Measurement of ultrafine particles at the apron of Copenhagen Airport, Kastrup - in relation to work environment

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Introduction

The present report to Copenhagen Airports Ltd. was prepared November 2010 by Denmark's Environmental Investigations (DMU), University of Aarhus. The work has been undertaken in connection with DMU Project 1 and 2, "Investigation of airborne pollution at the apron of Copenhagen Airport, Kastrup – in relation the work environment. This investigation was conducted for Copenhagen Airports Ltd., in the period 2009 – 2011.

In connection with Project 1 and 2 it was intended to conduct two measurement campaigns, running totally four months, including measurement of number and size-distribution of ultrafine particles at the measurement station at the apron (Gate B4), and at one of the two monitoring stations at Copenhagen Airport (Fig. 1). The plan was to carry out the campaigns spring and fall 2010. However, because of large-scale rebuilding at the gates B2 and B4, spring 2010, the spring measurement campaign was postponed, and the two measurement campaigns combined into a joint campaign in fall 2010.

The report starts off with a short review of some of the most important particle fractions, included in the total investigation of particle pollution. Secondly, results of measurements of number and size-distribution of ultrafine particles at the airport apron and at the monitoring station are presented, thirdly, results of literature studies are included, and finally there is a conclusion. Results as well as conclusions are preliminary, since Project 1 and 2 are not yet finished.

Particle fractions

Airborne particle pollution consists of many different types of particles, having varied physical and chemical characteristics among which, size and chemical composition have influence on the particles' effect on human health. Thus, the combined investigation of airborne pollution at the airport apron includes measurements of a number of different parameters, which each in its own way contributes to characterize different fractions of the particle pollution.

$PM_{2,5}$
Indicates the mass of particles with an aerodynamic diameter less than 2,5 µm (micrometer = a millionth of a meter); the so-called fine particles. The mass of a particle increases very strongly with the diameter, because the volume of a particle increases with the diameter in third power. Therefore, $PM_{2,5}$ will mainly depend on particles with a diameter between 0,5 og 2,5 µm. Combustion processes, such as exhaustion, lead to the formation of particles, which contribute to $PM_{2,5}$. $PM_{2,5}$ can also be formed in connection with for example tyre wear when braking the aircraft at the zone of landing. There is a documented connection between $PM_{2,5}$ and harmful effects on health. Therefore, the EU has defined a threshold limit for $PM_{2,5}$ in relation to assessment of air quality.

Ultrafine particles
Combustion processes lead to discharges of a large amount of very small particles with a diameter less than 100 nm (nanometer = a billionth of a meter). These particles are called ultrafine particles. The ultrafine particles have a very small mass. Therefore, the ultrafine particles are characterized by number instead of by mass. The number of ultrafine particles is far greater than the number of particles with a diameter from 0,5-2,5 µm. Many investigations point out, that especially the ultrafine particles constitute the most health hazardous part of the particles. But the effects on health are by far not conclusively illuminated yet. There is not set up threshold limits on number of ultrafine particles, and the EU does not expect this to occur within next few years.

Carbon
A non-transient fraction of the ultrafine particles consists solely of carbon and is described either as carbon or as elementary carbon (EC). Carbon is a major part of the particle pollution from diesel motors, and is also emitted from aircraft motors. Carbon is supposed to be health hazardous, but there are no threshold limits for carbon in relation to air quality.

This report focuses on the ultrafine particles, whereas $PM_{2,5}$ and carbon will be treated in the final report from this investigation.

Measurements

Measurements of number and size-distribution of the ultrafine particles at the apron of Copenhagen Airport were initiated during July 2010, so that measurement results were available from August 2010. The measurements were conducted at the measurement station located at Gate B4 (called Station B4) and at Station East, which is part of the day-to day monitoring of the air quality at the border of Copenhagen Airport. The localization of the measurement stations is shown in Figure 1.

Measurement of number and size-distribution of ultrafine particles was conducted with DMU's Differential Mobility Particle Sizer (DMPS), which includes particle sizes from 6-700 nm (mobility diameter), among which only particles under 100 nm, are defined as ultrafine. Measurements were conducted in scans of a 2 minute duration, which aggregates into ½-hour average values. The take-in of the DMPS was placed at about 2,5 m height.

Measurements at the street station at H.C. Andersens Boulevard (HCAB) and at the regional background station at Lille Valby, Roskilde are conducted by DMU as part of the national air quality monitoring and via a research project on particles, financed by the Environmental Board.

Results

Figure 2 shows times-series for ½-hour average values of number of particles measured at the apron (Station B4) and at the monitoring station (Station East), as well as at the street station at H.C. Andersens Boule-

vard (HCAB), and the regional background station at Lille Valby, Roskilde. The latter two stations are included as standard of reference.

There appears to be great variation over time, as well as great difference between the measurement stations. There clearly appeared to be considerably higher number of particles at Station B4 than at Station East. At Station B4 a particle number of over 500.000 particles/cm^3 was found, whereas particle number for Station East was about 130.000 particles/cm^3. Both at Station B4 og Station East the number of particles were found to be higher than measurements at HCAB, where there was maximally found about 40.000 particles/cm^3. HCAB is considered one of the most polluted streets in Copenhagen. Lille Valby was, with a maximum of about 25.000 particles/cm^3 , even lower than the three other stations. In average, for the period from 28.07.2010 to 30.09.2010 (Table 1), Station B4 showed a factor about 3,6 higher than found at Station East, and a factor 4,4 higher than HCAB. Furthermore, Station B4 had a factor almost 10 higher than the regional background outside Copenhagen.

Figure 1. Localization of Station B4 and Station East.

Table 1 also shows the average number of particles measured by the roadside of the Holbæk highway (Ellermann et al., 2008). The number of particles at the highway lies at about 50% of the level at Station B4. Note, however, that these measurements were taken in the springtime (March-April 2008), when the background level for number of particles is a little higher than typical for late summer – fall, when the measurement campaign was made.

Table 1. Average number of particles measured at Station B4, Station East, HCAB and Lille Valby in the period from 28.07.2010 to 30.09.2010. Furthermore, results from measurements of number of particles, carried out in connection with measurement campaign at the Holbæk highway in March-April 2008, is shown. (Ellermann et al., 2008).

Station	**Average number of particles Particles/cm^3**
Station B4	43.000
Station East	12.000
HCAB	9.800
Lille Valby	4.600
Holbækmotorvej	22.897

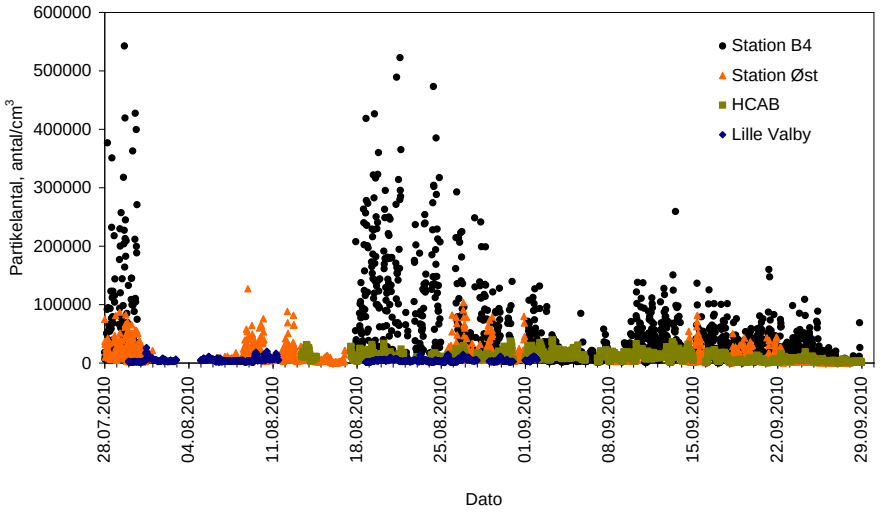


Figure 2. Total number of particlesl (½-hour average values) measured at the apron (Station B4) and at the monitoring station (Station East). For comparison, results from the street station HCAB and the regional background station, Lille Valby, Roskilde is also shown. The latter is included in the nation monitoring program for air quality.

Figure 3 shows the average particle-size distribution, which is praxis in connection with scientific publications in this professional domain. The particle diameter is shown on a logarithmic scale. In order to get a correct impression of particle-size distribution, the y-axis is depicted in the unit dN/d(logD), where N is number of particles and D is diameter. "d" indicates, that these are derived values. Thus, the total particle koncentration corresponds to the area under the curve.

Figure 4 shows a more simple version of the particle-size distribution, where the particles are divided into three size fractions:

- 6-40 nm, which contains the smallest particles, measurable with the instrument. These particles are typically discharged directly from the combustion processes.

- 40-110 nm, which among other things consists of the carbon particles from diesel motors.

- 110-700 nm, which for a major part consists of long transported particles, whereof some are secondary non-organic particles formed in the atmosphere, one of which is sulphur dioxide.

In figure 3 and 4 it is clearly seen, that the great number of particles at Station B4 is caused by a high number of the smallest particles from 6-40 nm. Station B4 was, furthermore, markedly higher than the other stations. Thus Station B4 was 4,5, 6,8 og 18 times higher than respectively Station East, HCAB and Lille Valby. The occurrence of a very high number of the smallest size fraction at Station B4 could presumably be explained by direct emissions from mainly jet motors (se the chapter on literature studies). Station East is also influenced by these emissions, either via transport with the wind from the apron, or because of emissions from planes' take-off or landing.

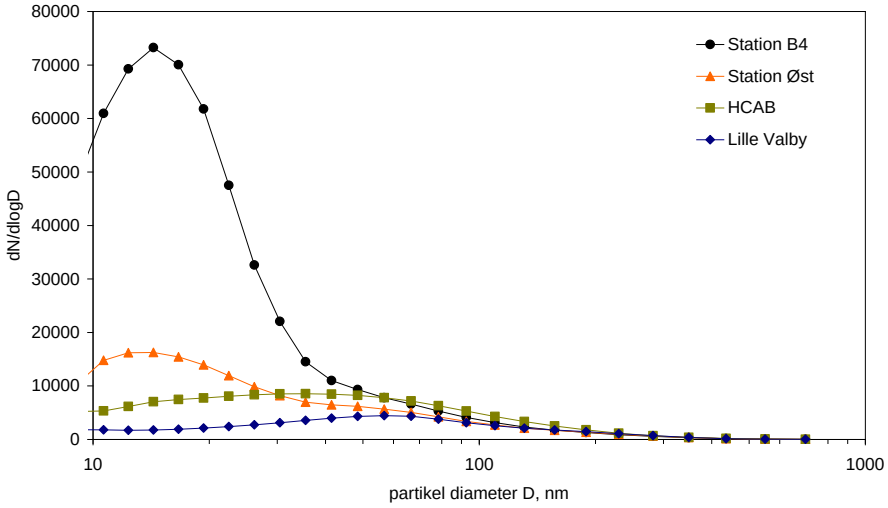


Figure 3. Average particle-size distribution, measured at Station B4, Station East, street station HCAB and the regional background station at Lille Valby, Roskilde. The measurements were conducted from 28.07.2010 to 30.09.2010.

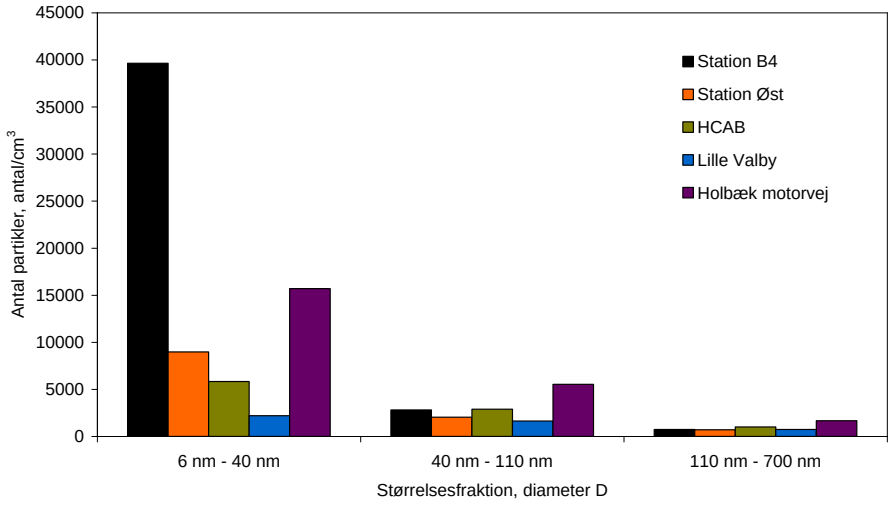


Figure 4. Average number of particles allocated to the three size-fractions measured at Station B4, Station East, street station HCAB and the regional background station at Lille Valby, Roskilde. The measurements were conducted from 28.07.2010 till 30.09.2010. Furthermore, measurements taken in connection with measurement campaign at Holbæk highway in March-April 2008 (Ellermann et al., 2008), are shown.

It appears, that difference between Station B4, Station East, HCAB and Lille Valby was much less for the middle size fraction (40-110nm). For

these four stations the number of particles was highest at Station B4 and HCAB, where there was the same amount of particles. Station East and Lille Valby were respectively about 30 and 40 % under Station B4.

At Station B4, Station East, HCAB and Lille Valby the level of the largest size fraction (110-700 nm) was lower than for the two smaller size fractions og the level was rather similar. HCAB was 30 % above the other stations, whereas the three other stations practically had the same level. This could be explained by the fact that a large part of the particles in this size fraction are long transported, and thus have an even geographical distribution.

Figure 4 shows data measured at the Holbæk highway (Ellermann et al., 2008) as well. It is seen, that at the Holbæk highway the very small particles (10-40 nm) also dominate. The number is about 40% of the number, measured at Station B4. These small particles derive solely from direct emissions from traffic exhaust. The larger fractions were found in greater particle numbers than at the other stations. The probable explanation is mainly a greater amount of dust from road, tyres and brakes, and because the measurements at the Holbæk highway were carried out in the spring, when the background level is greater than in late summer and fall.

The same figures are shown in Figure 5 as in Figure 4, but instead of particle number, particle volume is illustrated. By multiplying with particle density (about 1-1,5 g/cm^3), volume can be converted to particle mass. Particle volume was greatest for the large fraction from 110 – 700 nm. The largest volume was measured at HCAB, whereas Station B4 and Lille Valby were about 20 % lower. Station East was about 28 % lower than HCAB. This picture corresponds to the results from measurement of $PM_{2.5}$ at the four measurement stations, where the difference between the stations, however, was somewhat greater (data is not presented in this report.).

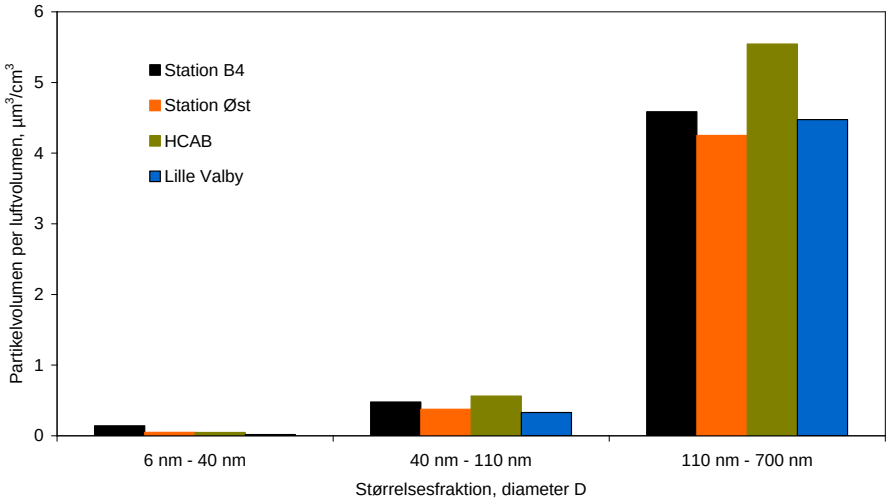
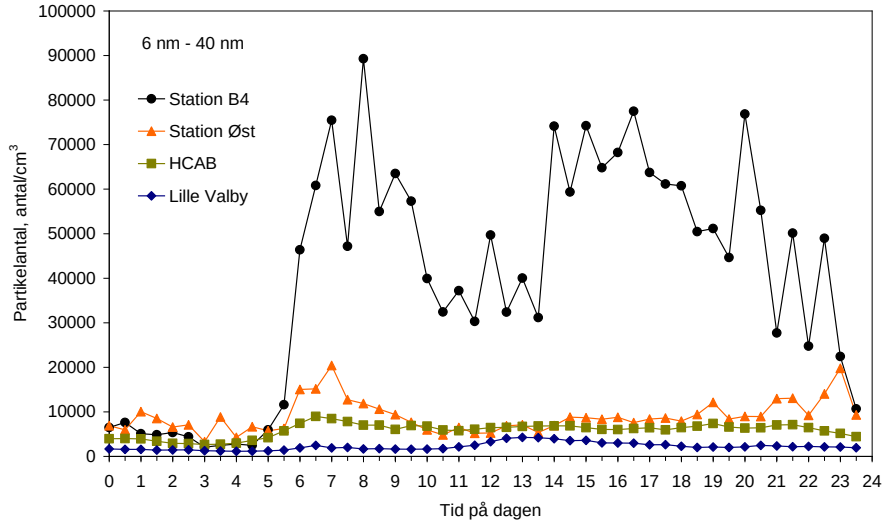
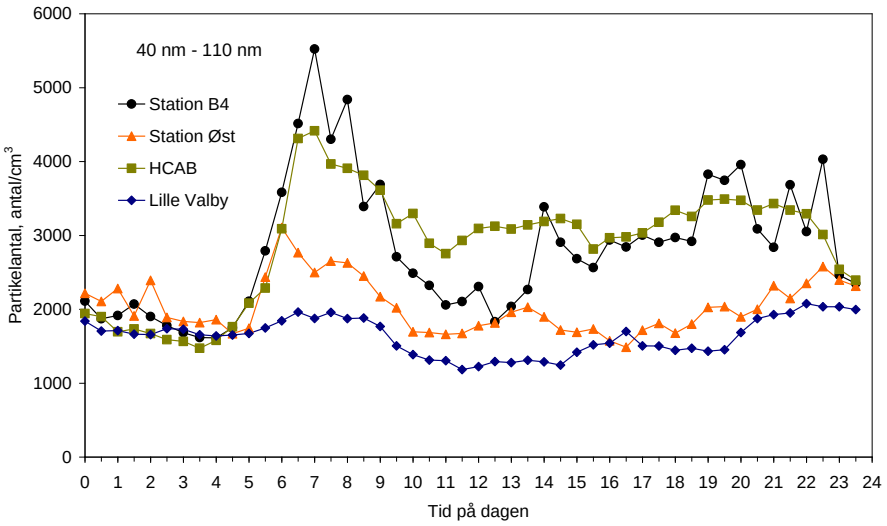


Figure 5. Average particle volume distributed on three size fractions measured at Station B4, Station East, street station HCAB and the regional background station at Lille Valby, Roskilde. The measurements were taken from 28.07.2010 to 30.09.2010.

As a first step to estimate, how many particles the employees at the places of handling are exposed to, we have looked at the 24-hour variation of the three size-fractions (Figure 6). Since the average 24-hour variation is only based on measurements from two months, there is a certain "noise" on the 24-hour variation, because of natural variation in the meteorological conditions.





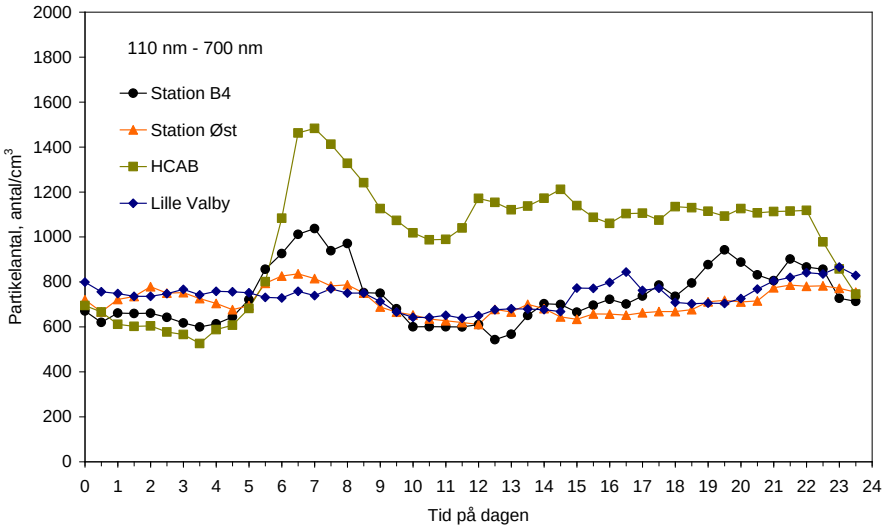


Figure 6. Average 24-hour variation for number og particles allocated to three particle sizes, measured at Station B4, Station East, street station HCAB and the regional background station at Lille Valby, Roskilde. The measurements were taken from 28.07.2010 to 30.09.2010. Note the difference on the y-axis of the three figures.

At Station B4 the particle number in the daytime was at an interval between 30.000 and 90.000 particles/cm^3, which was considerably higher than HCAB, where the daytime level was 5.000 to 10.000 particles/cm^3. Station East (5.000 – 20.000 particles/cm^3) was at little above the level of HCAB, whereas Lille Valby was the lowest with less than 5.000 particles/cm^3.

At Station B4 there was a marked 24-hour variation concerning the smallest size-fraction (6 - 40 nm), where particle number at night was similar to particle number at the background stations, whereas it at daytime ascended to 4-7 times the level at the background stations. The average 24-hour variation at Station B4 generally followed the expected 24-hour variation of number of flight operations at the airport. This underpins, that the great particle number in this size-fraction originates from the emissions at the apron. At Station East, the number of particles was much smaller, and there was a less distinct 24-hour variation.

Regarding the middle size-fraction (40 – 110 nm) the 24-hour variation at Station B4 also corresponded generally to the expected 24-hour variation in number of flight operations. The 24-hour variation at Station B4 was also very similar to the 24-hour variation at HCAB, but there was not a marked fall around dinnertime as at Station B4.

The largest size-fraction (110 – 700 nm) was at the same level and with hardly any 24-hour variation at Station B4, Station East and Lille Valby. But at Station B4 there was a top point about 50% higher in the morning than at night. The great similarity between the stations points at the fact, that a great amount of these particles come from the regional background, and that the particles mainly are long transported to the Copenhagen area. HCAB was distinctly above the three other stations. This is caused by traffic annoying particles from local sources (for example wear on road, tyres and brakes).

Literature studies

Several investigations of particle emissions from aircraft motors have been made. These have primarily focused on the effect of emissions on the free troposphere, where the flight traffic occurs. There have, however, also been investigations oriented toward the effect of the emissions on air quality at airports.

A number of the important results from these investigations will be outlined in the following:

- Fly jetmotors discharge a great number of particles. Herndon et al., (2005) and Mazaheri et al. (2009) measured emission index for number of particles (EI_n) of 3-50 x 10^{15} particles pr kilo fuel.

- EI_n depends on motor type and strain on motor. EI_n is highest during idle running (Herndon et al., 2005; Herndon et al., 2008; Mazaheri et al., 2009).

- Emissions are dominated by very small particles with a diameter from 10-40 nm (Mazaheri et al., 2008; Kinsey et al., 2010; Rogers et al., 2005).

- In the wake of smoke 80 m behind an aircraft in normal use during taxiing, was measured particle numbers (stated in dN/d(logD)) of about 1 x 10^6 particles/cm^3 for particles with a diameter of about 20 nm (Mazahari et al., 2009). (This way of stating particle numbers corresponds to Figure 3, which shows, that we - for particles with a 20 nm diameter - measured 70.000 particles/cm^3 as ½-hour average value).

Apart from these measurements, there are also studies, which characterize the physical and chemical characteristics of particles. For example Kinsey et al. (2010) have tested a number of different motor types and found, that 40-80% of the particle mass is composed of transient substances. This part of the literature study is not yet finished.

Preliminary conclusions

This report presents results of measurement of number and size-distribution of ultrafine particles at the apron of Copenhagen Airport, Kastrup. The measurements were made in the period from 28.07.2010 to 30.09.2010 at Gate B4 and at the eastern air quality monitoring station.

The measurements have shown, that the number of particles at the apron of Copenhagen Airport Kastrup is large, compared to H.C. Andersens Boulevard. In the measuring period the average number of particles was about 4.4 times higher at the apron (43.000 particles/cm^3) than at H.C. Andersens Boulevard (9.800 particles/cm^3), which is estimated to be one of the most air polluted streets in Copenhagen. The number of particles at the eastern air quality monitoring station (12.000 particles/cm^3) was about 28 % of the level measured at the front place, but was on the other hand 22 % higher than measured at H.C. Andersens Boulevard. The level at the apron was almost a factor 10 higher than measured at the regional background (Lille Valby, 4.600 particles/cm^3). The difference between number of particles at the apron and at the eastern air quality monitoring station is mainly due to emissions, concentrated at the apron, and a quick thinning out via mixture with the surrounding air.

The temporal and geographic variation in number of particles is big. The number of particles at the apron can, in ½-hour average value, be more than 500.000 partikler/cm^3 , whereas only up till 40.000 particles/cm^3 was measured at H.C. Andersens Boulevard.

Measurements of the particles' size-distribution have shown, that about 90 % of the particles at the apron are in the size-fraction from 6-40nm. About 8 % of the particles are in the size-fraction from 40-110 nm, and only 2 % lie in the size-fraction from 110-700 nm.

At the airport's apron the average 24-hour variation in number of particles from 6-40nm is great. At night the number of particles corresponds generally to the background level of about 5.000-10.000 particles/cm^3, whereas the average number in the daytime lies between 30.000 and 90.000 particles/cm^3. The average 24-hour variation corresponds generally to the expected 24-hour variation in flight operations at Copenhagen Airport, Kastrup.

According to literature studies, aircraft jetmotors discharge a great number of particles with a diameter less than 40 nm. In the wake of smoke from jetmotors was measured at great number of particles 80 m behind the motor, which was above the level, measured at the measurement station at the airport's apron.

Measurements and literature studies point out, that aircraft motors contribute considerably to the pollution with ultrafine particles as found at the apron. Until now the amount contributed by diesel vehicles has not yet been finally examined.

The measurements of number of ultrafine particles are not finished. Therefore, the above conclusions are provisional, based on the first two months' investigations.

Furthermore, we have not ended our work on assessing the chemical characteristics of the particles at the airport's apron. First of all, we are still conducting chemical measurements of organic air pollution at the apron. And secondly, the literature studies on the particles' chemical characteristics will be extended.

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