

Ground Power Unit (GPU) Exhaust Emissions at Zurich Airport




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1 Introduction

Zurich airport is subject to a number of environmental concerns and local air quality is very high on the priority list. PM10 standards are exceeded in the larger airport area and also NO₂ standards are locally exceeded (both as annual mean standards). The current airport's clean air programme has been formally enacted by the national authorities within the construction permit in the 5th expansion programme. One of the five stipulated measures addresses emissions from airside ground operations (ground support equipment, including GPU, and airside vehicle traffic).

At Zurich airport, Ground Power Units (GPU) are used to provide electric energy (usually 115V DC at 400 Hz) to aircraft during ground time or maintenance (table 1-1). They are operated by handling agents and maintenance companies for those aircraft and stands or locations where no fixed ground power system is available.

Table 1-1: GPU at Zurich Airport (year 2004)

Descriptor	Value	Comments
Total listed GPU (end of 2004)	54	Operations: 43 Maintenance: 11
GPU Types	Auto-Diesel 100 KVA Trilectron 120 KVA Trilectron Palmetto Hobart 90 KVA Strüver Hitzinger	
Total operating hours (2004)	53,540	Incl. maintenance
Total fuel use (litres Diesel)	499,300	Incl. maintenance

The challenge is to properly determine the actual emission loads of various emission species for GPU. There is little information available on actual (operational) emission factors and mostly assumptions in combination with standards have to be used.

The scope of this study is to discuss actual emission measurements and the derivation of emission factors to calculate an emission inventory for GPU at Zurich airport.

2 Emission Measurements

2.1 Measurement Campaign

Despite some information available, there are still some uncertainties about emissions during operations and in particular about particulate matter (PM). Preliminary opacity measurements on GPU in March 2005 showed a wide range of results and suggested to have more precise measurements done.

Commissioned by Unique, the Laboratory of IC-Engines and Exhaust Gas Control of the Berne University of Applied Sciences, supported by both handling agents Swissport and Jet Aviation Handling Ltd and SR-Technics (additional measurement devices and infrastructure) performed exhaust gas measurements on 6 GPU. To simulate operations, a dummy load was applied at about 30% and 60% of the electrical performance (referred to as measurement pt. 1 and measurement pt. 2 in this study or Pe in table 2-3).

Table 2-1: List of Measured GPU

GPU	Year	Engine Type
AT-10	1994	Cummins Turbodiesel, 149 kW, 5880 cm ³
AT-37	1997	Cummins Turbodiesel, 149 kW, 5880 cm ³
AT-39	1997	Cummins Turbodiesel, 149 kW, 5880 cm ³
AT-42	1999	Cummins Turbodiesel, 149 kW, 5880 cm ³
RG-4	2001	DEUTZ Turbodiesel, 139 kW, 7146 cm ³
RG-6	2004	DEUTZ Turbodiesel, 139 kW, 7146 cm ³

The measurement campaign set-up is illustrated in figure 2-1 and the ambient conditions are listed in table 2-2.

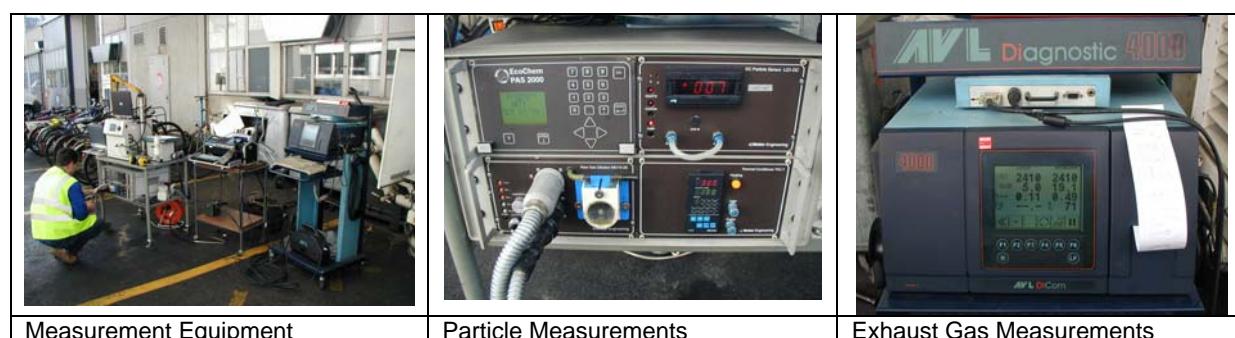


Fig. 2-1: Emission Measurements (October 2005)

Table 2-2: Ambient Conditions

Parameter	Unit	Value (range)
R _{amb air}	%	42.4 – 52.6
P _{atmosph}	Mbar	974 – 976
T _{amb air}	°C	18.0 – 21.9
CO _{2 amb}	%	0.045

2.2 Measurement of various Emission Species

In addition to the measured species CO, HC_{6IR}, NO, NO₂ and O₂, the following parameters have been calculated: CO₂, NO_x, NO₂/NO_x, λ. The results for all values are shown in table 2-3.

Table 2-3: Measured Emission Values for GPU

GPU	n	Pe	pme	CO	HC _{6IR}	NO	NO ₂	O ₂	CO ₂	NO _x	NO ₂ /NO _x	λ
	1/min	kW	bar	ppm	ppm	ppm	ppm	%	%	ppm	%	
AT-10	2400	39	0.13	141	61	261	30	15.2	4.3	291	10	3.6
AT-10	2400	78	0.13	101	79	485	21	13.4	5.6	505	4.3	2.76
AT-42	2000	38	0.13	100	54	432	31	14.1	5.1	573	5.3	3.03
AT-42	2000	75	0.13	67	72	971	40	11.7	6.8	1011	4	2.25
AT-49	2400	39	0.13	113	66	300	29	14.7	4.6	330	9	3.33
AT-49	2400	78	0.13	105	66	488	16	12.7	6.1	505	3.3	2.54
RG 4	1500	39	0.13	166	54	461	49	14.1	5.1	509	9.3	3.03
RG 4	1500	80	0.13	112	53	796	40	11.6	6.9	836	5	2.23
AT-37	2400	39	0.13	104	57	424	46	14.7	4.6	470	10	3.33
AT-37	2400	78	0.13	72	63	774	40	12.8	6	814	5	2.56
RG 6	1510	38	0.13	110	74	692	74	14	5.1	765	9.7	3.01
RG 6	1510	76	0.13	99	63	1081	69	11.6	6.9	1150	6	2.22

Complementing the measurements was obtaining values for the opacity. The values are, however, not reliable, as GPU are equipped with a RPM-limiter while opacity should be measured with free acceleration.

2.3 Particle Measurements

Particle measurements have been done using a SMPS-size spectra analyzer with NanoMet-diluter at the exhaust pipe. Figure 2-2 shows the particle number concentrations (cm^{-3}) for the measured GPU at the two operating points (pt.1 and pt. 2). Figure 2-3 shows the total active (LQ1-DC) and the total soot surface (PAS 2000)¹.

Integrated numbers of particles in the size spectrum 20-300 nm
field measurements in ZH Airport

	year	operating hours	pt.1	pt.2
AT-010	1994	12100	2.5E+08	7.0E+08
AT-042	1999	9085	4.3E+08	5.7E+08
AT-039	1997	6130	1.0E+08	1.9E+08
RG 4	2001	5819	8.5E+07	9.1E+07
AT-037	1997	5649	8.5E+07	2.1E+08
RG 6	2004	1576	5.6E+07	1.0E+08

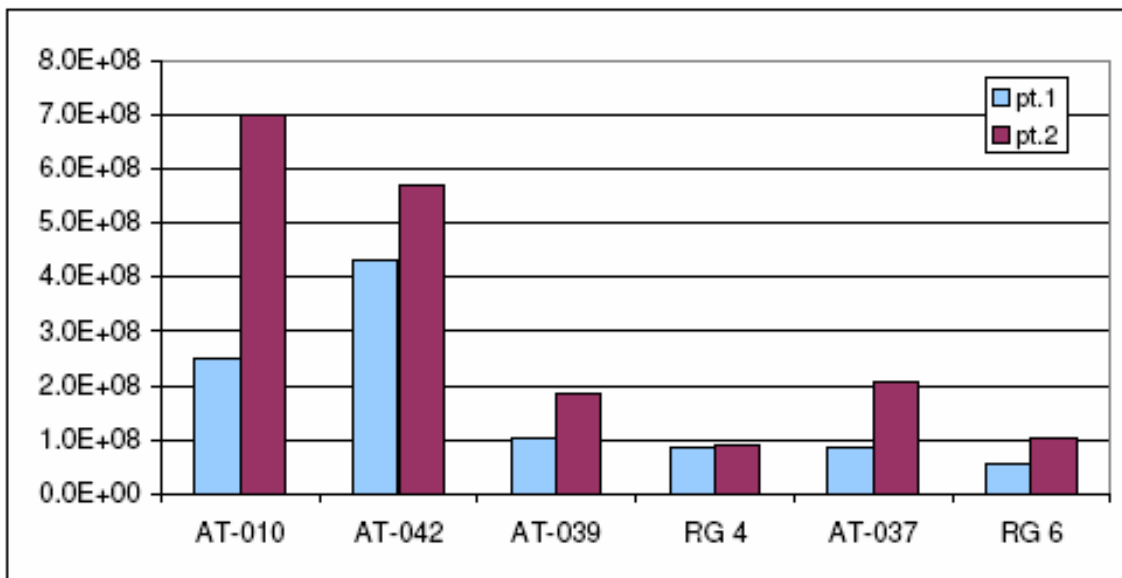


Fig. 2-2: Measurements for number of particles per cm^3

¹ Ref. 1

NanoMet sensors, GPU Kloten with NanoMet-diluter at exhaust pipe

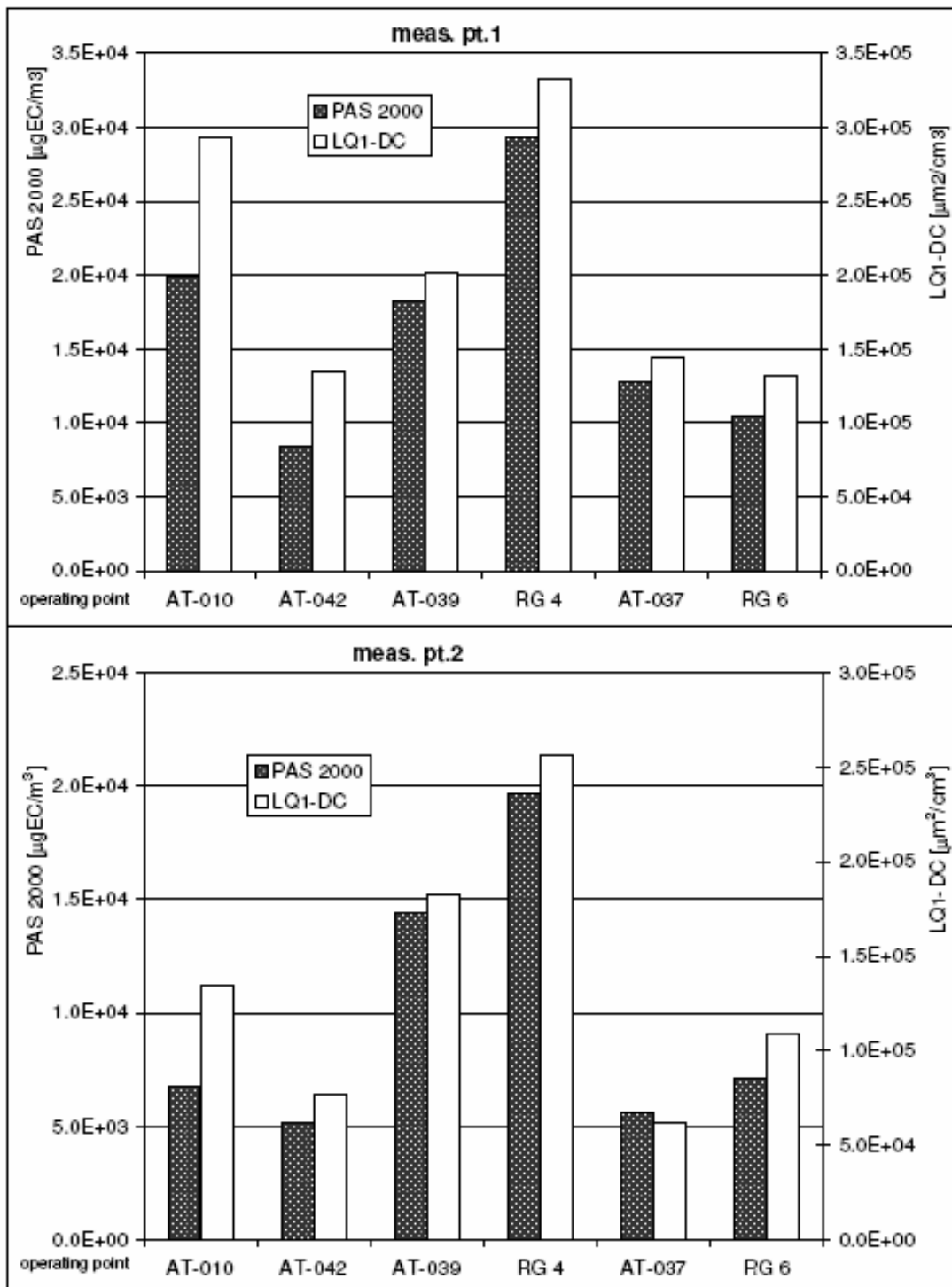


Fig. 2-3: Measurement of total active (LQ-DC) and total soot surface (PAS 2000)

3 Derivation of Emission Factors

For inventory calculation purposes, emission factors are often given in g/kWh or in g/kg fuel. The measured values of this study, however, are all expressed in ppm. Thus, the Swiss FOCA derived a methodology² to recalculate and estimate the emission factors from ppm to g/kg fuel (diesel). The results are shown in figure 3-1 (the first bar or set of bars of a GPU being measurement pt. 1, the second figure measurement pt.2).

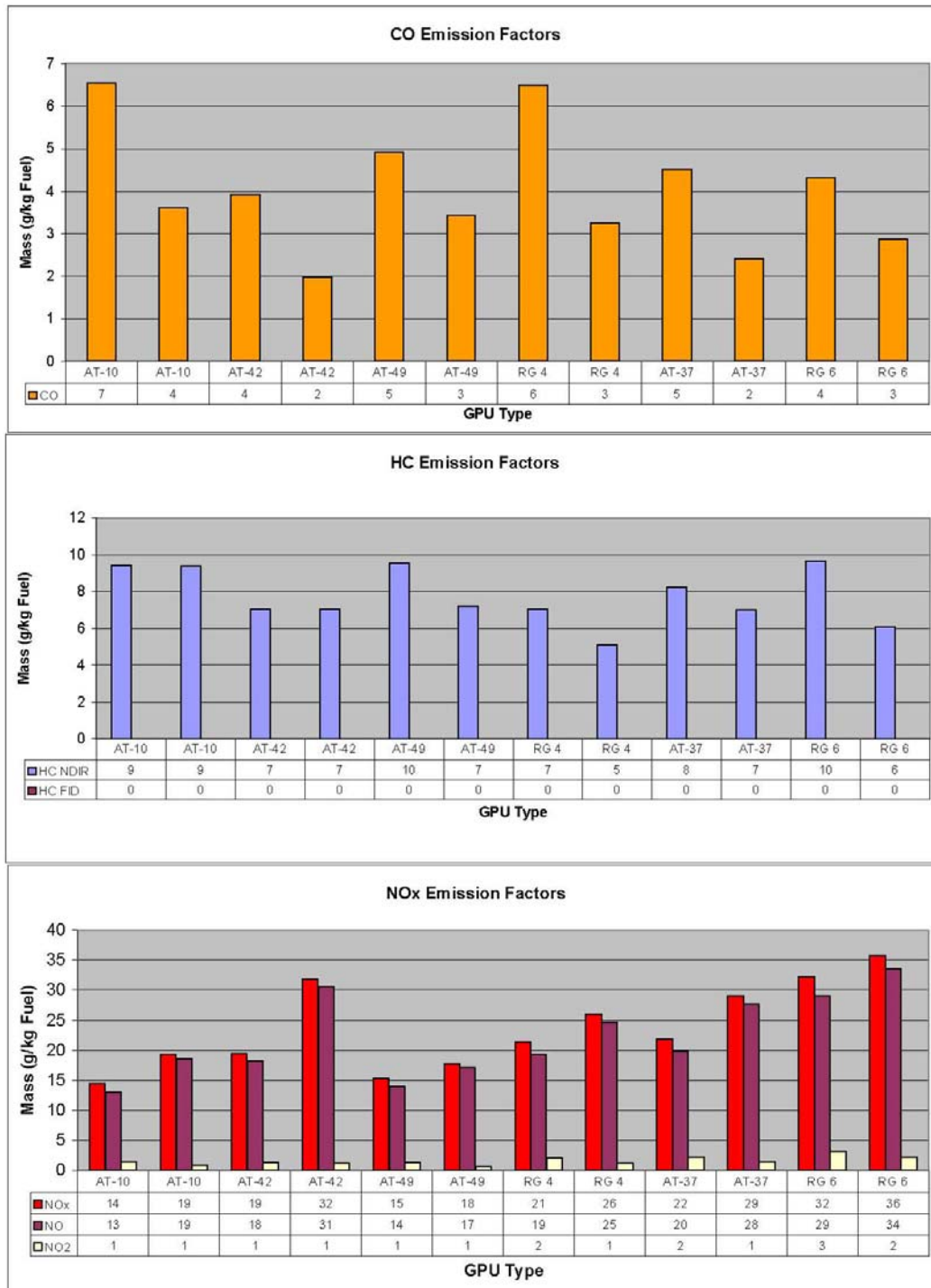


Fig. 3-1: Emission factors in g/kg fuel³

² FOCA data base for aircraft piston engine emission factors, Appendix 5 (Calculation of emission factors), 2006

³ FOCA, 2006

4 Emission Inventory Calculations

4.1 Simple Inventory with Emission Standards

A simple, straight forward and rather older methodology is based on using EUROMOT standard stage 1 emission factors expressed in g/kg fuel (table 4-3) and the following methodology:

$$\text{emissions [t]} = \text{amount of diesel [l]} \times a \times \text{emission factor [g/kg fuel]} / 1000$$

where $a = 0.83 \text{ kg/litre diesel}$

Using these emission factors without any correction parameters and the total amount of diesel fuel consumed, the total NOx emissions from GPU operation at Zurich airport in 2005 are approximately 39 t.

4.2 Advanced Inventory with Emission Standards

A more refined calculation methodology using emission standards is based on the EC Directive 97/68/EG (EC Non Road Mobile Machinery Stage 1). This methodology introduces to some degree operational data (work load of equipment). The information on the equipment has been retrieved from the handling agents and tenants. This includes the engine size, a typical work load and the time during which the equipment is in operation at the stand.

Table 4-1: EC Non Road Mobile Machinery (EEC EUNRMM Stage 1 and 2)⁴:

g/kWh	Power Band	CO	HC	NOx	PM	Introduction
Stage 1	37-75 kW	6.50	1.30	9.20	0.85	1. October 2001
	75-130 kW	5.00	1.30	9.20	0.70	1. October 2001
	130-650 kW	5.00	1.30	9.20	0.54	1. October 2001
Stage 2	18-37 kW	5.50	1.50	8.00	0.80	1 January 2001
	37-75 kW	5.00	1.30	7.00	0.40	1 January 2004
	75-130 kW	5.00	1.00	6.00	0.30	1 January 2003
	130-560 kW	3.50	1.00	6.00	0.20	1 January 2002

Further evaluations revealed that emission limits are usually not exhausted by the manufacturers of non road mobile machinery and that a certain "reserve" is being kept. This has been confirmed and assessed by the Swiss Agency for Environment, Forests and Landscape (SAEFL) for the different substances⁵:

Table 4-2: Difference of actual emissions to standards*

Substance	Emission Reduction
NOx	- 10 %
HC	- 50 %
CO	- 50%
PM	- 20%

* based on EUNRMM Stage 2, applied also to Stage 1

Emissions are then calculated using engine size, load factor and emission factor together with the operating hours:

$$\text{emission}_{\text{substance}} [\text{g}] = \text{engine size} [\text{kW}] \times \text{load factor} [\%] \times \text{emission factor} [\text{g/kWh}] \times \text{time} [\text{h}]$$

⁴ EC Directive 97/68/EG

⁵ Source: Communication SAEFL/Air Quality Control, 25. August 2004.

Taking an average engine size of 145 kW and a load factor of 25%, the total emissions are approximately 20 t NOx/a (for 2005, including maintenance GPU). PM emissions are estimated at 1 t/a.

4.3 Inventory with Measured Emission Factors

A different approach for calculating the emissions is using actual measured emissions from GPU in operation and under ambient conditions. Using average emission factors from the GPU measurement campaign at Zurich airport (table 4-3) and the calculation equation:

$$\text{emissions [t]} = \text{amount of diesel [l]} \times a \times \text{emission factor [g/kg fuel]} / 1000$$

where $a = 0.83$ kg/litre diesel

gives a total of 11.6 t NOx emissions for 2005 at Zurich airport.

4.4 Emission Comparison and Conclusions

The three different methodologies are compared in table 4-3 using the appropriate emission factors and additional parameters as needed.

Table 4-3: Comparison of GPU emission inventory with different methods/factors

Parameter	Unit	Euromot 1	EUNRMM Stage 1	ZRH/FOCA
Operations				
Average engine size	kW		145	
Total GPU-Diesel used	l in 2005	591'053		591'053
Volume to weight conversion (diesel)	kg/l	0.83		0.83
Total GPU Operating hours	h in 2005		66'885	
Average Load Factor (assumption)	%		25%	
Emission Factor				
Emission Factor NOx	g/kg; g/kWh	79.7	9.2	23.58
Emission Factor HOC	g/kg; g/kWh	11.3	1.3	7.67
Emission Factor CO	g/kg; g/kWh	43.3	5.0	4.00
Emission Factor PM	g/kWh	--	0.5	--
Correction Factor NOx	%		10%	
Correction Factor HC	%		50%	
Correction Factor CO	%		50%	
Correction Factor PM	%		20%	
Emissions				
NOx Emissions	t/a	39.10	20.08	11.57
HC Emissions	t/a	5.54	1.58	3.76
CO Emissions	t/a	21.24	6.06	1.96
PM Emissions	t/a	--	1.05	--

Both of the methodologies based on emission standards are conservative as they are based on values used for standard setting and certification purposes. They furthermore don't take the actual machinery or equipment type into account, but are developed generically for industrial internal combustion engines within certain power bands. Engine manufacturers

then tend to include some margin to the standards (cf. table 4-2), to ensure compliance in the certification process. The load factor as considered in section 4.2 is a very crucial parameter that influences the final emission mass. This parameter most often has to be assumed and provides a high level of uncertainty.

As opposed to these generic values, measurements give real values, also taking into account (current) ambient conditions. Thus, results tend to be more realistic. The emission factors measured at Zurich Airport are more representative for the actual emissions than those derived from standards. In comparison, the results using standards are overestimating the NO_x and CO emissions, but are underestimating HC.

5 Recommendation

It is recommended for the purpose of emission inventory calculations at Zurich Airport to use the methodology and emission indices of "ZRH/FOCA" in table 4-3 based on real measurements for the following reasons (in addition to the discussion and findings in section 4.4):

- Representative sample of GPU with regards, to types, technology and age;
- Reflecting actual operations by using representative dummy loads;
- Considering ambient conditions;

It is furthermore suggested to introduce an emission index for PM of 2.00 g/kg diesel fuel (derived from the EUNRMM Stage 1 value) as the measurements at Zurich airport only give information on NO_x, HC and CO. PM have been described in size and number concentrations only, whereas an emission inventory is usually expressed in mass.

The recommended emission factors (rounded) are listed in table 5-1.

Table 5-1: Diesel GPU emission factors used at Zurich Airport⁶

Pollutant	Unit	Emission Factor
NO _x	g/kg diesel	24.0
HC	g/kg diesel	8.0
CO	g/kg diesel	4.0
PM	g/kg diesel	2.0
CO ₂	g/kg diesel	3150.0

⁶ Supersedes emission factors indicated in Ref. 5 (emission certification standard based).

6 Appendix

6.1 References

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2. European Commission: EC Directive 97/68/EG, Non Road Mobile Machinery. Brussels, 1997.
3. SAEFL, Department of Air Quality Control. Personal Communication. 25. August 2004
4. Federal Office of Civil Aviation, FOCA: Calculation of GPU diesel engine emission factors, Report Number 0/3/33/33-05; August 2006.
5. Unique (Flughafen Zürich AG): Aircraft Ground Handling Emissions at Zurich Airport. Methodology and Emission Factors, Zurich, March 2006.

6.2 Abbreviations and Glossary

CO	Carbon Monoxide
DC	Diffusion Charging Sensor
EC	European Commission
EC	Elementary Carbon
EUNRMM	European Union Non Road Mobile Machinery
EUROMOT	European Association of Combustion Engine Manufacturers
FOCA	Federal Office for Civil Aviation, Switzerland
GPU	Ground Power Unit
HC	Hydrocarbons
kW	Kilowatt
NanoMet	modular measurement system for on-line characterization of aerosols, consisting of a diluter, evaporation tube, two sensors and various accessories. Used components: mini-diluter, thermal conditioner (evaporation tube), real time sensors (DC, diffusion charging sensor and PAS, photoelectric aerosol sensor for soot surface).
NO	Nitrogen Oxide
NO ₂	Nitrogen Dioxide
O ₂	Oxygen
PAS	Photoelectric Aerosol Sensor
PM	Particulate Matter
ppm	parts per million
SAEFL	Swiss Agency for Environment, Forests and Landscape, Switzerland
SMPS	Scanning Mobility Particle Sizer. Particle size distribution based on mobility diameter. High size resolution, but low time resolution, typically 1-3 minute scan time.