

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1. Introduction

Aircraft during ground times at airports require electrical energy (115/200 volts at 400 Hz) for flight systems and electrical consumers (lights, etc) and depending on the ambient conditions also pre-conditioned air (PCA) for heating or cooling of the cabin. Such energy can either be provided by the aircraft built-in APU (Auxiliary Power Unit) or typically by ground support equipment (GPU - Ground Power Unit, ACU - Air Climate Unit, mobile heating unit). In addition, fixed energy systems are installed and operated by the airport or its tenants (table 1).

Energy Systems for Aircraft

	Aircraft built-in APU	Mobile Ground System	Ground Energy Systems
			
Electricity (400Hz)	✓	✓	✓
PCA (air)	✓	✓ (if Air Climate Unit)	✓
MES (main engine start)	✓	✓ (if Air Starter Unit)	-

Table 1 Ways of providing energy to the aircraft during ground times

Operation of aircraft APU with its low efficiency rate of 8-14% is subject to gaseous emissions and noise, thus often contributing significantly to the local air quality impacts and site noise impacts. To mitigate emissions and noise, fixed energy systems can be designed that provide electrical energy and pre-conditioned air to aircraft.

This report looks at the specific Zurich Airport situation and the ground power support system installed at aircraft stands. While the focus is on the technical solution, operational, regulatory, environmental and economic aspects are qualified and quantified as well.

2. Zurich Airport Situation

Given the stringent environmental legislation in Switzerland and the ambient air quality conditions in the area where Zurich Airport is located, the airport authority has started as early as 1990 to design and implement air quality mitigation plans. Such mitigation plans have always covered all sources at the airport, including the aircraft handling. Part of the ground handling is the ground power delivery to aircraft during their ground time. To this end, Zurich Airport provides both stationary 400 Hz and PCA at all hard stands and 400Hz at most recent open stands. In addition, Zurich Airport mandates the airlines to use the systems where available and serviceable.

The general airport layout is depicted in Figure 1.

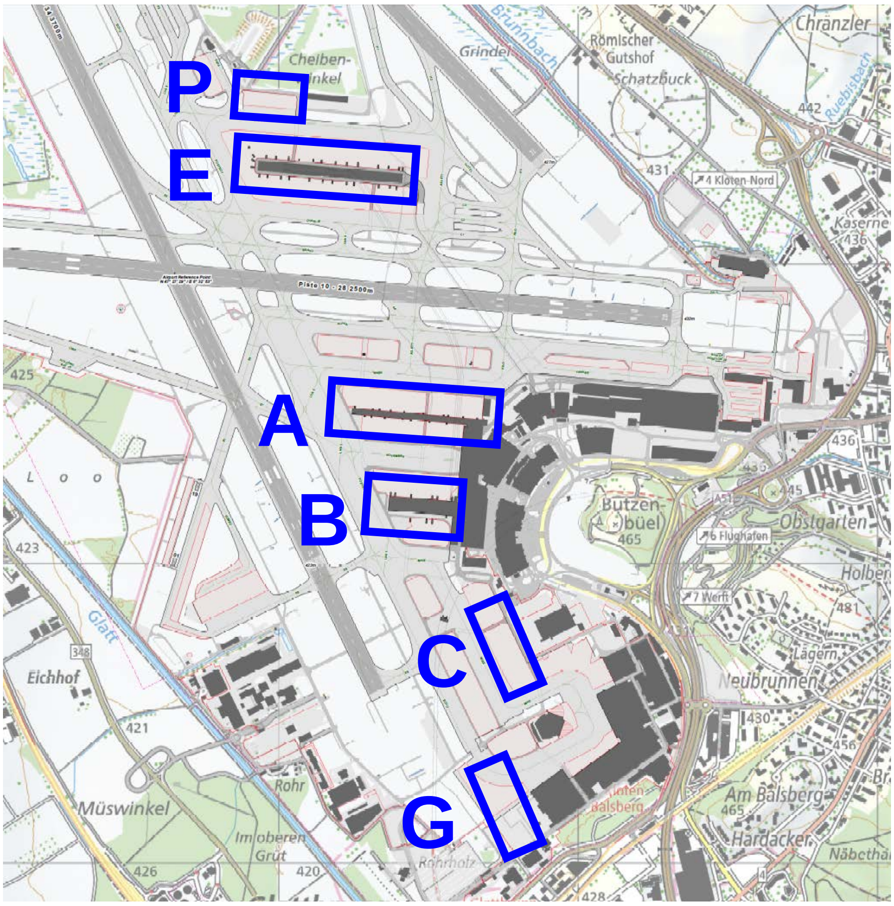


Figure 1 Zurich Airport aircraft piers and hard stands: Piers E, A, B and open stands P, C, and G

3. AGES Technical Description

3.1. General

Key to the schematic layout is the central provision of the energy (central 400Hz transformers and central chiller plants) with point of use hook ups. This setup with central ice storages prevents energy consumption for pre-conditioned air for large aircraft during peak time. The energy for PCA systems is usually produced during off-peak night hours and drawn from during daytime peak hours. The 400Hz electrical system is on demand usage from the public grid, even during peak hours.

Heat supply comes from the district heating network, which is fed by the airport's own heating plant and serves also the buildings.

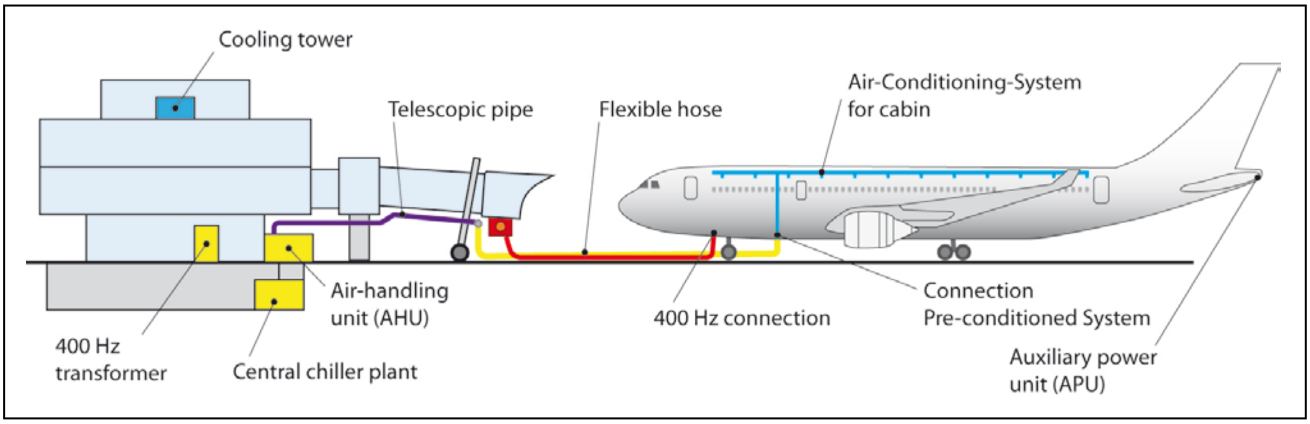


Figure 2 Basic layout of aircraft ground energy systems (AGES)

Reflecting the ambient and climate conditions of Zurich Airport, the systems for pre-conditioned air are designed for the following:

Ambient conditions:	Summer	+31°C, 80% humidity
	Winter	-11°C, 40% humidity
Cabin conditions:	Summer	+26°C
	Winter	+21°C
Air Handling Unit:	Outlet temp:	Min: -2°C, max: +50°C
	Air Volume:	Min: 2,000 m^3/h; max: 10,000m^3/h (Code F[1]: 12,000m^3/h)
	Pressure:	Min: 8,000 Pa; max: 9,500 Pa (Code F: 11,000 Pa)

[1] ICAO Aerodrome Reference Code: https://www.skybrary.aero/index.php/ICAO_Aerodrome_Reference_Code

3.2. Pier A

3.2.1. Electrical System 400 Hz

Pier A went into operation in 1985 and has a total of 17 stands for the handling of aircraft. When handling wide-body aircraft, the number of stands is limited to 13.

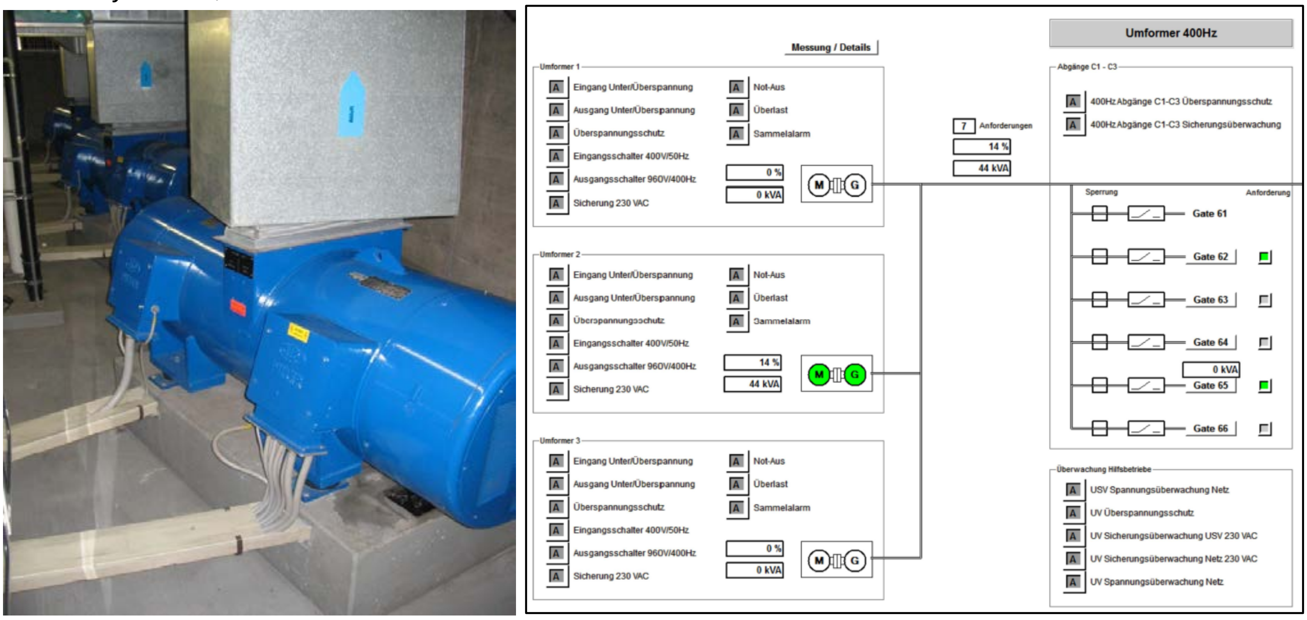


Figure 3 Transformer (left) and control panel (right).

The production is central with three rotating 50/400 Hz converters that are each switched on or off depending on the demand at the gates. The distribution to the individual gates is done via the 960 V grid. Each gate is equipped with a transformer, which contains one or two 90 KVA outlets, each with a 400Hz cable with plug.

A specialty of the plant is the monitoring and control syste, which collects data of around 1,000 objects like motors, converters, valves, sensors, switches etc. This control system logs all operating events and system errors. All important data can be trended, analysed and evaluated.

		Comments
Gates Pier A	17	Built 1985
Transformer Station	3	3x300 KVA
Distribution		960V / 400Hz
Local Transformer Total	17	
Cat. C	4	90 KVA
Cat. D, E	13	120 KVA

Table 2 Technical and operational information 400 Hz Pier A

3.2.2. Pre-conditioned Air System

The pre-conditioned air system for Pier A as it is today went into operation in 1998. Up to that time, air pressure compressors have been used for air-conditioning and main engine start. The system operates the same way as the one in pier E (see 3.4.2). Pier A offers one hose per gate for Code C aircraft and two hoses for Code D and E aircraft for air-conditioning. The air units have different capacities depending on the aircraft size.

Figure 4 Hose for pre-conditioned air at pier A.

	Amount	Capacity
Chiller (ammonium)	2	2 x 475 KW
Chiller Storage Capacity Stored Energy	9	 1,050 KW 4 MWh
Heating Converter	2	900 KW each
Air Conditioning Units (two hoses)	13	10,000 m^3/h
Heating capacity per unit		190 KW
Cooling capacity per unit		225 KW
Air Conditioning Units (one hose)	4	5,000 m^3/h
Heating capacity per unit		80 KW
Cooling capacity per unit		105 KW

Table 3 Technical data PCA Pier A

3.3. Pier B

3.3.1. Electrical System 400 Hz

Pier B went into operation in 2011 and has a total of 9 stands for the handling of aircraft. When handling wide-body aircraft, the number of stands is limited to 6. The stands are fed by two power buses, each supplied by a transformer of 1000 KVA. There are three stands for aircraft of category C, five stands for aircraft of category C, D, E and one stand for aircraft of category C, D, E and F. According to their size, they are equipped with one, two or four 90 KVA transformers.

		Comments
Gates Pier B	9	Built 2011
Transformer Station	2	2x1000 KVA
Distribution	2 power buses	230/400V / 50Hz
Local Transformer	16	16x90 KVA

Table 4 Technical and operational information 400 Hz Pier B

3.3.2. Pre-conditioned Air System

All stands at Pier B are equipped with a pre-conditioned air system. Heating is provided by the district heating system of the airport. Therefore, each apron tower comprises a heat-exchanger. For cooling, there are two chillers and five ice storages. The chillers are usually working at night, loading the ice storages when there is practically no other consumption. The stored capacity can then be used during the day. The two chillers of 300 KW each, together with the ice-storages (capacity 2,400KWh), allow a peak load of 1,200KW during four hours.

Figure 5 Hose for pre-conditioned air at pier B.

	Amount	Capacity
Chiller (R404A)	2	2 x 300 KW
Chiller Storage Capacity Stored Energy	5	 600 KW 2.4 MWh
Air Conditioning Units (one hose)	3	5,000m^3/h
Heating capacity per unit		80 KW
Cooling capacity per unit		115 KW
Air Conditioning Units (one hose)	5	10,000m^3/h
Heating capacity per unit		1900 KW
Cooling capacity per unit		225 KW
Air Conditioning Units (two hoses)	1	Max. 14,000m^3/h
Heating capacity per unit		Max. 201 KW
Cooling capacity per unit		Max. 329 KW

Table 5 Technical data PCA Pier B

3.4. Pier E

3.4.1. Electrical System 400 Hz

Pier E was built in 2001, went into operation in 2003 and provides 27 gates for aircraft handling. Two gates are for aircraft Code D to F (360 KVA), 14 gates are for Codes D and E (180 KVA) and 11 gates for category C (90 KVA) . The static converters are placed in the apron buildings. Depending on the stand size, one, two or four converters are available. The cable coils with 30 m cable are mounted underneath the passenger loading bridge.

Figure 6 Cable and hose coils (left) and 400Hz transformers (right)

The operation of the system can be done through the aircraft plug or the switch board on the passenger loading bridge.

The system contains a monitoring and control unit, which covers 1,650 objects. The system logs all operating events and system errors and all important data can be trended, analysed and evaluated. The gates are equipped with measurement systems for the electricity.

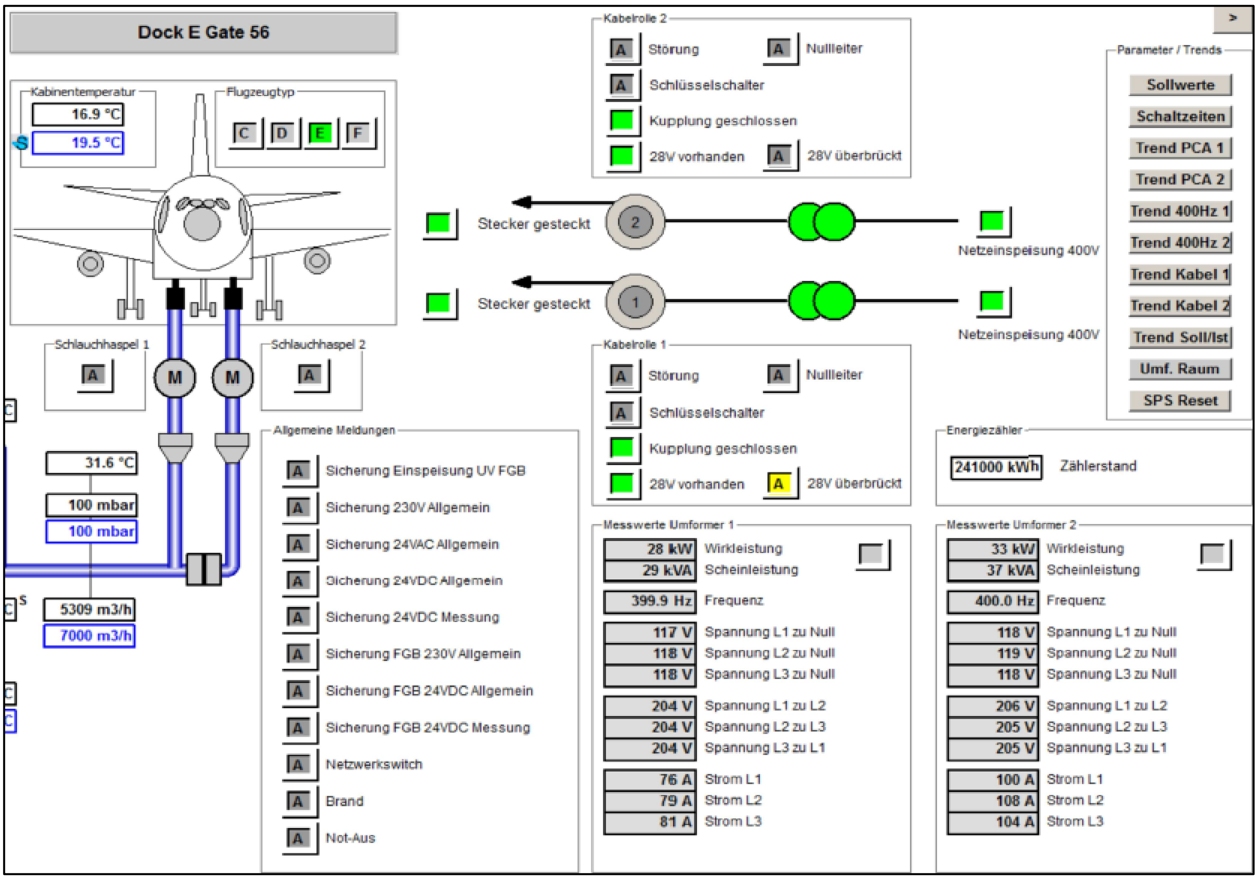


Figure 7 400Hz monitoring panel

		Comments
Gates Pier E	27	2x 360 KVA 14 x 180 KVA 11 x 90 KVA
Transformer station	2 1	2 x 1,600 KVA 1 x 700 KW (cooling)
Static converter 90KVA	47	Total capacity 4.23 MVA
Cable coils	47	

Table 6 Technical and operational information 400 Hz Pier E

3.4.2. Pre-conditioned Air System

The air-conditioning units deliver warm or cold air to the aircraft fuselage depending on the requirements. The air units are placed on the apron and connected to the hose reels over a telescope pipe under the passenger loading bridges. Of the two gates for Code D to F aircraft, one has four and the other two hoses. The gates for Code D and E aircraft have two hoses, the gates for category C aircraft one.

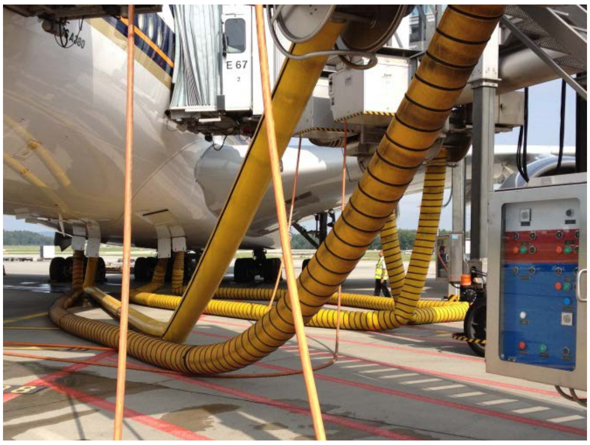


Figure 8 Hose for pre-conditioned air (left) and central PCA plant (right)

The ice machines produce binary ice (flow-ice) during the night which is stored in the energy storage unit. During actual operations, the stored energy helps to break the peaks of daily operation. This results in lower energy capacity requirements as peak hour demand has not to be met. Also, binary ice requires smaller transport pipes as the latent energy can be used. Some gates provide metering systems to monitor heat and ice consumption of individual aircraft types.

Figure 9 Chiller

The heating and cooling energy is provided through two separate pipe systems at each gate. This enables to heat or cool aircraft at the same time. All relevant data are displayed in the control system for trending, analysis and evaluation.

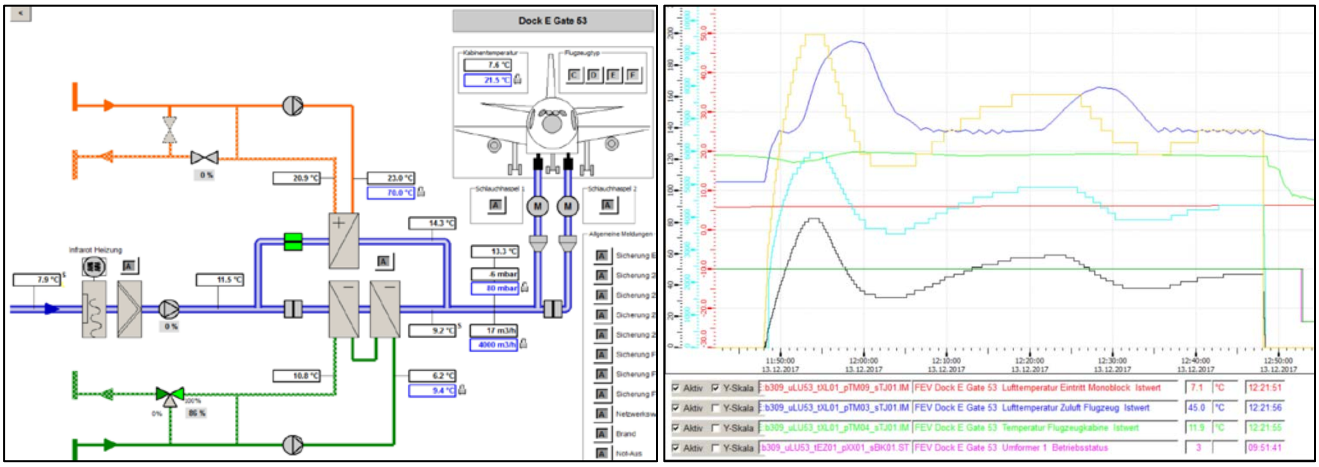


Figure 10 Control panel for pre-conditioned air (left) and analysis chart.

	Amount	Capacity
Chiller (ammonium)	3	3 x 410 KW
Ice Storage Stored Energy	1	220 m^3 10,000 MWh
Heating Transformer	2	1,100 KW each
Air Conditioning Units (four hoses)	1	2x 10,000 m^3/h
Heating capacity per unit		1x 190 KW
Cooling capacity per unit		1x 225 KW
Air Conditioning Units (two hoses)	15	12,000 m^3/h
Heating capacity per unit		190 KW
Cooling capacity per unit		225 KW
Air Conditioning Units (one hose)	11	6,000 m^3/h
Heating capacity per unit		80 KW
Cooling capacity per unit		105 KW

Table 7 Technical data PCA Pier E

3.5. Electrical System Open Stands “Charlie”

Eight open stands on the tarmac-area “South”, named C50 – C60, are equipped with stationary electrical systems. Five wide-body aircraft or eight narrow-body aircraft can be parked in the whole area. In total, there are five 50/400Hz converters with 180KVA each available. Three of them offer three plugs, from which only two can be used simultaneously. The other two converters are equipped with two plugs.

		Comments
Open Stands C	8	Built 2011
Converter Station	5	5x180 KVA

Distribution		115/200 V / 400 Hz
Connection Cables	13	13x90 KVA

Table 8 Technical data Open Stands “Charlie”

Figure 11 400Hz system open stands “Charlie”

3.6. Electrical System Open Stands “Papa”

North of pier E, there are located additional open stands. These are divided in a western and an eastern part. The western part accommodates two Code E and F aircraft or three aircraft Code C. The eastern part accommodates four aircraft Code C. All stands are equipped with stationary electrical systems. The western part comes with two converters of 2x180KVA, who are connected to three underground pits, one with 1x90 KVA and two with 2x90 KVA. The eastern part is equipped with four converters of 90 KVA, one for each stand.

		Comments
Open Stands P	7	Built 2014
Local Transformer	6	2x180KVA 4x90KVA

Table 9 Technical Data Open Stands “Papa”

Figure 12 400Hz system open stands “Papa” Eastern Part.

Figure 13 400Hz pit system open stands “Papa” Western Part.

4. System Operation

4.1. Energy Source

Heat energy is provided for all systems by the airport's central power plant. This energy plant is a combined heat and power co-generation plant, consisting of four boilers with two steam turbines and one gas turbine with a total heat capacity of 120 MW_{th} and 10 MW_{el}. The plant has been operated with 90% compressed natural gas (since 1998) and 10% heating oil (light). It supplies the whole airport with process energy and is optimised for operational and ecological parameters.

Electrical energy is taken from the public grid through two independent transformer stations.

4.2. Aircraft Operation and Handling

Operational procedures may vary from airport to airport. Aircraft in Zurich are handled on remote stands or on pier stands. On most remote stands, GPU are available for delivering electricity to the aircraft (owned and operated by the handling agents). There are only few air climate units (ACU) available. On all pier stands (piers A, B and E), fixed ground power systems for electricity and pre-conditioned air (AGES: aircraft ground energy systems) are available and energy is delivered to the aircraft by the handling agents immediately after on-block.

Figure 14 Air Climate Unit (ACU) on the left and Ground Power Unit (GPU) on the right.

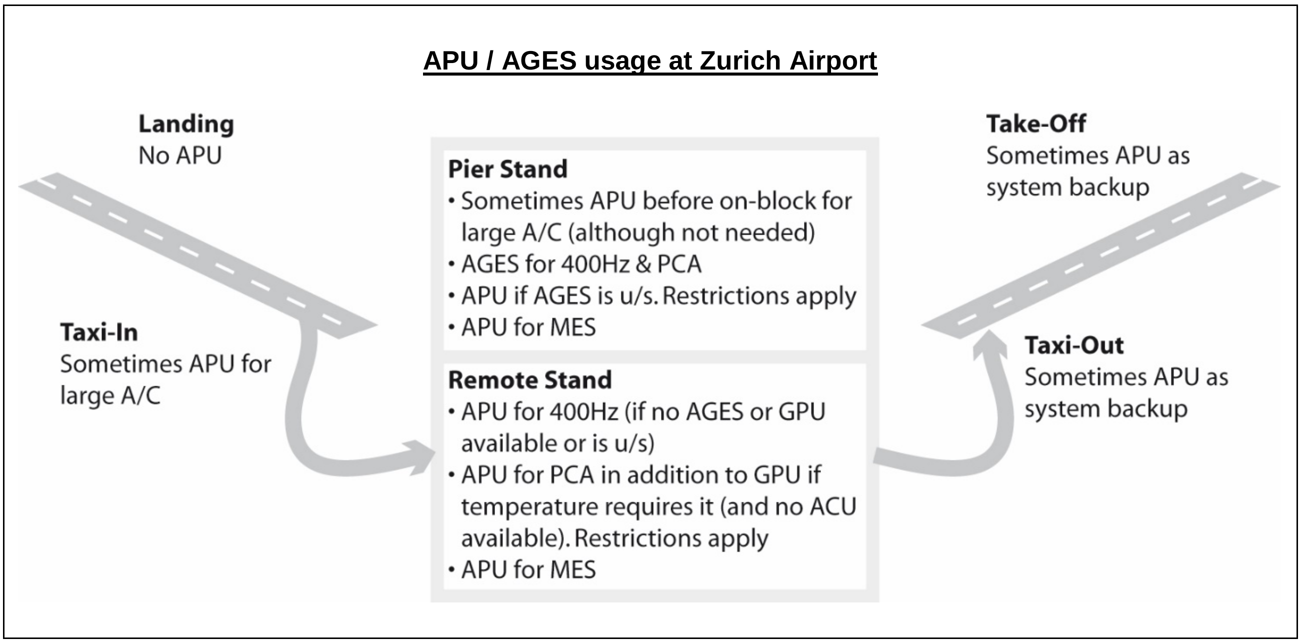


Figure 15 Operational characteristics of APU / AGES usage

The AGES are operated by the various handling agents. When an aircraft has reached the parking position, often with only one engine running, ground staff sets the chocks and attaches the aircraft to external power at the same time. As such it is not necessary for the aircraft crew to run the APU upon approaching the stand in order to timely shut down the main engines. The operation of the AGES is self-explanatory, although training is provided to ground handling staff by the technical maintenance department of the airport.

White section:

- Maintenance only

Red section: 400 Hz electricity

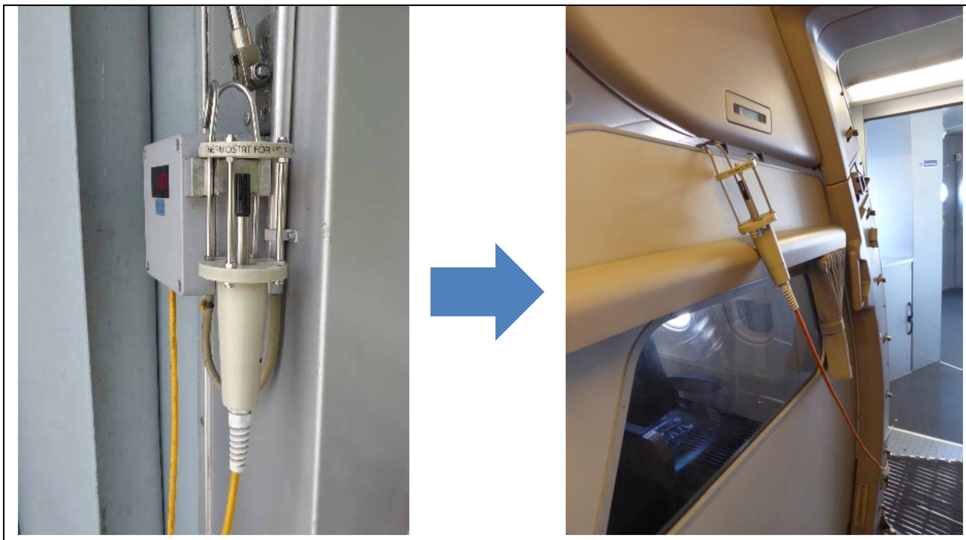
- Cable coil up/down for 2 systems
- On/off button

Blue section: PCA (heating, cooling)

- Hose reel up/down for 2 systems
- Aircraft category selectors:
  Code C: A318-A321, B737, MD80, F100
  Code D: A300, A310, B757, B767
  Code E: A330-A350, B747, B777, B787, MD11
  Code F: A380
- On/off button

Figure 16 Control panel on PLB for 400Hz and PCA (dual system layout for Code C, D, E)

A passenger loading bridge mounted sensor is placed in the cabin interior to control the cabin temperature. Depending on the outside temperature, the cabin temperature can range from 21°C (winter) to 26°C (summer). At an outside temperature of +31°C the cabin temperature is +26°C, at an outside temperature of +21°C, the cabin temperature is +21°C.



Initial position of the sensor in the passenger bridge.

Sensor placed for operation in the cabin.

Figure 17 Placement of the temperature sensor.

4.3. System Performance

The systems are owned and maintained by Flughafen Zurich AG as part of the core infrastructure of the airport. The technical availability of the system is >99% of all times. Any malfunctions are reported immediately to «Service 24» of Flughafen Zürich AG and repaired by technicians. Typical damages occur when 400Hz cable connectors or PCA hoses break.

5. Regulatory Framework

5.1. Environmental Regulations

Air quality regulations in Switzerland stipulate that emission mitigation measures have to be implemented when national standards of air pollutants are exceeded. The standards usually in question and directly linked to emissions are nitrogen dioxide (standard: 30 $\mu g/m^3$ annual mean) and PM10 (standard: 20 $\mu g/m^3$ annual mean). Both standards are currently exceeded at various spots within the airport perimeter, but also in various regions of the country with dense population and industrial activities.

By federal legislation, Zurich Airport is in most cases required to perform an environmental impact assessment (EIA) for infrastructure projects; this also includes an air quality assessment. Based on those results, Zurich Airport has to propose measures that reduce emissions which will then be included as mandatory measures into the permits by the federal aviation authority. In case of potential AGES, they are linked to aircraft related projects (e.g. runway, taxiway, apron/stands). Measures once enacted and implemented can usually not be lifted, even if the air quality situation improves and compliance is reached (prevention of slide back).

5.2. Aircraft APU Operational Restrictions

In order to yield maximum benefits of the implemented measure and based on the Operating License for Zurich Airport, the use of auxiliary power units (APU) is subject to certain restrictions. These are laid down in the AIP LSZH, section AD 2 [1].

AIP SWITZERLAND[1]
LSZH AD 2.21

1.2 Auxiliary Power Units (APU)
1.2.1 All stands
Primarily, the stationary airport pneumatic and electrical service units shall be used. Alternatively, mobile units shall be used.

1.2.2 The APU shall only be started:
- to start the engine, but no earlier than 10 MIN before off-block time
- if the stationary or mobile units are not available or unserviceable for specific aircraft types. In that case, the APU shall be started no earlier than:
  - 50 minutes before off-block time for aircraft Codes B and C
  - 70 minutes before off-block time for aircraft Codes D, E and F
  - 30 minutes before off-block time for GA sector 1

  and kept in operation no more than 20 minutes after the on-block time.
- if maintenance work on the aircraft makes it unavoidable; in that case the service period shall be kept as short as possible.

Exceptions have to be permitted by the Airport Authority

[1] 01 DEZ 2017 and AIRAC 07 DEZ 2017

5.3. Airline Operational Instructions

Some airlines establish additional and company based procedures for the usage of APU. These procedures can be dependent on aircraft type, actual take-off weight and characterisation of the airport (altitude, runway length, etc).

One airline operating in and out of Zurich has set up the following procedures in an effort to contribute to environmental protection:

4. USE OF APU

(…)

- ACFT on hard stands: switch off APU when GND Power Unit (GPU) connected.
- Terminal A/B: Preconditioned air and electrical power avbl.
- Energy saving:

  The crew shall decide, depending on WX COND or technical requirements, whether air conditioning is required or not.

  Generally, the air conditioning system should be switched off with AOT of APRX 10°C to 25°C. The air conditioning system should also be switched off after PSGR have disembarked or before leaving the ACFT.

6. Environmental Assessment

6.1. AGES Benefits

The combination of reliably providing electrical energy and pre-conditioned air, while at the same time mandating the airlines to use the systems when technically available, is the key to achieve maximum ecological benefits.

Already the specific emission reductions are considerable when comparing the CO_2 emissions per hour of operation for an APU, a GPU and the fixed energy system.

	APU kg CO_2/h	**Diesel GPU kg CO_2/h**	**400 Hz kg CO_2/h[1]**
Shorthaul Aircraft	337	19.1	0.7
Longhaul Aircraft	758	38.2	1.2

[1]Emissions from Swiss electricity production

Table 10 Specific CO_2-emissions (kg/h) of APU, GPU and fixed electricity

6.2. Airport Emissions

Airports are routinely calculating emission inventories and often do dispersion modeling for all airport induced emission sources. The current main guidance is ICAO Doc 9889 (Airport Air Quality Guidance Manual, 2011, [2]) which places all emission sources into one of four emission groups (aircraft, handling, infrastructure, landside access traffic). APU are listed in the “aircraft” group. According to Doc 9889, more or less advanced/ sophisticated approaches are used to reflect also “real world” operations.

Emission inventories often include the full ICAO certification LTO up to 3,000 ft. However, only emissions of the first 1,000 ft are actually relevant for the resulting concentrations at ground level. This has to be reflected in the modeling of the emission inventory as well as the dispersion modeling.

The following table shows an example of such an inventory for Zurich Airport using advanced and sophisticated approaches for the year 2016 (269,160 aircraft movements, 27.7 Mio. passengers, 464,859 tons cargo). Results are provided for both the standard certification LTO as well as for the concentration relevant section of the LTO cycle.

	Perimeter Variation			
Scenario	ZRH 2016, aircraft traffic, airport infrastructure, some landside access (dedicated access road only), actual APU regime (with AGES and GPU on aircraft stands), other GSE			
LTO cycle	ICAO LTO cycle (3,000 ft), ICAO EF, real Taxi Times		Concentration relevant cycle (1,000 ft), ADAECAM EF, real Taxi Times	
Total airport NO_X	1,455 t	100%	801.97 t	100%
APU NOx	17.25 t		17.25 t	
GPU NOx	3.2 t		3.2 t	
APU + GPU NO_X	20.45 t	1.4%	20.45 t	2.5%

Table 11 Zurich Airport and APU emissions 2016, share depending on the spatial perimeter

The benefits of APU mitigation options (on the total airport emissions) are presented in the following table. There are three different scenarios modelled:

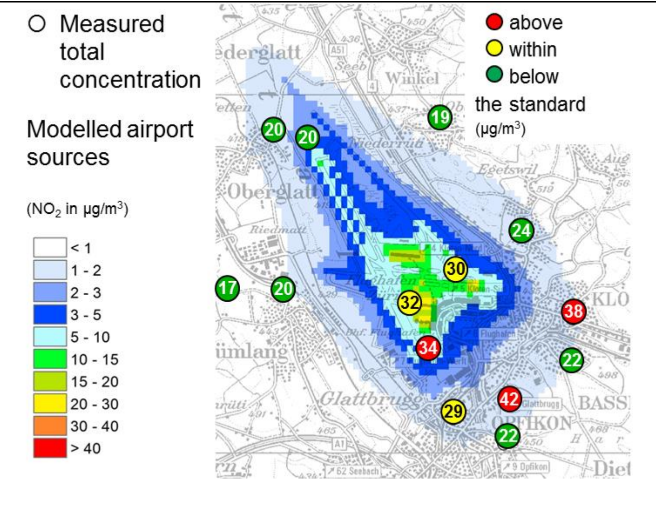
1. There are no AGES available and power/PCA for the aircraft is produced by the aircraft APU only during ground time at the stand.
2. Zurich Airport system: AGES (400Hz and PCA) available and utilised on Pier stands, 400Hz available and utilised on certain open stands during ground time (existing restrictions are applied).
3. Maximum: all stands are equipped with AGES for both 400Hz and PCA and the APU is only used for main engine start (MES).

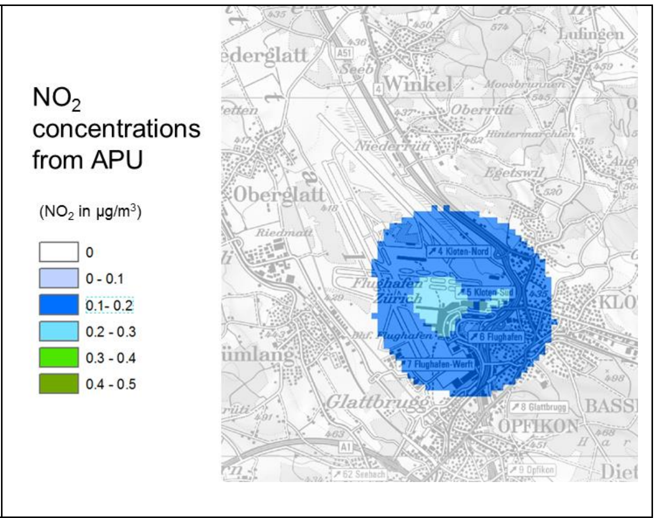
	Variation in operations (concentration relevant emission perimeter only)					
Scenario	no AGES / GPU avail. (full APU operations only)		AGES / GPU as it is today at Zurich Airport		APU for MES only (rest is AGES only)	
NOx 2016						
Total Airport 2016 (1,000m)	909 t	100%	802 t	100%	786 t	100%
APU	128 t		17 t		5 t	
GPU	0 t		3 t		0 t	
APU+GPU	128 t	14.1%	20 t	2.5%	5 t	0.6%
CO_2 2016						
APU	50,066 t		7,896 t		2,131 t	
GPU	0 t		1,050 t		0 t	
APU+GPU	50,066 t		8,945 t		2,131 t	

Table 12 Operational variations in APU usage for Zurich Airport 2016

6.3. Regional NO_2 concentrations

The following picture shows the dispersion of the APU NO_2 concentrations at Zürich airport for 2016 (with APU operations modeled as is, i.e. with available AGES/GPU and their use) and the total NO_2 dispersion from all airport related sources, compared to actual measured annual values (total, from all sources, also non-airport).





Total NO_2 annual mean value 2016 (area = airport sources only; points = measurement stations capturing all emission sources). Swiss standard: 30 µg/m^3	APU NO_2 concentrations only (annual mean) with maximum value indicated (actual APU/AGES regime as in 2016 at ZRH airport)

Figure 18 Regional NO_2 concentration (airport and APU) for Zurich Airport 2016

7. Economics of the System

7.1. Aircraft Ground Energy System

The required investments for 400Hz/PCA systems designed and implemented for Zurich Airport are between 340,000 Euros for a Code C gate and 1 million Euros for a Code F gate; the costs are about 30% for the 400 Hz systems and 70% for the PCA system. The costs generally vary depending on the required service level and the possibility to plan one comprehensive system rather than upgrading an existing 400 Hz system with PCA.

The costs of service vary according to the services required and the handling agent providing the service. By way of information, the following table gives an overview of the service charges at Zurich Airport (as levied by the handling agent).

MTOW Class	Base tariff per usage	Tariff per hour					
		Hour 1	Hour 2	Hour 3	Hour 4	Hour 5	Hour 6ff
Class 1-3	3.00		free				3.00
Class 4	4.50		free				4.80
Class 5	9.00		free				9.00
Class 6	15.00		free				15.00
Class 7	25.50			free			25.80
Class 8	34.50				free		34.80
Class 9	45.00				free		45.00

Table 13 400Hz prices in CHF at Zurich Airport (1.11.2017)

MTOW Class	Examples	Tariff per hour
Class 1-3	C182, C56X, LJ60	6.00
Class 4	GALX, CL64, AT73	9.00
Class 5	RJ85, CRJ9, GLEX	18.00
Class 6	A320, B737, CS100	30.00
Class 7	B763, IL76	51.00
Class 8	A333, B77W, B764	69.00
Class 9	A388	90.00

Table 14 PCA prices in CHF at Zurich Airport (1.11.2017)

7.2. Aircraft APU

APU operating costs vary depending on the aircraft type, the APU type, APU fuel consumption and operating times as well as fuel price and other APU operating/maintenance costs. An approximation for fuel costs for APU operation only is given in the following table. The costs do not reflect any potential CO_2 compensation costs.

Aircraft				**Costs**		
Type	Stand	400 Hz Time	PCA time	Total AGES	Total APU	Savings with AGES
		min	min	CHF	CHF	CHF
B764	Pier E	240	120	172.50	712.00	539.50
B788	Pier E	300	180	276.00	890.00	614.00
A321	Stands D	80	80	55.00	146.67	91.67
B739	Pier B	210	60	270.00	385.00	115.00

Table 15 Approximation of APU costs (in CHF/h)

8. Annex 1: Auxiliary Power Unit

8.1. Technical Issues

Auxiliary Power Units are gas turbines mounted usually in the aft part of aircraft. Fuels used are Jet A, Jet A1, Jet B or JP-4. The purpose of an APU is to:

- provide electrical energy (115V, 400 Hz) for aircraft systems during ground time;
- provide air to the environmental control system (air-conditioning) during ground time;
- provide air (bleed air) for main engine start;
- serve as electric and hydraulic back-up system in flight;

APU are available for large, medium, small jet aircraft, regional or commuter jet aircraft, corporate or business jets and turboprops (cf. annex).

Emissions of APU are similar to those of aircraft main engines. The following pollutants are of interest for emission inventory and dispersion calculation purposes:

- NOx Nitrogen Oxides
- HC Hydrocarbons
- CO Carbon Monoxide
- PM Particulate Matter
- CO_2 Carbon Dioxide

For dispersion calculations, the exhaust plume needs to be modelled, too. This requires additional data for exhaust nozzle diameter, exhaust gas temperature and exhaust gas velocity. Some limited information is available, e.g.

- Allied Signal 331-500: Exhaust nozzle diameter: 38.11 cm (Utzig, 2004);
- APS 500R APU: Max Continuous rated EGT: 704°C (Hamilton, 2004)
- TSCP700-4E: Continuous EGT: 585°C (JAA, 1998).
- Honeywell 36-150CX: Max. Continuous EGT: 665°C; Idle EGT: 300°C (HTG, 2004)

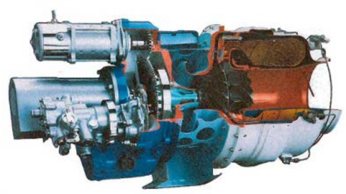
Hamilton Sundstrand APS 3200 APU for A320 family	Hamilton Sundstrand APS 500R APU for ERJ 135/140/145	Honeywell 36-150CX APU for Do328
		

Figure 19 Auxiliary Power Units for commercial aircraft

8.2. APU Modes of Operation

APU are operated in different modes, according to the desired operation (e.g. generating electricity). There are currently a number of different terms used to describe particular APU operations (ICCAIA, 1999).

Term	Explanation	Idle (no load)	Electricity (400Hz only)	PCA (air & 400 Hz)	Bleed Air (engine start)
No Load	same as Idle – no shaft or bleed load extracted – may be at 100% engine speed or reduced speed depending on the particular APU model.	X			
Combined Load	combination of shaft (electric) and bleed loads – bleed air could be for main engine starting (MES) or the environmental control system (ECS) – bleed air extraction could have been set to a specified corrected flow (ppm) or to a specified APU exhaust gas temperature (EGT).			X	X
Max Combined Load	combination of shaft and bleed loads, but engine is at the maximum EGT limit – test usually run by setting the shaft load to the maximum level, then extracting bleed air until the EGT limit is reached – load condition may be higher than an actual aircraft load condition.			X	X
Bleed Load	bleed air extraction only, no shaft (electric) load – usually a part power condition – may not be representative of an actual aircraft operating condition.			X	
Max Bleed Load	bleed air extraction only, no shaft (electric) load – test usually run by extracting bleed air until the APU EGT limit is reached – load condition may be higher than an actual aircraft load condition – not an actual aircraft operating condition.			X	X
Max Shaft Load	shaft (electric) load only, no bleed air extraction – a part power condition – shaft load could be representative of an aircraft load condition, or set to the APU gearbox load limit.		X		
ECS	environmental control system – bleed air supplied to the aircraft air conditioning packs – the bleed load condition is set for typical aircraft gate operation (depending on the aircraft type and size) - normally includes some shaft (electric) load.			X	
Max ECS	maximum environmental control system – bleed air supplied to the aircraft air conditioning packs – the bleed load is set for the maximum aircraft load condition – normally includes some shaft (electric) load.			X	
Max IGV	indicates the APU load compressor inlet guide vanes (IGVs) were set to the maximum, full open condition – usually this would be designated either a Max ECS or a MES condition – may or may not include shaft (electric) load.			X	X
MES	main engine start – bleed air supplied to the main engine air turbine starter – bleed load usually set to a specified corrected flow condition representative of typical aircraft operation – normally includes some shaft (electric) load.				X
MES+180KW	main engine start plus 180KW of electric load – same as MES, but the actual shaft (electric) load is specified for a particular aircraft.				X

Table 16 APU Terminology (ICCAIA, 1999)

8.3. Aircraft and Airport Operational Issues related to APU

The interdependencies of aircraft APU operations are characterised in Figure 19.

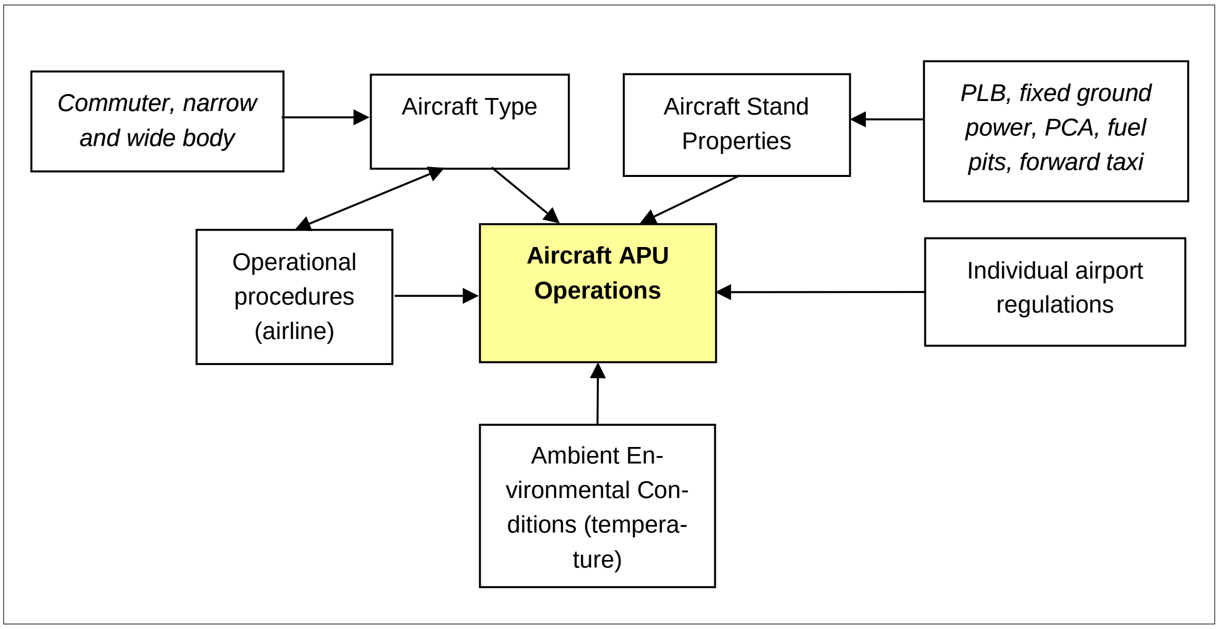


Figure 20 Characterisation of APU use.

It has to be recognised that the operation of an APU is determined by the aircraft and the aircraft stand as well as applicable operational procedures at the airport (e.g. restrictions).

8.4. Aircraft Type

The size of the aircraft often determines the stand allocation and the handling procedures. At Zurich Airport, all aircraft have been categorized into 8 groups. This grouping is used to attribute properties used to create and calculate emission inventories in a generalized manner.

Aircraft Group	Characterisation
Large Jet Aircraft (B777, B787, B747, A340, A380)	• Handling mostly at pier or occasionally remote stands • APU available
Medium Jet Aircraft (A330, B767)	• Handling mostly at pier or occasionally remote stands • APU available
Small Jet Aircraft (B-757, B-737, A319-A321)	• Handling at pier or remote stand • APU available
Regional Jet Aircraft (RJ-85, EMB-145, CL65)	• Handling mostly at remote stands • APU available
Turboprop Aircraft (S20, DH8, AT42/72, D328)	• Handling at remote stands • Sometimes no APU available
Business Jets (Citations, Falcon, LearJet, Global)	• Handling at remote stands • APU available
General Aviation Propeller Aircraft (Piper, Cessna)	• No APU available
Helicopter	• No APU available

Table 17 Aircraft group characterization

8.5. Aircraft Stand

At airports, two types of aircraft stands can be found:

- pier stands where a passenger loading bridge connects the aircraft to the building and
- remote stands where an aircraft is parked free of direct building connections (for passenger and/or cargo operations).

The stands themselves can show considerable differences in terms of place and technical equipment which can influence emissions from APU.

Properties	APU Consequences	Comments
No electrical or pneumatic equipment	APU required for ground power, air-conditioning and main engine start	Not in Zurich
Mobile GPU available	APU only required for air-conditioning and for main engine start-up	Common on remote stands
Stand equipped with fixed or semi-mobile 400 Hz	Does not require GPU; APU only required for air-conditioning and for main engine start-up	Common on stands with loading bridge and also on remote stands
Additionally equipped with PCA (stationary or through ACU)	Does not require GPU; APU required for main engine start-up only	Stationary equipment only together with 400 Hz

Table 18 Properties of aircraft stands

8.6. APU Emission Calculation Methodology

For emission inventory purposes and subsequent concentration modelling, Zurich Airport uses an APU-cycle that reflects APU operations in a simplified manner and that is used to build the model for the emission calculation (next table).

APU-Mode	Operations	Time in Mode
Idle	Idle operation	3 min
Load (400 Hz/PCA)	Provides electricity when aircraft is on ground and in operations (e.g. pre-flight) and provides pre-conditioned air (cooling or heating) if needed for pre-flight (boarding) or post-flight (disembarking) activities;	as modelled
Bleed air	Provides necessary bleed air MES (main engine start);	35 sec (shorth.) 140 sec (longh.)

Table 19 APU-Operations and times (ICAO Document 9889)

The turnaround times of all aircraft equipped with an APU are thus covered either by APU, GPU or fixed energy systems (GPSS). The model built for the emission inventory for Zurich Airport makes use of the available ambient information (temperature), operational data like aircraft turn-around times, total GPU operating times and the availability of the fixed energy system (AGES). This returns APU running times for both pier and remote stands, also reflecting the airport's APU operating restrictions and airlines' procedures.

On remote stands, no GPSS is available, only GPU; in this case the APU times have been derived from the difference between the average turn-around time of the aircraft and the average GPU operating time per cycle.

The APU/GPU/AGES times can vary annually, depending on the turnaround times of aircraft, the total GPU running time and the technical availability of the fixed energy system.

The fuel flow data and emission factors are available from the ICAO Doc 9889 [2]. Initially, an airport APU database had been setup in 1994 with support of the manufacturers. This has been replaced in 2010 with the new information. Each aircraft type is been assigned an APU group model with information on fuel flow, HC, CO and NO_X emission indices for different operating modes.

9. Annex 2: Abbreviations

ACFT	Aircraft
ACU	Air Climate Unit
AGES	Aircraft Ground Energy Systems
AHU	Air Handling Unit
AOT	Ambient Outside Temperature
APRX	Approximate
APU	Auxiliary Power Unit
ASU	Air Starter Unit
CHF	Swiss Francs
CO_2	Carbon Dioxide
ECS	Environmental Control System
EGT	Exhaust Gas Temperature
GPU	Ground Power Unit (diesel-operated)
GSE	Ground Support Equipment
Hz	Hertz
ICAO	International Civil Aviation Organization
IGV	Inlet Guide Valves
KVA	Kilovoltampere
kW	Kilowatt
LTO	Landing and Take-off Cycle (standard 4 modes)
MES	Main Engine Start
NOx	Oxides of Nitrogen
NO_2	Nitrogen dioxide
MWh	Megawatt-hours
PCA	Pre-conditioned Air
PLB	Passenger loading bridge
PM	Particulate matter
PSGR	Passengers
V	Volts
WX COND	Weather Conditions

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Sources

No.	Document Name
[1]	AIP, 2017: *Aeronautical Information Publication Zurich Airport*. Flughafen Zurich AG, Zurich, 2017.
[2]	ICAO: Local Air Quality Guidance Manual, ICOA Doc. 9889 (1st Edition, 2011).
[3]	Flughafen Zürich AG: Emission Charges Zurich Airport. Review 2003. Zurich, 2003
[4]	Flughafen Zürich AG: Energy Management Zurich Airport. Zurich, 2005
[5]	Flughafen Zürich AG: Aircraft APU Emissions at Zurich Airport. Zurich, 2005
[6]	Hamilton, 2004: http://www.hs-powersystems.com/2190600_web.pdf
[7]	Honeywell, 2000: Letter to US EPA by Honeywell; Phoenix, 29 September 2000
[8]	HTG, 2004: http://thermlab.web.arizona.edu/projects/gas_turbine_instruction.html
[9]	ICCAIA, 1999: Letter to Airport Authority Zurich from ICCAIA; Seattle, 19. August 1999
[10]	JAA, 1998: JAA/25/91-001, Issue 6, 28 May 1998
[11]	Utzig, 2004: Untersuchung der geometrischen Form und Ausbreitung von Abgasfahnen von Flugzeugen mittels abbildender FTIR-Spektroskopie. Selina Eva Utzig, Diplomarbeit Fachhochschule Bingen, Deutschland, Dezember 2004.

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