AIR POLLUTION IN AIRPORTS

Ultrafine particles, solutions and successful cooperation

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THE URGENT CHALLENGE

Persons working close to exhaust from aircraft engines (main engines and the APU: Auxiliary Power Unit) and/or diesel engines (vehicles, handling and loading equipment etc.) in airports are exposed to a complex mixture of potential health damaging air pollution. The first study documenting that these persons have an increased occurrence of DNA-damages was released five years ago. The National Board of Industrial Injuries in Denmark has now recognised several cancer cases most likely caused by air pollution in airports. The pollution is a serious and overseen work related threat.

The main concern is related to ultrafine exhaust particles from aircrafts and diesel engines. Ultrafine diesel particles are known to cause cancer, heart disease, blood clots, brain haemorrhage and airway diseases (bronchitis, COPD), thereby increasing the risk of serious work related illness and premature death. However, not much is known about the toxicity of ultrafine particles from aircrafts.

For more than a decade it has been well known that diesel engines used for loading and handling in airports emit high concentrations of ultrafine particles. During the recent years, several American studies have documented high concentrations of ultrafine particles in exhaust gas from aircrafts. However, very few airports monitor ultrafine particles. The losers in the long run are both employees and employers.

This booklet presents a new exhaustive study from Danish airports focusing on air pollution in airports, pollution sources, employee exposure to ultrafine particles and actions to limit the pollution. The booklet is thereby *state of the art* regarding air pollution in airports. In addition, the booklet illustrates the success of solution-orientated cooperation involving Copenhagen Airport, companies operating in the airport and unions representing employees in the airport. Every airport can make a difference by local actions but international organizations must act as well to solve the problem.

Millions of people working in airports may be affected by potentially damaging air.

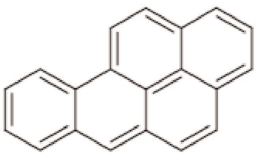
AIR POLLUTANTS

Air pollution in airports originates from background pollution, from outer sources carried with the wind to the airport, and pollution produced in the airport. The key focus in this booklet is pollution produced in airports resulting in potentially harmful pollution levels.

In airports the main sources of air pollution are exhaust from aircrafts and diesel engines, direct fuel emissions from refuelling aircrafts and larger dust particles from brakes, tyres, asphalt, soil etc. The key pollutants can be divided into: Polycyclic aromatic hydrocarbons (PAHs), volatile organic compounds (VOCs), inorganic gases like sulphur dioxide (SO_2) and nitrogen oxides (NO_X) and particulate matter (PM).

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are a group of organic compounds consisting of fused aromatic rings. Several PAHs are mutagenic and/or carcinogenic. Benz[a]pyrene is a PAH of specific interest since the compound is carcinogenic in low concentrations. Benz[a]pyrene is often used as an indicator compound for PAH-pollution. In airports PAHs are mainly produced due to incomplete combustion in aircraft and diesel engines. PAHs will exist bound to particulate matter and as gases in the exhaust gas.



Benz(a)pyren

Benz[a]pyrene is carcinogenic in low concentrations.

Volatile organic compounds

Volatile organic compounds (VOCs) are a very large group of organic compounds mainly present as gases. Some VOCs, e.g. benzene, are carcinogenic while others, e.g. aldehydes, can cause irritation of eyes and airways. In airports VOCs mainly originate from fuel vaporised during fuelling and unburned or partly burned fuel in the exhaust gas. Some VOCs will be bound to particulate matter in exhaust gas. Aldehydes are also formed by photochemical reactions in the surrounding air.

Inorganic gases

Sulphur dioxide (SO_2) is a harmful gas that can cause irritation of eyes and airways. Jet fuel contains high concentrations of sulphur; about 1,000 ppm. In comparison, the sulphur content in diesel fuel is 10 ppm, i.e. approximately 100 times lower than that in jet fuel. In engines most sulphur is oxidised to SO_2, which leaves the engine as SO_2 or sulphate particles (e.g. ammonium sulphate particles). Aircraft engines are a key source to SO_2 in airports.

Nitrogen oxides (NO_X) consist of nitrogen oxide (NO) and nitrogen dioxide (NO_2). NO is harmless in normal concentrations. NO_2 is a harmful gas that can cause irritation of eyes and airways. NO_X is formed in aircraft and diesel engines when free nitrogen (N_2) is oxidised under high temperatures. The majority of NO_X is leaving the engines as NO, but a significant part of this is oxidised to NO_2 when reacting with ozone in the surrounding air.

	Size, PM_{xx} (xx: diameter in micrometers)	Term and measurement
Coarse particles	< 10	PM_{10}: Mass
Fine particles	< 2.5	$PM_{2.5}$: Mass
Ultrafine particles	< 0.1	$PM_{0.1}$: Number
Nanoparticles	< 0.03	$PM_{0.03}$: Number

Table 1: Particles in air

Characterisation of the different types of particles.

Particulate matter

Particulate matter (PM), or simply *particles*, are solid matter in air. Further classification of particles can be done by size into coarse, fine, ultrafine and nanoparticles (see Table 1).

Notice that the amount of coarse and fine particles is measured in mass, whereas ultrafine particles and nanoparticles are measured in numbers. The larger particles constitute the majority of the total particle mass, but only a small part of the total particle number. On the other hand, ultrafine particles and nanoparticles constitute the majority of the total particle number, but an insignificant part of the total particle mass (see Figure 1).

Organic ultrafine particles are formed in aircraft and diesel engines due to incomplete combustion, and in the surrounding air as condensates. Aircraft engines are believed to be a key source to inorganic sulphate particles due to the high sulphur content in jet fuel.

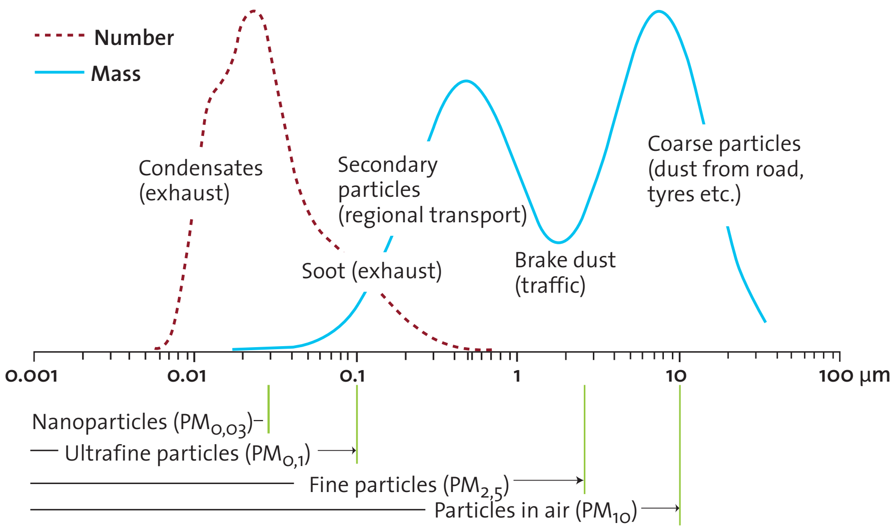


Figure 1: Mass and numbers of particles in air

Larger particles dominate the total particle mass, while the total number of particles is dominated by ultrafine particles and nanoparticles.

For decades the key focus has been on particulate mass, predominantly coarse and fine particles. The main reason for this is that these larger particles have been easy to measure and because there is a connection between particulate mass and health effects. However, several newer investigations report that ultrafine particles ($PM_{0.1}$) measured in numbers seem to be a better indicator of harmful air pollution from local exhaust. This is explained by the fact that ultrafine particles have a large surface area available for sorption of toxic compounds (PAHs, VOCs etc.), and that they have a high deposition rate in the finest and most critical parts of the lungs (the alveolar). A part of the deposited ultrafine particles containing the toxic compounds will be transferred from the alveolar directly to the blood and be transported around the body. Furthermore, newer investigations find that nanoparticles might be assimilated directly through the nasal mucous membrane and reach the brain.

Finally, the chemical composition of the ultrafine particles is believed to be crucial for their toxic properties as well. Particles with a high content of soot (black carbon) are believed to be the most dangerous particles, while inorganic sulphate particles are believed to be the least harmful. However, the inhaled particles will often be a complex mixture since organic and inorganic particles aggregate after leaving the engines, and because PAHs and VOCs will be sorbed to the particle surfaces.

LIMIT VALUES

Exposure of employees at work to air pollution is regulated by limit values according to the national *Health and Safety at Work Act*. The limit values do not necessarily protect the employees from dangerous air pollution and should be considered as a compromise between the health aspect and technical aspect, as well as the economic.

In Table 2 the Danish limit values for air pollution at workplaces compared to the general Danish (EU) minimum air quality limits in public locations (streets etc.) are shown. Danish airports fulfill all air quality limits.

Table 2 shows that significantly more air pollution is accepted in workplaces compared to public locations. The explanation is that people only spend a limited time at work, sensitive persons are not protected in workplaces and because the employee is expected to accept a certain risk with the job. However, even the limit values for coarse and fine particles on public locations do not protect human health. Each year this pollution is estimated to cause around three thousand premature deaths, tens of thousands of airway diseases and many hundred thousands of illness days in Denmark, even though all particle limit values are met. In the EU each year, 300-500,000 premature deaths are caused by pollution with fine particles. Still no official estimates of premature death and illness due to ultrafine particles have been made. However, the European Commission has taken ultrafine particle pollution and soot particles as a key focus area and will most likely introduce a limit value before 2020.

Ultrafine particles

In the Danish regulation concerning workplaces, it is stressed that compounds without limit values in the regulation, can be just as harmful as those compounds with limit values. A lack of limit values for ultrafine particles does not indicate that ultrafine particles are not dangerous. Furthermore, the following is specified in the Danish regulation concerning workplaces: *On places where health damaging air pollution is unavoidable must every possible effort be taken to protect the employees*. This is very relevant in relation to ultrafine particles.

	Workplaces (8 hour average, $\mu g/m^3$)	**Public locations** (annual average, $\mu g/m^3$)
Benz[a]pyrene	–	0.001 a)
Benzene	1,600	5
Formaldehyde	400	–
Acroleine	115	–
Sulphur dioxide	1,300	125 b)
Nitrogen dioxide	90,000	40
Coarse particles	3-10,000	40
Fine particles		25 c)
Ultrafine particles	**No limit values yet**	
Nanoparticles		

Table 2: Limit values for air pollution

Limit values for air pollution in workplaces and on public locations.

Explanation: a) From 2013, b) 24 hour average, c) From 2015.

EMISSION STANDARDS

The EU regulates the emission from road vehicles according to specific emission standards, called *Euro-norms*, and from non-road vehicles according to a specific directive setting emission standards for non-road vehicles (mobile machinery). Diesel engines used for handling and loading in the airport are included in the directive for non-road vehicles. Emission standards for NOx and particles are shown in Table 3.

The emission standards must be fulfilled under standard test conditions in order to sell vehicles in the EU. However, several new investigations have documented that the emissions are higher under real life conditions compared to test conditions, and that the emissions increase with the age of the vehicles. In addition, many exemptions exist from the general regulation for non-road vehicles.

From Table 3 it can be seen that new road and non-road vehicles have much lower emissions today than 10-15 years ago. However, some non-road vehicles used in many airports are often more than 15 years old. Emission standards for light vehicles (cars and vans) are in mg/km and cannot be directly compared to emissions from non-road vehicles, which are measured in mg/kWh. Emission standards for trucks and busses are also measured in mg/kWh. When emissions measured in mg/kWh are compared, it is clear that the standards for trucks/busses are much stricter than the standards for non-road vehicles, allowing a higher pollution from non-road vehicles. Finally, Table 3 shows that EU for light diesel vehicles (Euro V and VI) and gasoline cars with direct injection (Euro VI) have introduced a standard for particle number, and thereby a specific limit targeting ultrafine particles.

Emission standards for aircrafts are established by the International Civil Aviation Organization. The emission standards have mainly focused upon VOCs and inorganic gases (especially NO_x) and a more diffuse measurement of particles as *smoke number*. This is calculated from the reflectance of a filter paper measured before and after the passage of a known volume of a smoke-bearing sample. In 2010, it was decided to establish a certification requirement for particles in 2013 followed by a certification standard for particles in 2016. Earlier estimates indicate that aircraft engines emit more than 1,000 times more particles (in numbers) per kg fuel compared to modern diesel cars (Euro V).

Road vehicles		NO_x / Particles car/van: mg/km and trucks/busses: mg/kWh		Non-road vehicles	NOx / Particles mg/kWh	
Euro III (2000-1)	Gasoline car	150 / –		**Stage I** (1999)	A	9,200 / 540
	Diesel car	500 / 50			B	9,200 / 700
	Delivery van	780 / 100			C	9,200 / 850
	Trucks/busses	5,000 / 100			–	–
Euro IV (2005-6)	Gasoline car	80 / –		**Stage II** (2001-4)	E	6,000 / 200
	Diesel car	250 / 25			F	6,000 / 300
	Delivery van	390 / 60			G	7,000 / 400
	Trucks/busses	3,500 / 20			D	8,000 / 800
Euro V (2009-10)	Gasoline car	60 / 5 a)		**Stage IIIA** (2006-8)	H	4,000 / 200
	Diesel car	180 / 5	Particle number $600 \cdot 10^9$		I	4,000 / 300
	Delivery van	280 / 5			J	4,700 / 400
	Trucks/busses	2,000 / 20			K	7,500 / 600
Euro VI (2013-15)	Gasoline car	60 / 5 a)	Particle number $600 \cdot 10^9$ a)	**Stage IIIB** (2011-13)	L	2,000 / 25
	Diesel car	80 / 5	Particle number $600 \cdot 10^9$		M	3,300 / 25
	Delivery van	125 / 5			N	3,300 / 25
	Trucks/busses	400 / 7			P	4,700 b) / 25

Table 3: Emission standards for road vehicles and non-road vehicles
Small non-road vehicles are allowed to pollute more than trucks.

Explanation: a) Only for gasoline cars with direct injection. b) Sum of HC and NO_x.

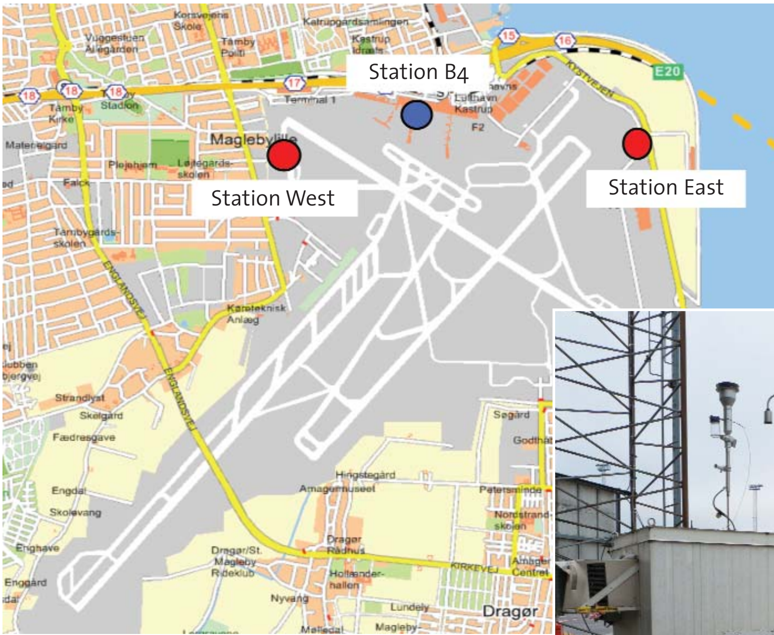


Figure 3: Stationary measurements
The stationary measurements were performed on three locations.

Figure 2: The monitor station
Stationary measurements were performed by DCE at Aarhus University.

STATIONARY MEASUREMENTS

The stationary measurements were conducted in 2010-11 in Copenhagen Airport. The purpose was to conduct detailed and long-term measurements of air pollution in the airport. The monitor station was placed in the airport yard close to the employees loading and handling aircrafts using gate B4; referred to as station *B4* (Figure 2). At station *B4* all groups of relevant pollutants (cf. page 4) were measured. Furthermore, nitrogen dioxide and fine particles as well as ultrafine particles, were measured at station *East* and station *West* that are official monitoring stations used in accordance with the environmental approval. Station *West* is close to houses in the residential area near the airport (Figure 3).

DCE at University of Aarhus performed all sampling and analyses connected to the stationary measurements. The analysed air samples from station *B4* were taken 2.5 metres above ground level and analysed for 9 PAHs, 33 VOCs incl. 9 aldehydes, SO_2, NOx, fine particles, ultrafine particles and soot (black carbon). The size interval for the measured particle number was 6-700 nm and will thereby include some particles larger than ultrafine particles (above 100 nm). However, the particle number is clearly dominated by particles below 100 nm and is not significantly influenced by particles from 100-700 nm (Figure 4).

	Stations in airport			Limit values		Reference measurements		
	B4	East	West	WP	PL	HCBA	HCOE	LV
Benz[a]pyrene	0.00012	–	–	–	0.001	0.00034	–	–
Benzene	0.6	–	–	1,600	5	–	0.7	–
Formaldehyde	5.5	–	–	400	–	–	–	–
Acroleine	6.8	–	–	115	–	–	–	–
Total VOC	5.4	–	–	–	–	–	5.3	–
Sulphur dioxide	1	–	–	1,300	125	1	–	–
Nitrogen dioxide	24	18	16	90,000	40	56	17	11
Fine Particles	17	15	16	3-10,000	25	17	14	13
Ult. part. 24h	32-38,000	10,000	11,000	No limit values yet		13-16,000	6,000	4,000
Ult. part. 6-22	30-90,000	5-20,000	–			5-10,000	–	5,000

Table 4: Stationary measurements in Copenhagen Airport

The number of ultrafine particles at station B4 is two-three times higher than on city streets with heavy traffic.

All values in µg/m3 except ultrafine particles that are measured in number of particles per cm3.
Measurements for Benz[a]pyrene, VOCs and SO_2 are average levels over a month while values for NO_2 and particles are average values over minimum half a year.
Limit values: WP: Workplaces, PL: Public locations (see table 2 for further explanation).
HCAB: One of the most polluted city streets in Denmark, *HCOE*: building roof in Copenhagen and LV: *Lille Valby* in the open countryside.
Ult. Part.: Ultrafine particles (6-700 nm) measured in particle number per cm3
Reference: DCE at Aarhus University, 2010 and 2011

Table 4 shows results from the stationary stations. Not all PAHs and VOCs are shown, but omitted results do not alter the overall picture. For comparison limit values and concentrations are shown from one of the most polluted city streets in Denmark (*HCAB*), city background (*HCOE*, building roof in Copenhagen) and measurements from the open countryside (*Lille Valby*).

Synchronic measurements of NO_2, benzene and fine particles were performed at twelve other gates in Copenhagen Airport during four weeks. These results indicated that the stationary measurements at station *B4* were generally comparable and thereby representative to air pollution close to most other gates (within ± 25%) in the airport.

From Table 3 it is observed that the concentration of all air pollutants, except ultrafine particles, are much lower than limit values for workplaces and lower than air quality limit values for public locations. The concentration of nitrogen dioxide measured at the airport gates is comparable to city background (*HCOE*) and much lower than the concentration on city streets with heavy traffic (*HCAB*), but higher than in the open countryside (*Lille Valby*). The total VOC concentration was comparable to city background. In contrast, the concentration of fine particles is comparable to the concentration measured at city streets with heavy traffic and thereby significantly higher than in the open countryside.

The picture from Table 3 is quite different for ultrafine particles. The average 24-hour concentration of ultrafine particles at station *B4* is two-three times higher than on city streets with heavy traffic (*HCAB*). And the numbers of ultrafine particles for stations *East* and *West* were only 20-30 percent below concentrations on city streets with heavy traffic. However, both the concentration at station *B4* and station *East* was higher than on city streets with heavy traffic in the main working hours (6-22).

Figure 4 illustrates the number of particles after particle size at station *B4* and *East*. The particles size distribution found at station *West* is close to the distribution found at station *East*. For comparison the particle distribution from city streets with heavy traffic (*HCAB*), city background (*HCOE*) and the open countryside (*Lille Valby*) are shown.

From Figure 4 it is clear that the particle number in the airport is dominated by particles between 6-40 nm. These particles are particles with a high deposition rate in the finest parts of the lungs; the alveolar. These particles are typically emitted directly from aircraft and diesel engines and constitute about 90 % of the particle number at station *B4* and approximately 70 % at stations *East* and *West*. This particle fraction is the main reason why the number of ultrafine particles in the airport is several times higher than on city streets with heavy traffic (*HCAB*). The particle concentration on station *East* and *West* was high when the wind came from the airport.

The measurements showed to some degree, a convergence between sulphur and the number of ultrafine particles in the airport air, which indicates that a significant part of ultrafine particles in the airport is sulphur particles. The main source of sulphur particles is probably aircrafts due to the high sulphur content in jet fuel.

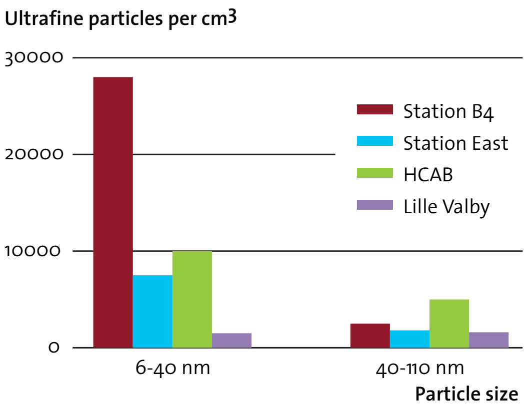
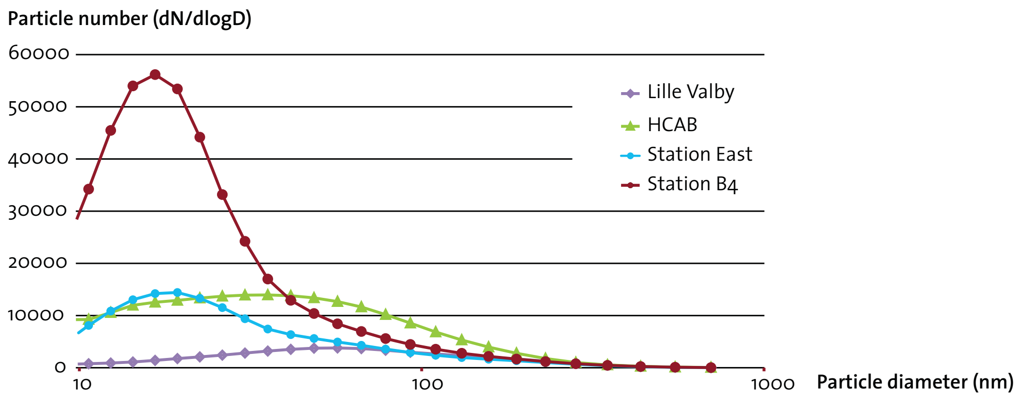


Figure 4: Ultrafine particle sizes

The particle number in the airport is dominated by particles of 6-40 nm.

Reference: DCE at Aarhus University, 2011



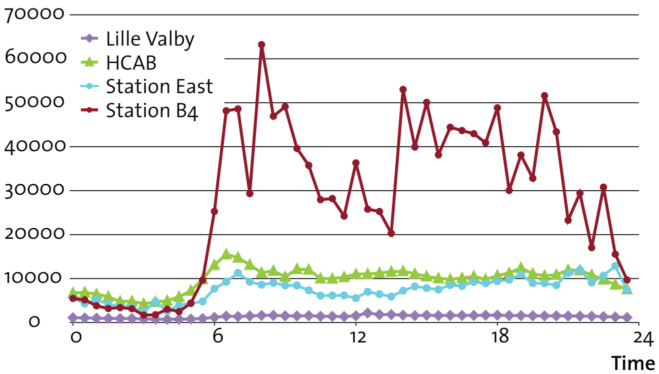
Furthermore, Figure 4 underlines that the number of particles from 40-109 nm seems to be almost the same for station *B4* and city streets with heavy traffic, while significantly less at stations *East* and *West*. These particles are of specific interest since toxic soot-particles belong to this particle fraction (Figure 1). However, results from analysis of soot in collected fine particles showed a lower soot-concentration in those fine particles collected in the airport compared to city streets with heavy traffic (*HCAB*). This indicates that fine particles from city streets may be more dangerous than fine particles in airports. But this does not necessarily indicate that ultrafine particles from 40-109 nm in airports are less dangerous than the same particle fraction from city streets with heavy traffic, since particles of 40-109 nm only account for a small and not necessarily representative part of the fine particles. However, the particle composition could very significantly among different particle sizes resulting in very different toxicity.

Figure 5 shows the 24-hour variation in the concentration of ultrafine particles in the airport compared to the variation on city streets with heavy traffic (*HCAB*) and measurements from the open countryside (*Lille Valby*).

From Figure 5 it is apparent that the concentration of ultrafine particles is time-related to traffic activity in the airport and on city streets with heavy traffic, i.e. peak times from morning and afternoon/evening traffic is clearly reflected in the concentration of ultrafine particles. Furthermore, it is clear that very high peak levels of ultrafine particles between 6 and 40 nm are observed over most of the day and that this particle fraction dominates the ultrafine particles in the airport. In comparison, the concentration of ultrafine particles in the open countryside with no local pollution sources is low and almost constant over the day. During night the particle concentration is the same in the airport and in the open countryside.

The highest half-hour peak values observed were above 500,000 particles per cm3 at station *B4*, about 130,000 particles per cm3 at station *East* and about 40.000 particles per cm3 on city streets with heavy traffic.

Particle number per cm^3 (6 - 40 nm)



Particle number per cm3 (40 - 110 nm)

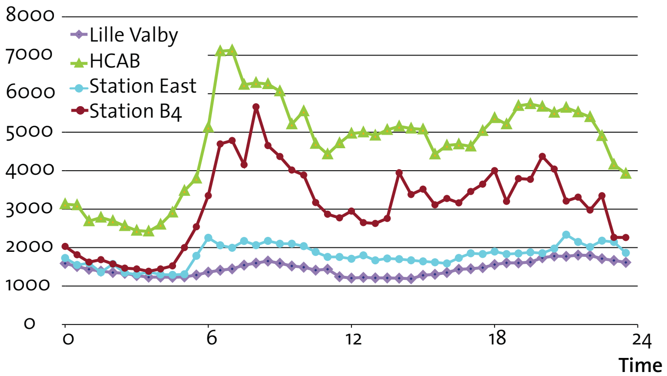


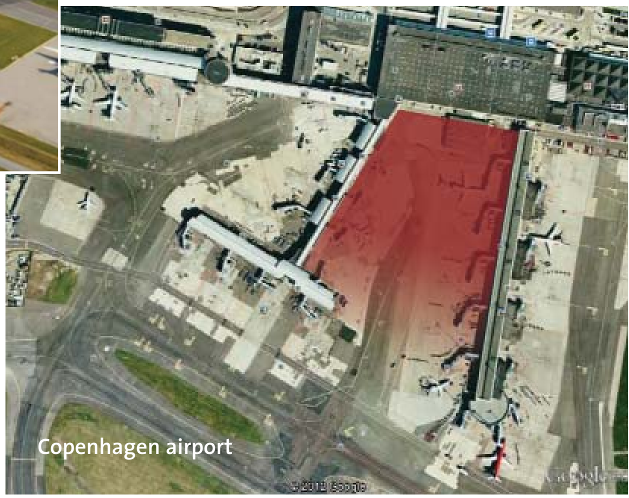
Figure 5: Variation in ultrafine particles over the day

The concentration of ultrafine particles is clearly related to traffic activity

Reference: DCE, Aarhus University, 2011

Figure 6: Aalborg Airport and Copenhagen Airport

Due to the physical construction, free dilution can occur at three sides of Aalborg Airport (left) but only on one restricted side of Copenhagen Airport (right).



EMPLOYEE EXPOSURE

Measurements in Danish airports to determine employee exposure were conducted in 2010-11. The measurements were performed close to employees at work in order to find the actual employee exposure to ultrafine particles over a working day or longer working periods.

Mobile measurements were taken with a P-Trak (Model 8525 Ultrafine Particle Counter) as close to employees loading and handling aircrafts as possible without disturbing their work. Several different categories of employees were followed for longer or shorter periods of their working day. Mobile measurements were taken both in Copenhagen Airport and in Aalborg Airport to measure airports constructed with very different physics. Solely based on physics, Aalborg Airport is expected to be close to a *best case* regarding air pollution since free dilution and wind exposure are possible from three sides (Figure 6 left). In comparison, the yard in Copenhagen Airport is constructed as a funnel only with free dilution and wind exposure from one side (Figure 6 right).

Employees from Copenhagen Airport were educated and measured employee exposure in the airport. The Danish Ecocouncil measured employee exposure in Aalborg Airport. The size interval for particle number was 20-1000 nm, and therefore includes some particles larger than ultrafine particles (above 100 nm) and excludes the smallest ultrafine particles (below 20 nm). Therefore, results from the mobile measurements cannot be directly compared to the stationary measurements since a significant part of the ultrafine particles are below 20 nm (Figure 4). As a result the measurements underestimate the employee exposure to ultrafine particles in absolute numbers. Despite this, the measurements in relative numbers are believed to provide a quite good picture of the exposure.

	Start (Time)	End (Time)	Total time (Hours: Min)	Average (Part./cm3)	Max. ½-hour (Part./cm3)	Function in airport yard
21.01.2011	10:55	14:24	03:29	40,400	75,000	Baggage handler
27.01.2011	10:55	14:24	03.29	82,800	140,200	Baggage handler
02.02.2011	06:55	15:13	08:18	75,000	104,100	Baggage handler
04.02.2011	10:29	14:42	04:13	32,400	55,500	Baggage handler
15.02.2011	06:57	12:59	06:02	95,000	213,900	Baggage handler
16.02.2011	06:55	13:29	06:34	82,000	220,000	Baggage handler
25.01.2011	08:00	13:46	05:46	52,500	120,800	Workman
Average of all measurements above				65,700	132,800	–
Rush hour on city streets with heavy traffic				40-45,000	50-60,000	–
Typical concentrations in office environments				2-4,000	3-6,000	–
Typical concentrations in the open countryside				2-3,000	4-6,000	–

Table 5: Employee exposure to ultrafine particles in Copenhagen Airport

The employee exposure in the airport is much higher than on city streets with heavy traffic.

The number of ultrafine particles is given as particle number per cm^3. Source: Copenhagen Airport.
Concentrations from city streets are from the rush hours at Nørre and Øster Søgade in Copenhagen, concentrations from office environments and the open countryside are from multiple measurements over several years. Source: The Danish Ecocouncil.

Copenhagen Airport

In Table 5 is shown results from measurements of employee exposure to ultrafine particles.

From the measurements in general, it is observed that employee exposure to ultrafine particles in the airport is higher than exposures during rush hour on city streets with heavy traffic in Copenhagen. The average of all exposure measurements taken in the airport is higher than the measurement taken during rush hour on city streets with heavy traffic. The average maximum half hour exposure is more than twice the maximal exposure on city streets with heavy traffic. Many baggage handlers in the airport yard inhale about 25 times more ultrafine particles than a typical office employee, with some baggage handlers inhaling up to 50 times more ultrafine particles. The measurements clearly show large variations between the employee exposure, which reflects different activities occurring in the airport, the location and time of day.

In Figure 7 is shown the employee exposure over 6 hours of work for a baggage handler.

The figure shows that there are many different sources contributing to employee exposure in the airport and that variations over a working day are large, up to

Box 1: Billions of ultrafine particles

If a baggage handler inhales air containing 65,000 ultrafine particles per cm^3 on average (Table 5), and inhales 0.5 litre of air per breath 15 times per minute (quiet work), the result will be inhalation of 500 million particles per minute. This equates to 240 billion ultrafine particles per workday, of which a significant part are deposited in the most critical parts of the lungs (the alveoli), allowing release of some of the toxic compounds sorbed to the particle surface directly into the bloodstream. The health effects are difficult to quantify and predict, but this exposure is definitely not healthy.

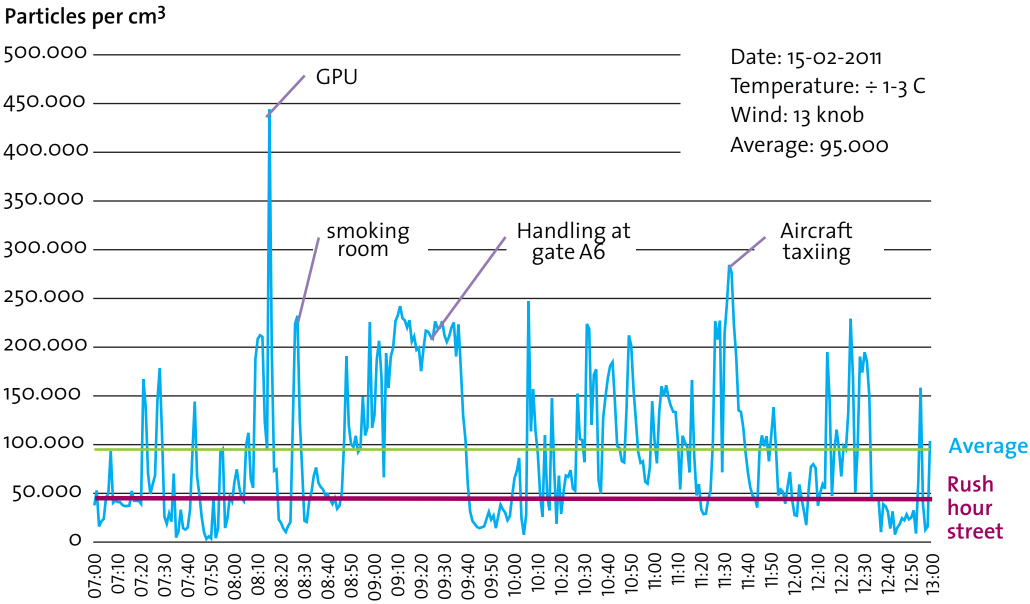


Figure 7: Employee exposure in Copenhagen Airport

Baggage handlers working in the airport yard are particularly exposed to ultrafine particles.

Source: Copenhagen Airport.

a factor 150: From approximately 3,000 particles per cm^3 at 07:50 to about 445,000 particles per cm^3 25 min. later. Hence, the levels of pollution can vary significantly. Some peak concentrations are easy to explain since the pollution source can be directly identified. On the other hand, the exposure from 09:10 to 09:40 contributes significantly to the total employee exposure (high concentrations for a long time), but no direct pollution sources can be identified, suggestive of the pollution is probably carried with the wind from one place to another in the airport. Furthermore, it is seen that the concentration level of ultrafine particles in a confined smoking room is approximately the same as the concentration levels originating from aircrafts and diesel engines in the airport. Finally, the data shows that throughout much of the day a baggage handler is exposed to much higher levels of ultrafine particles than those found on city streets with heavy traffic during rush hour.

	Start (Time)	End (Time)	Total time (Hours: Min)	Average (Part./cm3)	Max. ½-hour (Part./cm3)	Place in airport yard
10.02.2011	07:23	13:03	05.40	40,000	83,900	Garbage truck
22.02.2011	09:24	14:00	04:36	40,000	94,300	Car repair/garage
25.02.2011	08:42	12:11	03:29	27,900	81,000	Fire stations
Rush hour on city streets with heavy traffic				40-45,000	50-60,000	–

Table 6: Measurements at relevant places in Copenhagen Airport

Employees not working directly in the airport yard may also be heavily exposed.

The number of ultrafine particles is given as particle number per cm^3. Source: Copenhagen Airport. Concentrations from city streets are from the rush hours at Nørre and Øster Søgade in Copenhagen. Source: The Danish Ecocouncil.

Table 6 shows results from measurements of ultrafine particles in various other places in the airport.

From Table 6 it is seen that groups of employees working in other areas of the airport are exposed to ultrafine particles. These groups seem to be exposed to lower concentrations than baggage handlers. However, they are exposed to similar concentrations as those found during rush hour on city streets with heavy traffic, which is also cause for concern. Additional measurements taken in public areas in the airport buildings (data not shown) were low, and comparable to other public buildings.

Aalborg Airport

Figure 8 shows measurements of employee exposure during a handling in Aalborg Airport compared to concentrations found during the rush hour on streets with heavy traffic in Copenhagen (Nørre Søgade).

From figure 8 it is clear that the employee exposure to ultrafine particles during the handling is much greater than it would be if the work had taken place in the rush hour on a city street with heavy traffic. The high pollution during the handling completely overshadows the street pollution. The first peak (1) is an aircraft taxiing from another gate (by the main engines) to take-off. The second peak (2) is a third aircraft from an adjacent gate turning on its APU. The third peak (3) is this aircraft turning on its main engines and taxiing to take-off. The fourth peak (4) is the aircraft just handled turning on its APU. Notice that in the time between peaks 3 and 4, the concentration of ultrafine particles does not fall below the concentration on city streets with heavy traffic. This is due to pollution from diesel engines used for handling and loading.

From the measurements in Aalborg Airport it is clear that even in small airports with almost optimal dilution conditions (Figure 6) serious exposure of employees to ultrafine particles can occur.

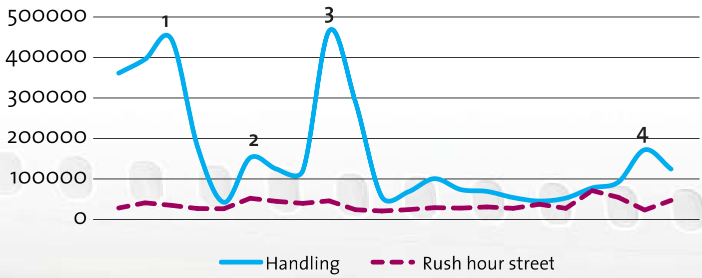


Figure 8: Employee exposure during a handling in Aalborg Airport (22 min.)

Source: The Danish Ecocouncil.

POLLUTION SOURCES

To quantify the pollution from different sources in Copenhagen Airport a detailed study of emissions from pollution sources followed by model calculations on pollution in the airport yard (Figure 9) was made.

From the figure it is clear that about 90 % of the ultrafine particles originate from sources in the airport. The opposite is the case for fine particles, where NOx is more evenly distributed between sources both inside and outside the airport. Furthermore, it is clear that diesel engines from handling is the dominant source in the airport contributing to pollution containing NOx and fine particles. However, aircraft engines (main engines and APUs) contribute significantly to pollution with NOx and fine particles as well. The contribution from road traffic within the airport is insignificant.

A quantification of sources of ultrafine particles has not been carried out. But both aircraft engines and diesel engines are believed to contribute significantly to pollution with ultrafine particles in the airport. The dominant source will depend on the location and the local activity, i.e. number of diesel engines vs. aircraft engines in use. During the handling in Aalborg Airport (Figure 8) diesel engines increased the basic level of ultrafine particles to about 55,000 particles per cm^3 over 22 minutes. If this pollution is subtracted from the total concentration minute by minute, then aircraft engines contribute about 105,000 particles per cm^3 on average for 22 minutes. Thereby aircraft engines contribute about 2/3 of the total exposure to ultrafine particle concentration, and diesel engines contribute about 1/3 during this specific handling situation.

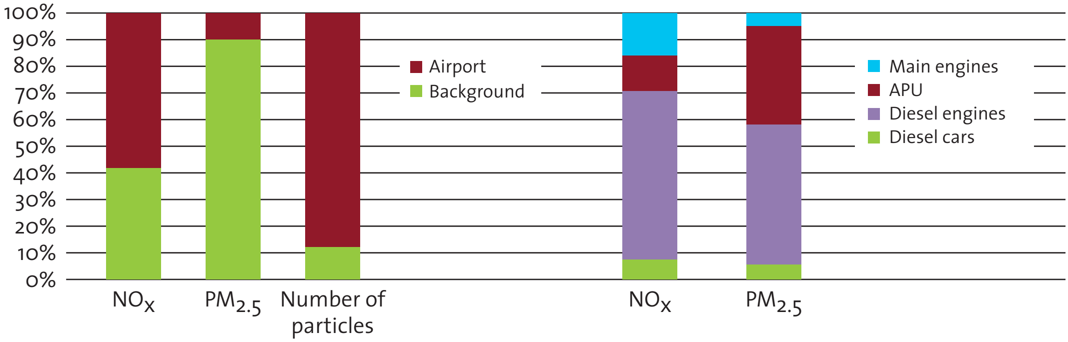


Figure 9: Sources of pollution in Copenhagen Airport

Left: Ultrafine particles are produced in the airport. Right: Both diesel engines for handling and aircraft engines (main engines and the APU) contribute significantly to pollution in the airport yard.

Reference: DCE at Aarhus University, 2011

Box 2: Copenhagen Airport has a policy on green engines
Copenhagen Airport and companies operating in the airport have agreed on binding targets for green engines. A still rising percentage of the engines in the airport needs to be green engines. The purpose is to increase the replacement of old engines used for handling and loading with new and less polluting engines (cf. Table 3). The definition of green engines is revised as less polluting engines are developed

POLLUTION SOLUTIONS

The key focus is how to reduce the employee exposure to ultrafine particles since ultrafine particles are believed to be the key health challenge in the airport related to air pollution. In addition, reducing the exposure to ultrafine particles may reduce the exposure to other pollutants as well.

As mentioned earlier, the main sources of ultrafine particles are aircraft engines (main engines and the APU) and diesel engines. The dominant source depends on the location and the local activity, i.e. number of diesel engines vs. aircraft engines in use. But other factors also play a part, such as the sulphur content in jet fuel, and the specific placement of local diesel engines during a handling etc.

The solutions can be divided into two main categories:

1. Solutions to avoid or limit formation of pollution.
2. Solutions to avoid or limit employee exposure.

Limit formation of pollution

A significant part of the ultrafine particles formed in the main engines and the APU are believed to be sulphate particles. Hence, the formation of ultrafine particles can be limited by reducing the sulphur content in jet fuel. This needs to be decided by the relevant international organisations. Another possibility is to increase the efficiency of the engines and optimise the engines in order to reduce the formation of ultrafine particles. Energy efficiency and emission reductions are already a key focus area in the International Civil Aviation Organization (ICAO). However, specific focus on reducing the emission of ultrafine particles from aircrafts (like the number limit for euro V diesel cars cf. Table 3) would enhance this development.

Many diesel engines used for handling and loading can be replaced with newer diesel engines or electrical engines (Figure 10, left). Replacing old diesel engines with new diesel engines (Stage IIIB) will reduce the emissions of fine particles significantly (Table 3) and thereby, all other things being relative, reduce the emissions of ultrafine particles as well (Box 2). Furthermore, electricity to aircrafts can be directly delivered from the central power supply instead of using a diesel ground power unit (GPU). This requires electricity at the gates or electrical GPUs used as extension cords (Figure 10 right).

Figure 10: Electricity can today replace most diesel engines
Electrical engines cause no local pollution.

Limit employee exposure
Generally, the way to limit employee exposure is to contain the spread of ultrafine particles away from locations where people work. Another possibility is, of course, to protect employees with respirators or gas masks to prevent inhalation of the pollution. However, equipment like this will increase the risk of physical accidents at work, make it difficult and inefficient to work and pose other health risks for serious acute lung diseases. Hence, the focus below is to avoid spreading ultrafine particles.

The best solution is to contain the pollution and prevent it from leaving the aircraft. However, particulate filters for aircraft engines (main engines and the APU) have not yet been developed. The safety aspect makes the development of filters for the main engines a unique challenge. However, filters could probably be developed for the APU. Another possibility is to avoid use of aircraft engines close to places where people work, e.g. by using an electrical push-back tractor to taxi aircrafts to take-off (Figure 11). If push-back is impossible then the aircraft may taxi to/from the runway using only one main engine (two main engines for four-engine aircrafts), which will also reduce the emissions. Alternatively, the aircraft might reverse (taxi) to take-off sending the emissions to the runway where there are very few, if any, personnel. Furthermore, take-off marks may be moved to more remote places limiting the exposure of employees to the pollution from the aircraft engines to reach the employees. However, it is important that moving the take-off marks does not increase the waiting time before take-off increasing the time with engines and APUs turned on. By waiting as long as possible to turn on the APU the employee exposure can be reduced (Box 3). This requires efficient external air conditioning and ventilation at gates and that the capacity matches the actual demands.

Figure 11: Electrical push-back tractors eliminate local emissions
Using an electrical push-back tractor to taxi aircrafts to take-off eliminates a significant local pollution source.

Box 3: Copenhagen Airport has an APU policy
Copenhagen Airport has APU rules to limit air pollution. APUs can only be used five minutes after the aircraft is *on block* and five minutes before the aircraft is expected *off-block*. But in general, use of the APU should be limited as much as possible. However, exceptions exist depending on outside temperature, aircraft type etc. All violations are reported to the safety inspector and will be investigated further to make sure everybody obey the regulation.

Many diesel engines used for handling and loading can be retrofitted with standard particulate filters removing ultrafine particles (Figure 12). However, experiments from Copenhagen Airport underline that a satisfying reduction is not achieved automatically and that filters need be chosen carefully. Another option is to turn off diesel engines when possible by running *turn off* campaigns addressed to employees operating diesel engines during handling and loading of aircrafts. In some vehicles this requires extra batteries and heaters. When educating new employees a specific focus could be on the importance of turning off engines during idle periods. In addition, diesel engines could be used in locations and in manners where employee exposure to exhaust is limited. Employees could also be reminded not to stay waiting in critical locations longer than needed.

Figure 12: Particulate filters can remove ultrafine particles
Filters for diesel engines should be tested to ensure a satisfying efficiency towards ultrafine particles.

Box 4: Turn off the engine campaign in Copenhagen Airport
Copenhagen Airport has for five years been running a *turn off* the engine campaign targeted people operation diesel engines and driving in the airport. When educating new employees, there is focus on turning off engines. The purpose is to limit air pollution from idle running engines. Idle running engines must be turned off after maximum one minute. However, exceptions exist because some diesel engines need to be on to function. All violations are reported, investigated and sanctioned.

A third possibility is to shield employees against the pollution. Figure 13 shows measurements of ultrafine particles from the luggage hall in Aalborg Airport comparing 'closed gate' and 'open gate' (sunny days to avoid overheating) to the hall from 1-2 minutes before take-off until 16 min. after take-off.

From Figure 13 it is clear that the gate should be closed to shield against ultrafine particles. Overheating on sunny days can be avoided by solar screening, permitting the gate to be closed. With a closed gate the average concentration of ultrafine particles is about 18,000 particles per cm3, whereas the average concentration with an open gate is about 142,000 particles per cm3. The gate reduces exposure in the luggage hall by almost 90 percent during a typical take-off pollution period.

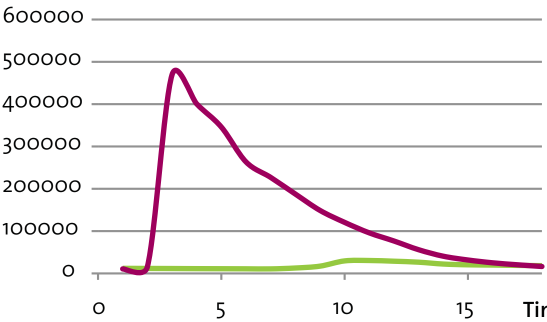


Figure 13: Employees may be shielded from ultrafine particles

A simple gate can efficiently shield some employees against ultrafine particles.

Source: The Danish Ecocouncil.

SUCCESSFUL COOPERATION

For many years air pollution in Copenhagen Airport has been a *hot topic* among the employees. The focus was intensified in 2006 when an international study documented a work-related occurrence of DNA-damages among airport employees. However, the turning point came two years later in 2008 when The National Board of Industrial Injuries in Denmark acknowledged the first cancer case of an airport employee as *most likely* caused by work-related air pollution. As a consequence, an official working group consisting of managers from Copenhagen Airport, companies operating in the airport and unions representing employees in the airport was established. The working group is coordinated by the airport.

The working group quickly decided that the first step was to conduct detailed investigations of the air pollution in the airport yard, where the highest air pollution was expected and many employees spend most of their working day. The Department for Environmental Science at the University of Aarhus was hired to do the measurements beginning in autumn 2009. The department is the leading Danish research unit in stationary air quality measurements and air pollution modelling.

In 2010 3F – United Federation of Danish Workers decided to hire an air pollution specialist from The Danish Ecocouncil to advise them in the working group. The Danish Ecocouncil had experience with measurements of ultrafine particles from road traffic with mobile measuring devices. Subsequently in the same year, Copenhagen Airport hired The Danish Ecocouncil to introduce them to mobile measurements in order to conduct measurements of employee exposure to ultrafine particles parallel to the stationary measurements.

In autumn 2010, the first special report from stationary measurements concerning ultrafine particles was published. The report documented much higher concentrations of ultrafine particles in the airport yard compared to city streets with heavy traffic. The report received much attention in the press. In early 2011 additional results came from investigations of employee exposure, again underlining that ultrafine particles were a key challenge. This completely changed the focus in the working group. Everybody recognised the challenge with ultrafine particles and the focus was moved to solutions.

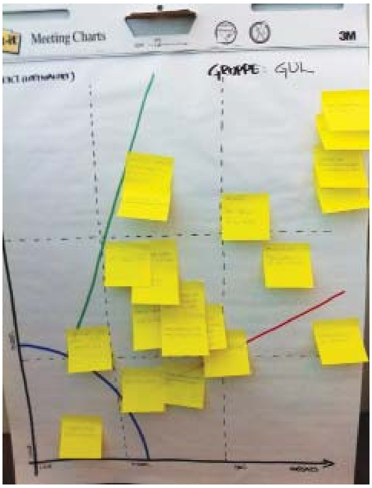
Work-related injury: Stig Jeppesen got cancer from his job in the airport.

Solution-orientated cooperation

From the measurements it was clear that both aircraft and diesel engines contributed to the pollution with ultrafine particles. The working group arranged workshops where all members of the working group brainstormed in smaller groups to find solutions. Some suggestions were implemented immediately (Awareness on APU regulation, *turn off the engine* campaigns etc.), whereas other more complex suggestions (aircrafts taxiing to/from take-off using only one main engine, moving take-off marks etc.) were investigated in detail to assess the effects on both air pollution and safety.

> **"In Copenhagen Airport nobody should be ill from doing their job"**
>
> Kristian Duurhus, manager, Copenhagen Airport

All members of the working group were very enthusiastic and felt committed to cooperate and use their varying knowledge and resources in a synergistic way to find, discuss and test new solutions and ideas to reduce employee exposure to ultrafine particles. Most suggested actions described above to reduce employee exposure are a result of this unique solution-orientated cooperation between the airport management, companies operating in the airport and unions representing the employees.



The following key actions have been accomplished to reduce the pollution with ultrafine particles in Copenhagen Airport:

- Investment in electrical GPUs (Figure 10 right).
- Requirements for *green engines* (Box 2).
  - Increased share of newer (*green*) engines.
  - Retrofitted particulate filters on snow removal vehicles.
  - Installed batteries and heaters in vehicles to avoid idle running.
  - Campaigns to ensure the APU regulations are fulfilled (Box 3).
  - Campaigns to ensure engines are turned off when possible.
- Rules for aircraft taxiing to/from take-off on one engine.
- Ongoing measurements to monitor and improve air quality.
- An action plan with deadlines and clear division of responsibilities.

The measurements and the working group will continue until the challenge with ultrafine particles is solved. An exhaustive cohort study carried out from 2012-15 will clarify illness among present and former employees in the airport.

Due to the measurements (Figure 6 and Figure 13) Aalborg Airport has decided that all aircrafts must be taxied to take-off by push-back tractors and that all new engines must be electrical if possible.

RECOMMENDATIONS

Employee exposure to ultrafine exhaust particles from aircraft and diesel engines in airports is an urgent and overlooked work-related challenge potentially affecting the health of millions of people. The solution is a target-orientated effort to limit employee exposure to ultrafine particles by the relevant international organisations, and in every single airport.

International organisations

The International Civil Aviation Organization, the Airport Council International, European Transport Workers' Federation and the European Commission are important stakeholders. It is highly recommended that these organisations promote a better work environment in airports by:

1. Investigating the possibilities to significantly reduce the sulphur content in jet fuel.
2. Providing a binding limit value for emissions of ultrafine particles (measured in numbers) from new aircraft engines (both the main engines and the APU).
3. Setting a limit value for ultrafine particles in the *Health and Safety at Work Act*.
4. Establishing an obligation for airports to monitor the number of ultrafine particles.
5. Developing and requiring cleaner APUs e.g. by particulate filters, fuel cells etc.
6. Initiating detailed cohort studies of illness among present and former employees in airports.
7. Supporting efforts in every single airport to reduce employee exposure to ultrafine particles (see below), e.g. by establishing web-platforms, conferences and detailed information material for knowledge sharing concerning best practice, new investigations, new engines etc.

Every single airport

In order to improve the work environment as fast as possible every airport is recommended to:

1. Establish a committee with focus on ultrafine particles consisting of relevant stakeholders e.g. the airport management, companies operating in the airport, unions etc.
2. Monitor the number of ultrafine particles and reduce employee exposure to ultrafine particles by, as a minimum, introducing the actions on an airport level described in this booklet.
3. Implement specific and measurable targets with deadlines for reductions of ultrafine particles.
4. Follow the general international efforts to reduce employee exposure to ultrafine particles and investigate specific actions to limit the pollution with ultrafine particles in their airport.

3F – United Federation of Danish Workers will be pleased to assist airports to improve air quality and the work environment. Contact: Lars Brogaard, (+45) 21 49 09 78 / lars.brogaard@3f.dk

Figure 14: Copenhagen Airport may increase the particle pollution in the nearby city

EFFECTS OUTSIDE AIRPORTS

Air pollution from airports may affect the air quality in cities or neighbourhoods near airports.

The measurements (Table 4) indicate that the concentration of Benz[a]pyrene in the central airport yard (station *B4*) of Copenhagen Airport is less than half the concentration on city streets with heavy traffic (*HCAB*) whereas the concentrations of benzene and total VOC are close to city background (*HCOE*). The concentrations of sulphur dioxide are close to the level on city streets with heavy traffic but far below the limit value. The pollution containing PAHs, VOCs and sulphur dioxide from the airport does not seem alarming in relation to air quality outside the airport.

The measurements from station *West* (Table 4), close to houses in the city of *Maglebylille*, show that the concentration of fine particles and nitrogen dioxide is close to city background, but higher than measurements from the open countryside (*Lille Valby*), whereas the concentration of ultrafine particles is 25 percent below city streets with heavy traffic (24h basis). Taking into account the daylight hour (6-22) measurements from station *East*, the concentration of ultrafine particles at station *West* during the same hours is expected to exceed the concentration on city streets with heavy traffic. Especially pollution with fine and ultrafine particles from the airport could thereby affect the air quality in the city a few hundred meters away (Figure 14).

FURTHER INFORMATION

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AIR POLLUTION IN AIRPORTS

Ultrafine particles, solutions and successful cooperation

Persons working close to exhaust from aircraft and/or diesel engines in airports are exposed to a complex mixture of potentially health damaging air pollution. The National Board of Industrial Injuries in Denmark has now recognised several cancer cases, most likely caused by air pollution in airports. The pollution is a serious and overseen work-related threat. The losers in the long run are both employees and employers.

The main concern is related to ultrafine exhaust particles from aircraft and diesel engines. Ultrafine diesel particles are known to cause cancer, heart disease, blood clots, brain haemorrhage and serious airway diseases, thereby increasing the risk of serious work-related illness and premature death. However, not much is known about the toxicity of ultrafine aircraft particles.

This booklet presents a new exhaustive study focusing on air pollution in Danish airports, pollution sources, employee exposure to ultrafine particles and actions to limit the pollution. The booklet is thereby *state of the art* regarding air pollution in airports. In addition, the booklet illustrates the success of solution-orientated cooperation involving Copenhagen Airport, companies operating in the airport and unions representing employees in the airport.

The main aim of the booklet is to inspire decision makers and other key stakeholders in national and international organisations and in every airport to take action to reduce employee exposure to air pollution with ultrafine particles from aircraft and diesel engines.

THE DANISH ECOCOUNCIL