Aircraft Ground Energy Systems

at Zurich Airport

Contents

1. Introduction

Aircraft during ground times at airports require electrical energy (115 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.

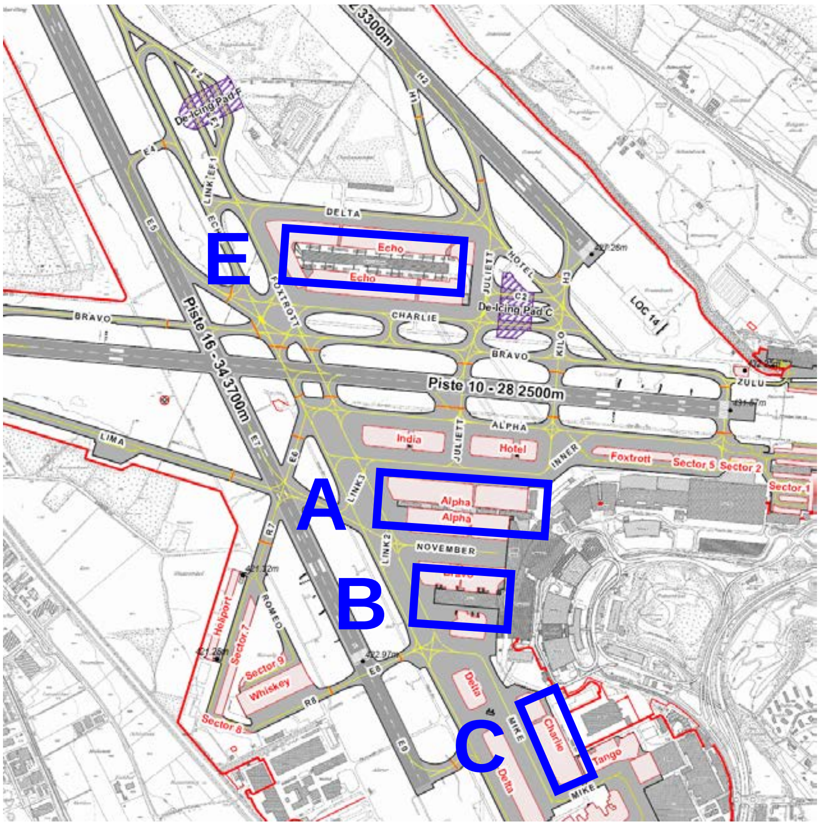


Figure 1 Zurich Airport aircraft piers and hard stands: Piers E, A, B and open stands C

3. Technical Description

3.1. General

The general layout is depicted in Figure 2. 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 prevents energy consumption for pre-conditioned air for large aircraft during peak time. The energy for PCA systems is 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.

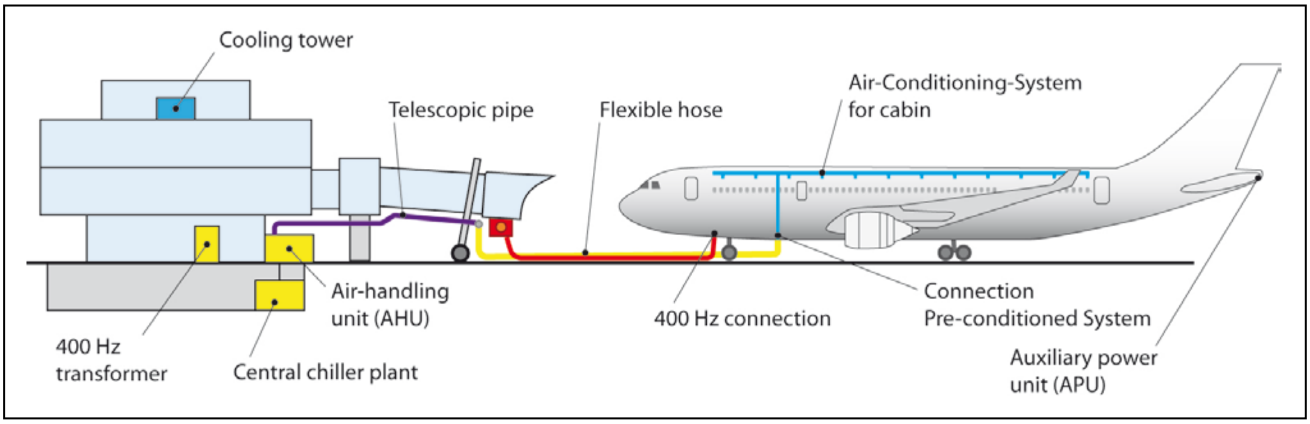


Figure 2 Basic layout of aircraft ground energy systems (AGES)

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
AHU:	Outlet temp:	Min: -2°C, max: +50°C
	Air Volume:	Min: 2,000 m^3/h; max: 10,000m^3/h (Code F: 14,000m^3/h)
	Pressure:	Min: 8,000 Pa; max: 9,500 Pa (Code F: 11,000 Pa)

3.2. Pier E

3.2.1. Electrical System 400 Hz

Pier E went into operation in 2003 and provides 27 gates for aircraft handling. 16 gates are for aircraft categories 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 or two converters are available. The cable coils with 30 m cable are mounted underneath the passenger loading bridge.

Figure 3 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. For open handling, four pit systems are available.

The system contains a monitoring and control unit with 2,500 data points. The system logs all operating events and system errors and all important data can be analysed and evaluated. The temperatures of the various phases are measured in the 400 Hz plugs and three gates are equipped with measurement systems for the electricity.

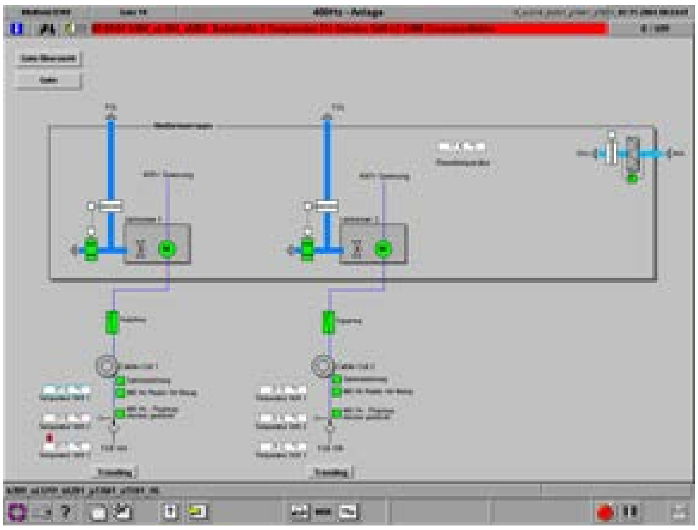


Figure 4 400Hz monitoring panel

		Comments
Gates Pier E	27	16 x 180KVA 11 x 90KVA
Transformer station	2 1	2 x 1,600 KVA 1 x 700 KW (cooling)
Static converter 90KVA	45	Total capacity 4.05 MVA
Reserve for converter NLA (new large aircraft)	4	2 gates with 360KVA
Cable coils	43	
PIT Systems	4	

Table 2 Technical and operational information 400 Hz Pier E

3.2.2. 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. The gates for category D and E aircraft have two hoses, the gates for category C aircraft one.

Figure 5 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 is sufficient for a standard day of 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. The gates provide metering systems to monitor heat and ice consumption of individual aircraft types.

Figure 6 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 analysis and evaluation.

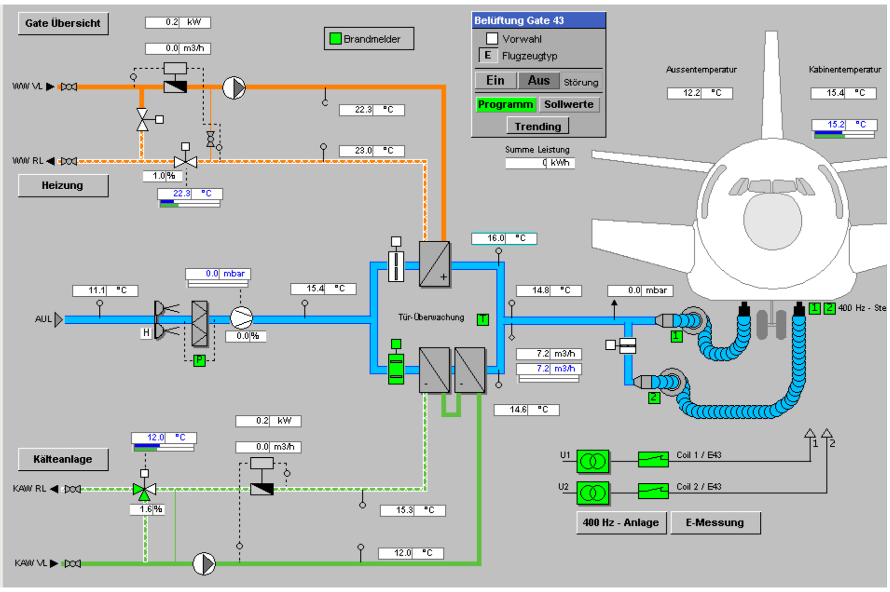


Figure 7 Control panel for pre-conditioned air.

	Amount	Capacity
Chiller (ammonium)	2	2 x 410 KW
Ice Storage Stored Energy	1	220 m^3 10,000 MWh
Heating Transformer	2	1,100 KW each
Air Conditioning Units (two hoses)	16	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 3 Technical data PCA Pier E

3.3. Pier A

3.3.1. Electrical System 400 Hz

Pier A went into operation in 1985 and has a total of 18 stands for the handling of aircraft. When handling wide-body aircraft, the number of stands is limited to 13.

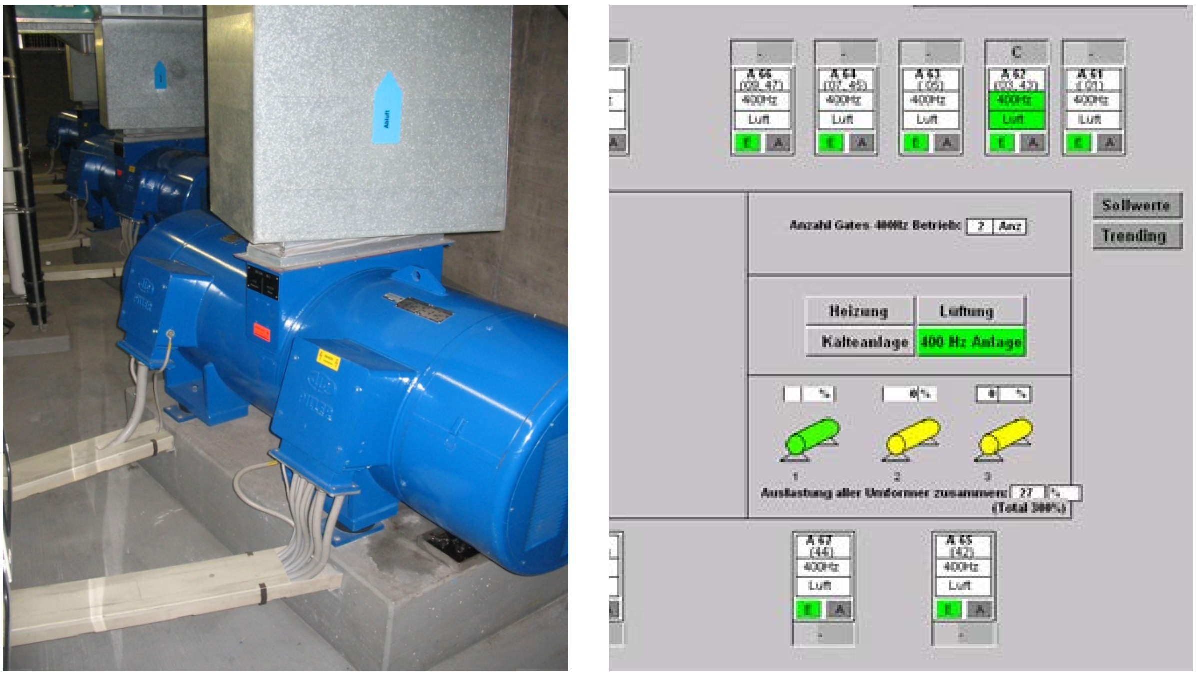


Figure 8 Transformer (left) and control panel (right).

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 90 KVA transformers and contains a 400 Hz cable with plug. For wide-body aircraft, a so called "Y"-cable is used that distributes the electricity to both aircraft plugs.

A specialty of the plant is the monitoring and control system with 1,500 data points. This control system logs all operating events and system errors. All important data are trend analyzed and evaluated.

		Comments
Gates Pier A	18	Built 1985
Transformer Station	3	3x300KVA
Distribution		960V / 400Hz
Local Transformer	18	18x90KVA

Table 4 Technical and operational information 400 Hz Pier A

3.3.2. 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. However, pier A only offers one hose per gate for air-conditioning. The air units have different capacities depending on the gate size.

Figure 9 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)	5	5,000 m^3/h
Heating capacity per unit		80 KW
Cooling capacity per unit		105 KW

Table 5 Technical data PCA Pier A

3.4. Pier B

3.4.1. 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 three 90 KVA transformers.

		Comments
Gates Pier B	9	Built 2011
Transformer Station	2	2x1000KVA
Distribution		960V / 400Hz
Local Transformer	16	16x90KVA

Table 6 Technical and operational information 400 Hz Pier B

3.4.2. 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 10 Hose for pre-conditioned air at pier B.

	Amount	Capacity
Chiller (R404A)	2	2 x 300KW
Chiller Storage Capacity Stored Energy	5	 600 KW 2.4 MWh
Air Conditioning Units (one hose)	3	5,000m3/h
Heating capacity per unit		80KW
Cooling capacity per unit		115KW
Air Conditioning Units (two hoses)	6	Max. 14,000m3/h
Heating capacity per unit		Max. 201 KW
Cooling capacity per unit		Max. 329 KW

Table 7 Technical data PCA Pier B

3.5. Electrical System Open Stands “Charlie”

Eight stands on the tarmac-area “South”, named C50 – C60, are equipped with stationary electrical systems. There can five wide-body aircraft or eight narrow-body aircraft be parked in the whole area. In total, there are five 50/400Hz converters with 180KVA 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
Transformer Station	5	5x180KVA
Distribution		960V / 400Hz
Local Transformer	13	13x90KVA

Figure 11 400Hz system open stands "Charlie"

4. System Operation

4.1. Energy Source

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 12 Air Climate Unit (ACU).

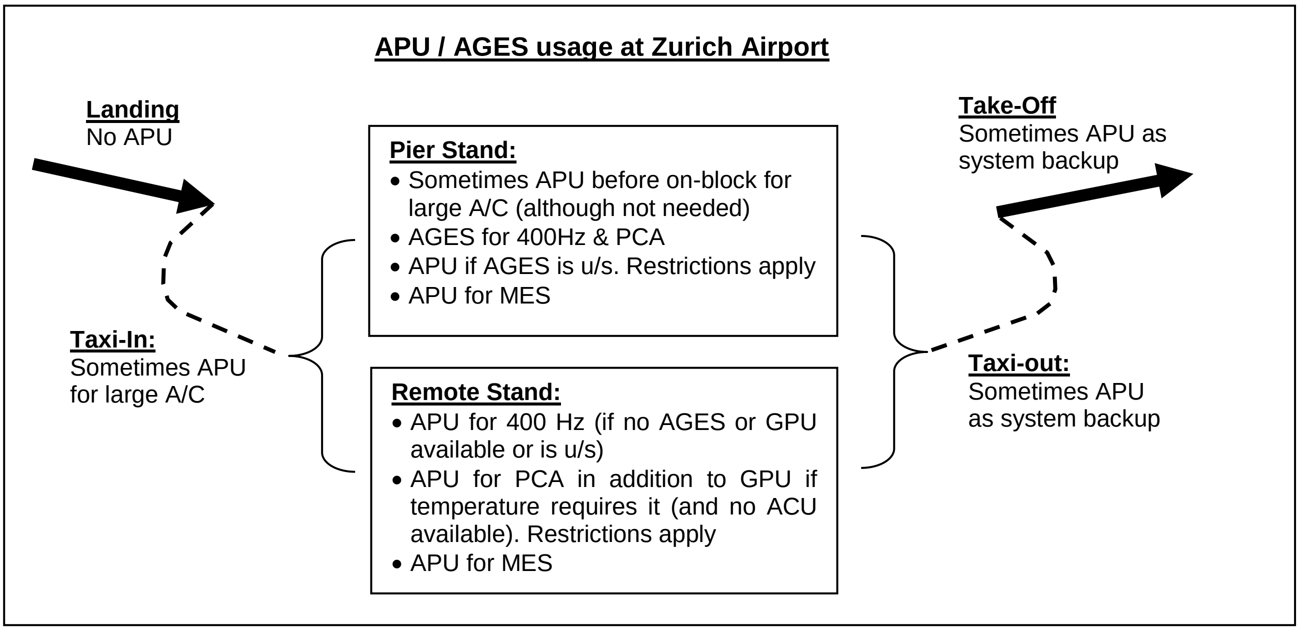


Figure 13 Operational characteristics of APU / AGES usage

The AGES are operated by the various handling agents. When an aircraft approaches the parking position, often with only one engine operating, ground staff sets the chocks and hooks up 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 14 Control panel on passenger loading bridge 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.

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 are fixed. 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 criteria 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 human 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 articles 36 and 51 of the Operating License for Zurich Airport (of 1.6.2001), the use of auxiliary power units (APU) is subject to certain restrictions. These are laid down in the AIP LSZH, section AD 2.

AIP SWITZERLAND[1]
LSZH AD 2.21

1.2 Auxiliary Power Units (APU)

1.2.1 Docking stands

Primarily, the stationary airport pneumatic and electrical service units shall be used. Alternatively, mobile units shall be used.

1.2.2 Other stands

For pneumatic and power supply of aircraft not parked at docking stands, mobile units shall be used.

1.2.3 APU shall only be started:

- to start engine, but no earlier than 5 minutes before off-block time
- if maintenance work on the aircraft makes it unavoidable; in that case the service period shall be kept as short as possible.
- if the stationary or mobile units are not available or unserviceable for specific aircraft types. In that case APU shall be started no earlier than at 60 minutes before off-block time (exemption: GA sector 1: no earlier than 30 minutes before off-block time) and kept in operation no more than 20 minutes after the on-block time.

In particular cases the airport authority may permit longer service periods.

[1] 8 MAR 2012 and AIRAC 15 APR 2004

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 established the following procedures (properly reflecting the airport's regulations):

4. <u>USE OF APU</u>

- Use of APU restricted.
  Use APU for ENG – start MAX 5 MIN before block off.
  If GPU U/S: Start APU MAX 60 MIN before block off.
  APU OPS MAX 20 MIN after block on.
  For A320 taxi-in without APU approved.
- 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 8 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 2012 (270,000 aircraft movements, 24.8 Mio. passengers, 450,000 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 2012, 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)		Concentration relevant cycle (1,000 ft)	
Total airport NO_X	1,098 t		699 t	
APU NOx	16.8 t	1.54%	16.8 t	2.4%
Total airport CO_2	334,560 t		240,214 t	
APU CO_2	7,867 t	2.35%	7,867 t	3.3%

Table 9 Zurich Airport and APU emissions 2012, 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.

	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)	
Total airport NOx	868 t		699 t		683 t	
APU NOx	190.1 t	22%	16.8 t	2.4%	4.6 t	0.7%
Total airport CO2	305,833 t		240,214 t		233,564 t	
APU CO2	73,388 t	24%	7,867 t	3.3%	2,120 t	0.9%

Table 10 Operational variations in APU usage for Zurich Airport 2012

6.3. Regional NO_2 concentrations

The following picture shows the dispersion of the APU NO_2 concentrations at Zürich airport for 2012 (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).

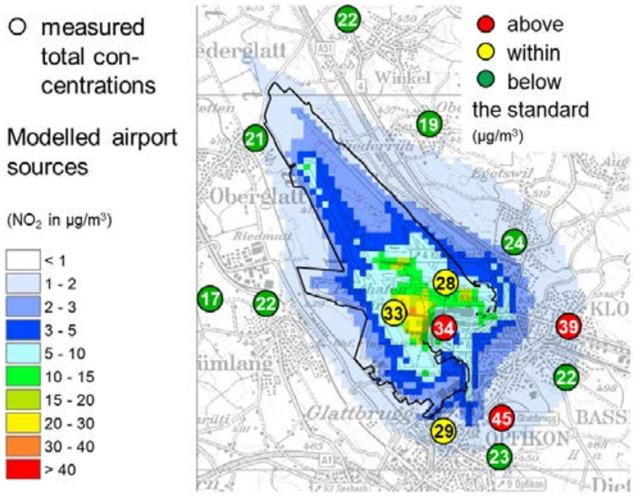
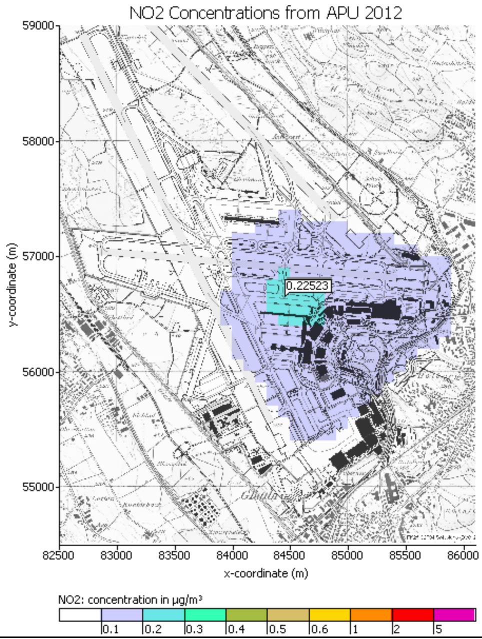
	
Total NO_2 annual mean value 2012 (area = airport sources only; points = measurement stations capturing all emission sources). Swiss standard: 30 $\mu g/m^3$	APU NO_2 concentrations only (annual mean) with maximum value indicated (actual APU/AGES regime as in 2012 at ZRH airport

Figure 15 Regional NO_2 concentration (airport and APU) for Zurich Airport 2012

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 approximately 1 million Swiss francs (CHF) per gate; the costs are about 45% for the 400 Hz systems and 55% 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).

Aircraft Group	**400 Hz Electricity (CHF/hour)**	**Pre-Conditioned Air (CHF/hour)**
Size A: RJ70, RJ100, B737, F70, F100, MD80	36.-	75.-
Size B: A300, A310, A319/20/21, B757, B767	62.-	130.-
Size C: A330, A340, B747, B777, MD11	87.-	190.-

Charging Rules:

0-10 min.	no charge
11-70 min.	1.0 hour (=minimum charge)
71-100 min.	1.5 hours
101-131 min.	2.0 hours
131-160 min.	2.5 hours
etc.	

Table 11 AGES prices at Zurich Airport (1.11.2013, as levied by a Handling Agent)

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 Group	**APU Fuel (kg/h)**[1]	**Fuel Costs (CHF/h)**[2]	**Maint. Costs (CHF/h)**	**Total Costs (CHF/h)**
Short haul aircraft	107	115.00	35.00	150.00
Long haul aircraft	240	255.00	85.00	340.00

Table 12 Approximation of APU costs (in CHF/h)

[1] ICAO Doc 9889, Version 1, Table A1.4.6
[2] IATA, Basis April 2013 (1,100 USD/mt)

Comparisons:

- A large aircraft (A330) using fixed 400Hz for 3 hours plus fixed PCA for 1 hour pays 451.- CHF for the service, while the total costs for the APU over the same 3 hours are approximately 1,000.- CHF.
- A small aircraft (RJ100) using fixed 400Hz and PCA for 1 hour each pays CHF 111.- for the service, while the total costs for the APU are approximately CHF 150.-

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)

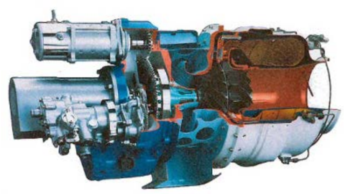
Hamilton Sundstrand APS 3200 APU for A320 family	Hamilton Sundstrand APS 500R APU for ERJ 135/140/145	Honeywell 36-150CX APU for Do328
		

Figure 16 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 13 Zurich Airport APU Terminology (ICCAIA, 1999)

8.3. Aircraft and Airport Operational Issues related to APU

The interdependencies of aircraft APU operations are characterised in Figure 17.

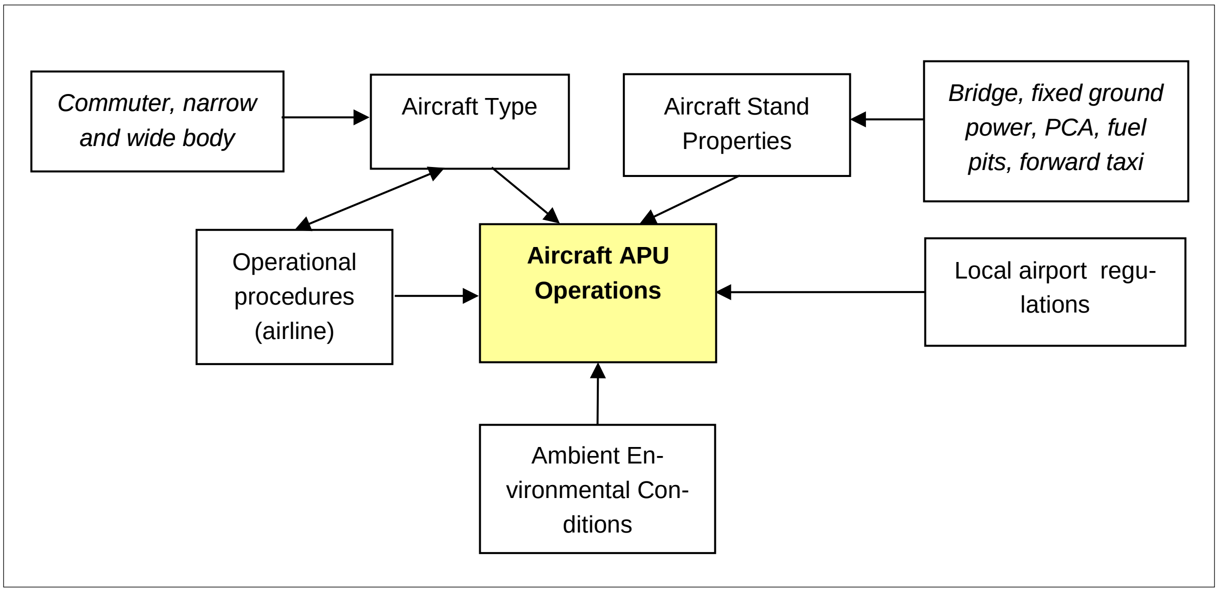


Figure 17 Characterisation of APU use.

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 (B-777, B-787, B-747, A340, A380)	• Handling at pier or remote stands • APU available
Medium Jet Aircraft (A330, B767)	• Handling at pier or 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 14 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 15 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 16 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

A/C	Aircraft
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
ENG	Engine
FES	Fixed Energy System
GPU	Ground Power Unit (diesel-operated)
GSE	Ground Support Equipment
hp	Horsepower
Hz	Hertz
ICAO	International Civil Aviation Organization
IGV	Inlet Guide Valves
kW	Kilowatt
LTO	Landing and Take-off Cycle (standard 4 modes)
MES	Main Engine Start
NOx	Oxides of Nitrogen
NO_2	Nitrogen dioxide
mt	metric ton
MWh	Megawatt-hours
OPS	Operations
PCA	Pre-conditioned Air
PLB	Passenger loading bridge
PM	Particulate matter
PSGR	Passengers
V	Volts
WX COND	Weather Conditions

Figures

Tables

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