Investigations into the emission of fine and ultra-fine particles during laser printer operations

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1. Introduction

The current discussion surrounding fine dusts also raises the question of whether fine particles (particle diameters of between 0.1 and 10 micrometres (µm) – one micrometre is a thousandth of a millimetre) and ultra-fine dust particles (particle diameters of < 0.1 µm) are emitted into the surrounding indoor air during the operation of PC-based laser printers. The 'Test procedure for determining the emissions of hard copy machines' currently used for awarding the 'Blue angel' environmental label stipulates that the dust emissions rate be calculated using a gravimetric method, i.e. by weight. Following this procedure, a machine must not emit more than 4 milligrams (mg) of dust an hour during a standardised test and continuous printing operations. This gravimetric method of measurement is based on the statutory rulings for measurements in outdoor air. It does not however provide any information about the extent to which the printing process emits ultra-fine particles, since these have virtually no impact on the mass. Fine particles may however have health implications when present in large numbers. When evaluating impact, measuring the number of particles is perhaps more useful than calculating their mass.

The Federal Environmental Agency (FEA) has therefore measured random samples of the emissions (by quantity) of fine and ultra-fine particles emitted when using standard laser printers of various ages and origins. The measurements were taken in a test chamber and an office environment. The results of these measurements are described below. The results are only provided in a descriptive and comparative form. In this initial form, they do not provide information about the type and chemical composition of the particles or the health risk presented by the emitted particles. In other words, they do not state whether printer operations represent an additional health risk or not. This will need further and more intensive investigations under real conditions (printer operations in normal offices and living quarters, the influence of room size, air circulation, sinks, secondary sources in the room etc.) and an accurate analysis and evaluation of the risks involved.

2. Methodology

To date there have been no standardised rules on measuring concentrations of particle numbers for fine and ultra-fine particles from printers. The FEA has therefore broken new ground. On the basis of past experiences, the FEA selected a method that ensures that only the particles emitted by printing operations are measured (see 2.2). The printers were tested in a hermetically sealed test chamber so that any external factors such as fine dust from other sources in the indoor air were excluded.

2.1 Printers investigated

Printers were selected randomly depending on the availability of machines. They do not give a representative overview of the market. The FEA investigated several printers:

Printer (printer type)	Year of production	Speed of printing
A (laser)	1993	3 pages / min
B (laser)	1999	4 pages / min
C (laser)	2000	15 pages / min
D (laser)	2004	19 pages / min
E (laser)	2005 (straight from the factory)	21 pages / min
F (laser)	2005 (virtually new, had printed around 1000 pages)	28 pages / min
G (laser)	2005 (virtually new, had printed around 1000 pages)	16 pages / min
H (inkjet)	2000	3 pages / min

The speed of printing was established during the tests. All printers, with the exception of printer H, are monochrome laser printers. Printer G also prints in colour. Printer H, an inkjet printer, was tested for comparison. All the printers were tested in a test chamber. Printer E was also tested in a normal office.

2.2 Measurement procedures

The following measurement procedures were used:

Object measured	Device	Measurement range	Volumetric flow
Fine particles (FP)	API Aerosizer	0.1 – 10	2.5 l / min
Ultra-fine particles (UFP)	GRIMM SMPS+C	5 – 350 nm	0.3 l / min

The API Aerosizer is an optical particle counter which classifies particles by their aerodynamic diameter. The measurement range covers particle sizes between 0.1 µm and around 10 µm. The GRIMM SMPS+C[1] device classifies the particles by their electric mobility and measures particle core sizes of between around 5-350 nm (nanometers, i.e. a millionth of a millimetre). Both devices were set to a measuring time interval of 230 seconds in order to record complete particle size distribution. This measuring time interval was short enough to be able to distinguish between the various printer operating statuses, such as idling, printing and after-running.

[1] The GRIMM SMPS+C device used here was selected from a range of devices for measuring ultra-fine particles during the evaluation of comparative measurements in December 2004 (IfT, Leipzig). It was selected as the standard system due to the fact that it correlated very well with a reference device.

The test chamber (glass cube) is 1 cubic metre in size, is not air-conditioned and has no enforced aeration (and no internal ventilation). To compensate for the air samples removed, totalling around 180 litres an hour (l/h), cleaned air from outside was supplied to the test chamber through an HEPA filter (High Efficiency Particulate Air), at a rate which replaced 1/5th of the air every hour. Each of the samples of air were taken from around 30 cm above the printer's paper output.

2.3 Test process

The day before testing, each of the printers were placed in the test chamber and fully connected up so that a sufficiently low concentration of particles could be produced before testing. The printers could be controlled remotely, allowing them to be switched on and to transfer print commands without the chamber having to be opened up again. This procedure was necessary because the method used to measure the number of particles was very sensitive to disturbance and this was therefore the only way in which the particle emissions from the test specimens could be recorded.

White IGEPA Recycling Copy, 80 g/m² DIN-A4, ‘Blue Angel’-certified paper was used. Depending on the printer capacity, 30 or 50 pages were printed as either ‘full’ or ‘empty’. The ‘full’ pages were Excel spreadsheets covering the entire page where all the spreadsheet cells were full of text (sequences of figures 0 to 9), Arial 10, normal font (monochrome print).

Particle measurements during colour printing were also taken using printer G. The print template was the same template document used for Blue Angel testing of hardcopy machines (RAL-UZ 114).

The idea behind printing ‘empty’ and ‘full’ pages separately was to distinguish between particle emissions from paper alone (paper dust) and additional particle emissions when using the toner.

After each printing process, the fall in particle concentration was measured . A complete measurement cycle lasted a total of around 6 to 7 hours. Each printer was investigated between 3 and 7 times using this pattern.

Printer E was also tested 3 times in an office under normal room usage conditions. Here too, the sample of air was taken from around 30 cm above the paper output.

3. Results and discussion

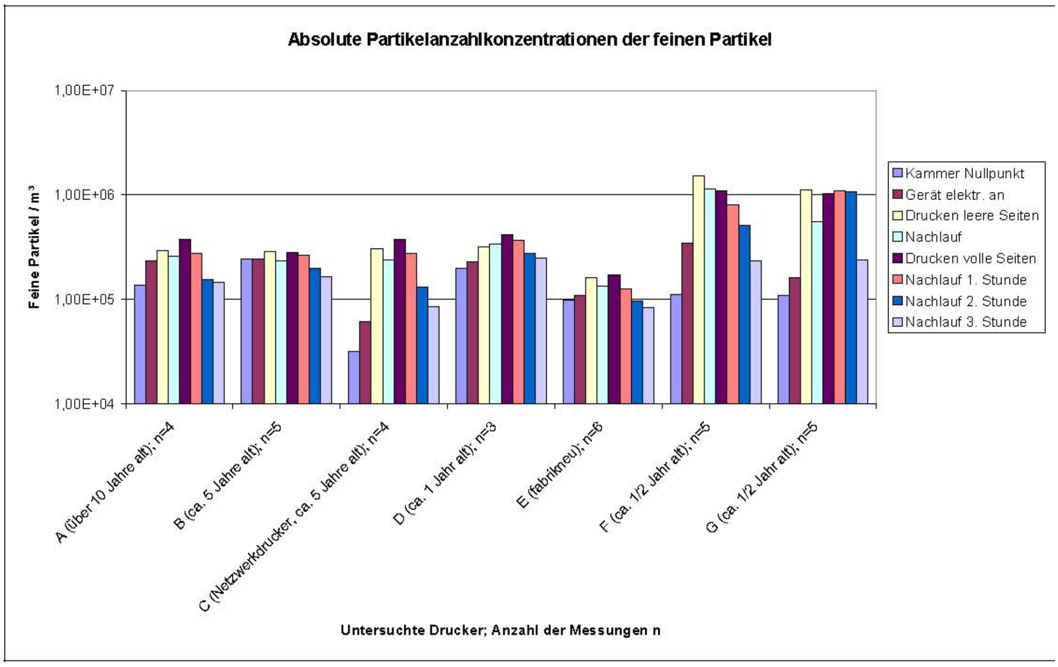
The measurement results of the concentrations of particle numbers are given below, split as follows: a) for all fine particles (here: 0.1 to 10 µm) and b) for the fraction of ultra-fine particles (here: 5 to 350 nm) because different emissions levels were found for the two ranges of particle size.

3.1 Fine particles

Figure 1 provides an overview of the emissions of fine particles. The absolute particle concentrations are given in particles per cubic metre (m³) for the printers investigated. The results are split into the individual stages of the measurement cycles. The concentrations of particle numbers for the individual repeat tests (n = 3-7) were also calculated. The first bar (the one on the left in each case) shows the initial concentration in the test chamber before the tests started (‘chamber datum point’). Depending on printer type, the levels rise from these initial concentrations in bands ranging from ‘slight’ to around 13-fold. For some printers, no difference could be seen between printing ‘empty’ and ‘full’ pages. The relative increase in particle emissions when printing ‘full’ pages was between 20 and 30 % compared with printing ‘empty’ pages (relative standard variance of around 20 to 30 %). This means that the fine dust emissions when printing ‘full’ pages do not rise significantly in comparison with those produced when printing ‘empty’ pages.

The maximum particle size of the fine particles in all measurements was around 1 (see Fig. 2). The concentrations of particle mass can also be calculated using this measured distribution of particle size. At an assumed particle density of 1 gram per cubic metre (g/cm^3), converting the concentrations of particle numbers into the concentrations of particle mass produced a figure of 0.1 microgram/m^3 and therefore only a very slight additional concentration of dust in indoor air as a result of the printing process.

Fig.1: Absolute particle emissions (fine particles) for the individual measurement programme parts of the measurement cycles (test chamber measurements)



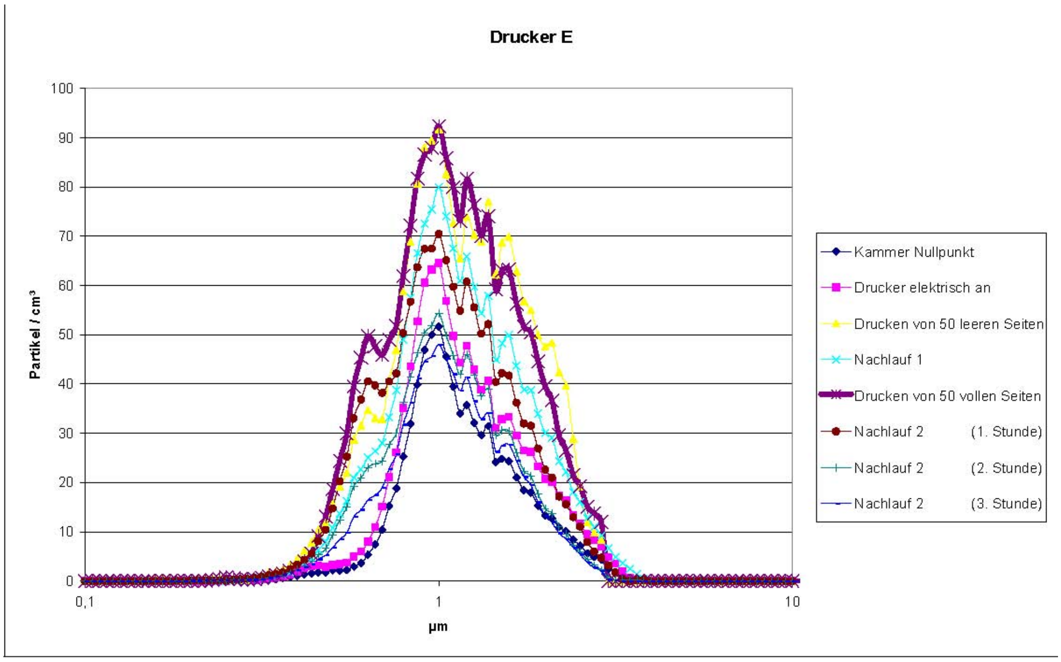
Absolute concentrations of particle numbers for fine particles

Left side	***Right side (from up to down)***	***Underneath (from left to right)***
Fine particles/m^3	***Chamber datum point***	***A (more than 10 years old); n=4***
	Device elec. power supply on	***B (approx. 5 years old); n=5***
	Printing empty pages	***C (netwk. printer, ap. 5 years old) n=4***
	After-running	***D (approx. 1 year old); n=3***
	Printing full pages	***E (new from factory); n=6***
	After-running, 1st hour	***F (approx. ½ year old); n=5***
	After-running, 2nd hour	***G (approx. ½ year old); n=5***
	After-running, 3rd hour	

Printers investigated; number of measurements n

Source: Federal Environment Agency

Fig. 2: Typical particle size distributions (fine particles) for the individual measurement programme parts for printer E (test chamber measurements)



Printer E

Left side
Particles/cm3

Right side (from up to down)
Chamber datum point
Device elec. power supply on
Printing 50 empty pages
After-running 1
Printing 50 full pages
After-running 2, (1st hour)
After-running 2, (2nd hour)
After-running 2, (3rd hour)

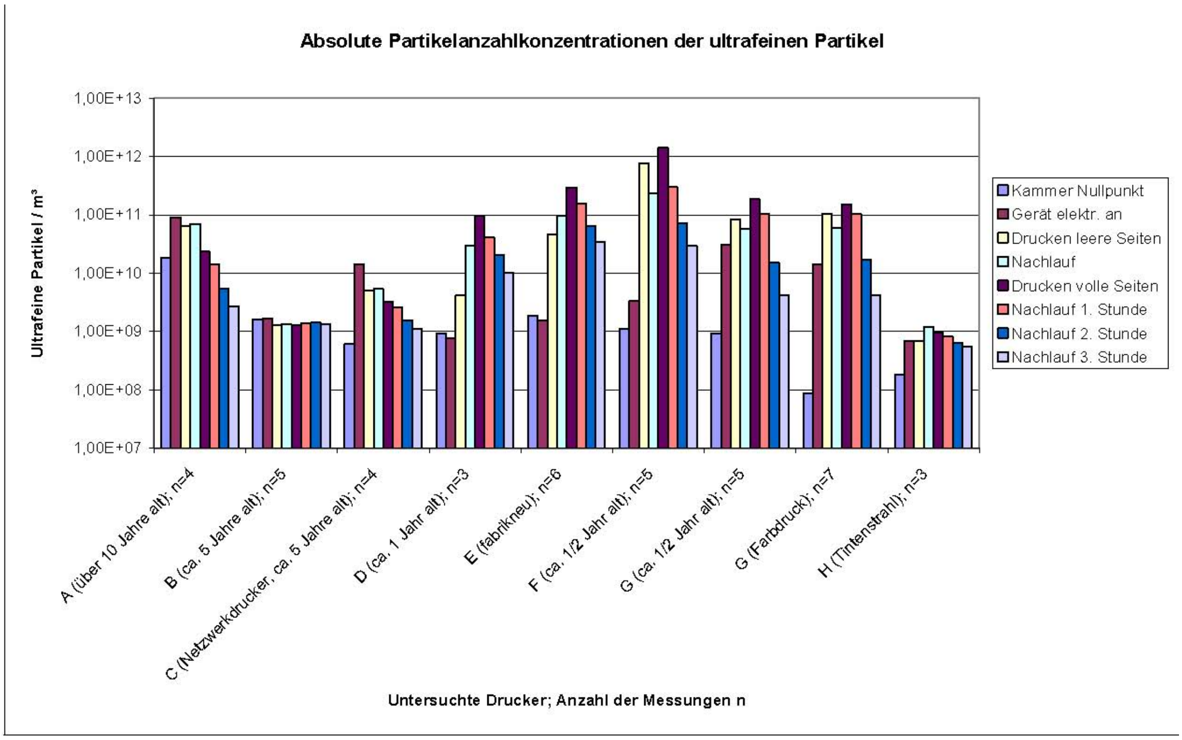
underneath
µm

Source: Federal Environment Agency

3.2 Ultra-fine particles

Figure 3 provides an overview of the absolute concentrations of particle numbers for ultra-fine particles (for our purposes: range of particle sizes of between 5 and 350 nm). The concentrations of particle numbers are given in particles/m³ for the printers investigated. The results are split into the individual stages of the measurement cycles. The concentrations of particle numbers for the individual repeat tests (n = 3-7) were calculated.

Fig. 3: Absolute particle emissions (ultra-fine particles) for the individual measurement programme parts of the measurement cycles (test chamber measurements)



Absolute concentrations of particle numbers for ultra-fine particles

Left side
Ultra-fine particles/m³
Right side (from up to down)
Chamber datum point
Device elec. power supply on
Printing empty pages
After-running
Printing full pages
After-running, 1st hour
After-running, 2nd hour
After-running, 3rd hour

Underneath (from left to right)
A (more than 10 years old); n=4
B (approx. 5 years old); n=5
C (network printer, approx. 5 years old); n=4
D (approx. 1 year old); n=3
E (new from factory); n=6
F (approx. ½ year old); n=5
G (approx. ½ year old); n=5
G (colour print); n=7
H (inkjet); n=3

Printers investigated; number of measurements n

Source: Federal Environment Agency

For some printers, it can be seen that even starting up the printer causes the emission of ultra-fine particles to rise to such high levels that no additional increases in concentration can be measured in the subsequent measurement cycle. This could be explained by deposits in the machine, for example, because particles are emitted to the ambient air when heating up and starting up the fan.

To allow a better comparison to be made between the printer results, in Figure 4 the number of particles when printing ‘empty’ pages was set to ‘1’ and the ratio of particle concentrations shown in comparison with printing ‘empty’ pages.

Abb. 4: Verhältnis der Partikelzahlkonzentrationen (Ultrafeine Partikel) der verschiedenen Betriebszustände zur Zahlkonzentration beim Druck leerer Seiten

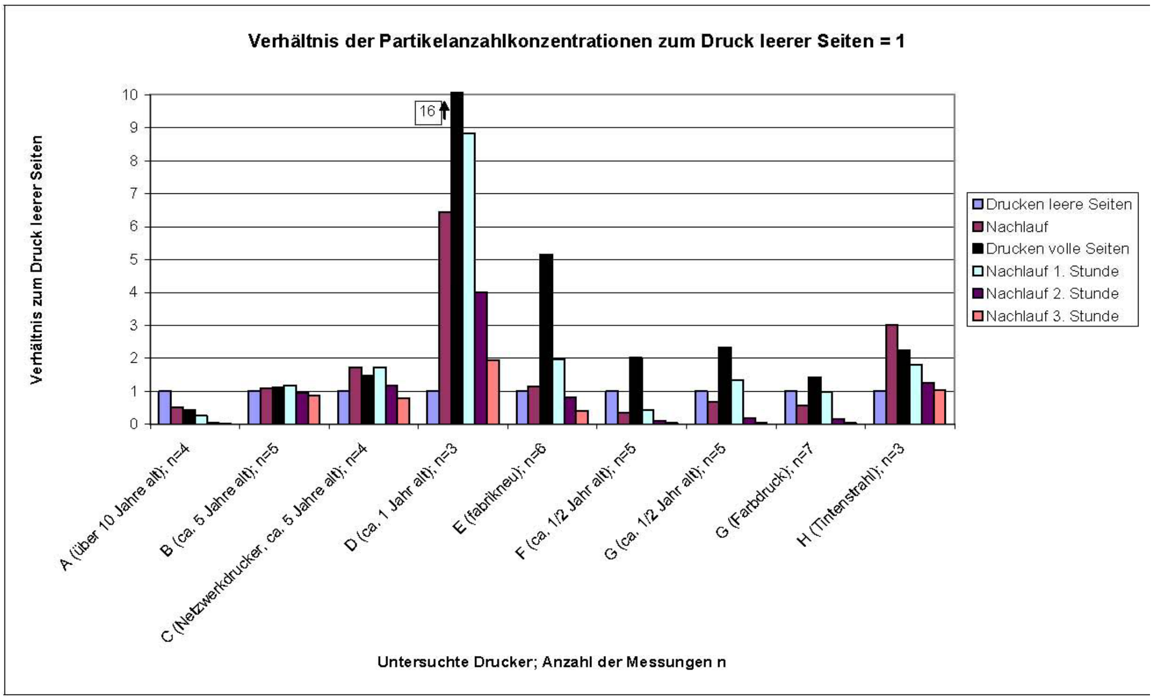


Fig. 4: Ratio of concentrations of particle numbers (ultra-fine particles) of the various operating modes to the concentration of numbers when printing empty pages

Ratio of concentrations of particle numbers to printing empty pages = 1

Left side
Ratio to printing empty pages

Right side (from up to down)
Printing empty pages
After-running
Printing full pages
After-running, 1st hour
After-running, 2nd hour
After-running, 3rd hour

Underneath (from left to right)
A (more than 10 years old); n=4
B (approx. 5 years old); n=5
C (netwk. printer, ap. 5 years old); n=4
D (approx. 1 year old); n=3
E (new from factory); n=6
F (approx. ½ year old); n=5
G (approx. ½ year old); n=5
G (colour printer); n=7
H (inkjet); n=3

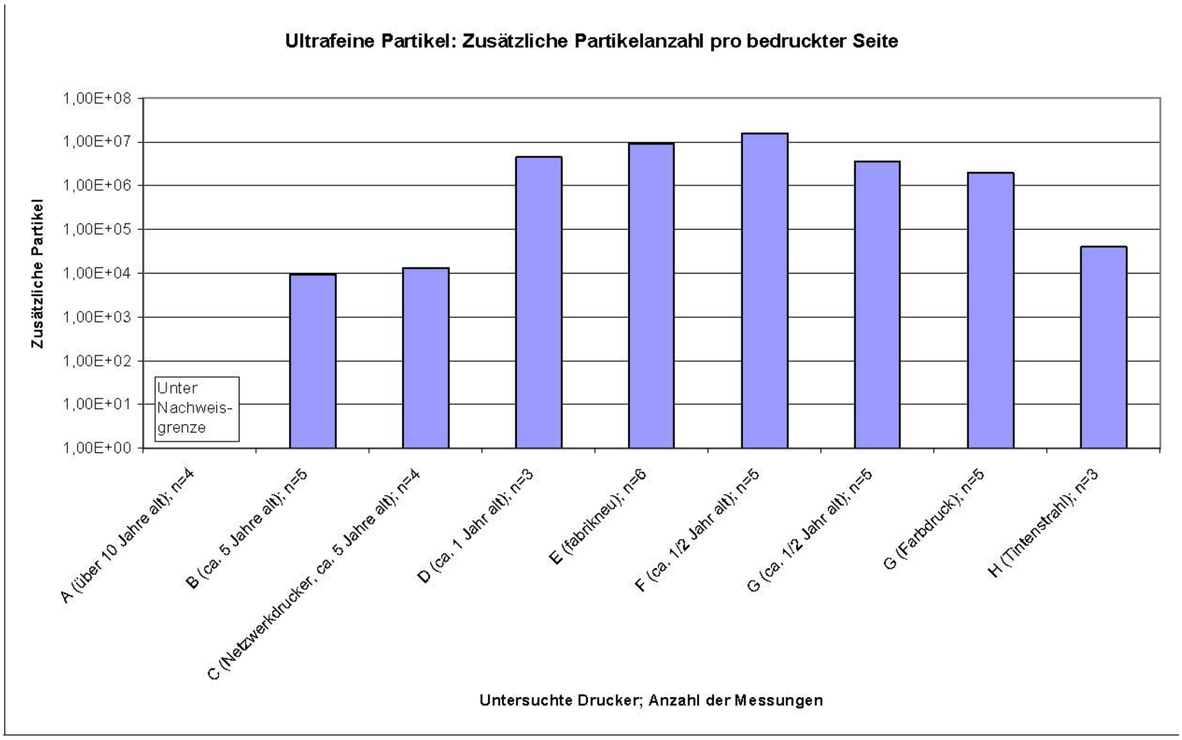
Printers investigated; number of measurements n

Source: Federal Environment Agency

From this diagram we can see that when printing full pages, the concentrations of particle numbers for some printers rise when compared with printing empty pages. However, this increase varies greatly. Differences in total fine dust levels also result (see 3.1).

In order to take account of the influence of different speeds of printing, the concentrations of particle numbers measured when printing the full pages was converted and related to printing *one* page. The result can be seen in Figure 5.

Fig. 5: Number of particles in the test chamber air when printing full pages – converted to the same printing output (1 page)



Ultra-fine particles: additional number of particles per printed page

Left side
Additional particles

Underneath (from left to right)
Minimum detection limit

A (more than 10 years old); n=4
B (approx. 5 years old); n=5
C (network printer, approx. 5 years old); n=4
D (approx. 1 year old); n=3
E (new from factory); n=6
F (approx. ½ year old); n=5
G (approx. ½ year old); n=5
G (colour printer); n=5
H (inkjet); n=3

Printers investigated; number of measurements

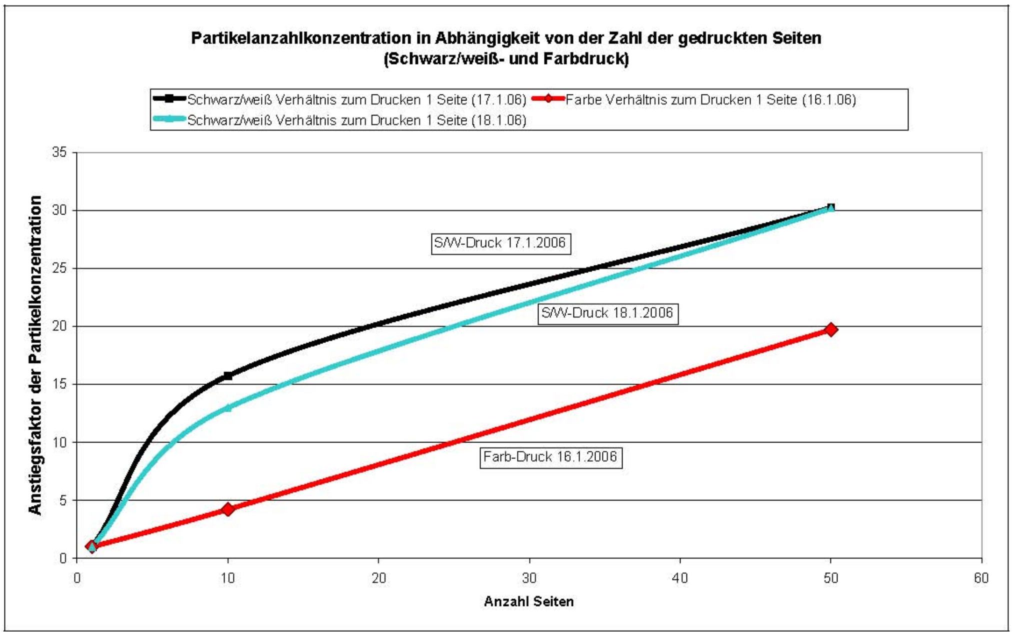
Source: Federal Environment Agency

The individual printers have different results in this respect too. The emissions of the new machines (D, E, F and G) are not lower than those of the older machines. On the contrary, printer F had the most significant increases in particle numbers of all the machines. In terms of printing one page, the inkjet printer H emits considerably fewer ultra-fine particles than newer laser printers.

1, 10 and 50 full pages were printed with printer G to determine the possible influence of the number of pages printed. Figure 6 shows the result of two tests using pages printed in monochrome and one test using colour printing.

When colour printing, there may be a linear relationship between the number of pages printed and the concentrations of particle numbers. Monochrome printing demonstrates a non-linear relationship. The different thermal characteristics of the printing system perhaps explain this, but this factor could not be investigated further during these tests.

Fig. 6: Dependence of concentrations of particle numbers on the number of pages printed (printer G); factor of increase as an indication of the increase in concentrations of particle numbers



Concentrations of particle numbers depending on the number of pages printed (monochrome and colour printing)

Monochrome ratio to printing 1 page *Colour ratio to printing 1 page*

Monochrome ratio to printing 1 page

Monochrome printing
Monochrome printing
Colour printing

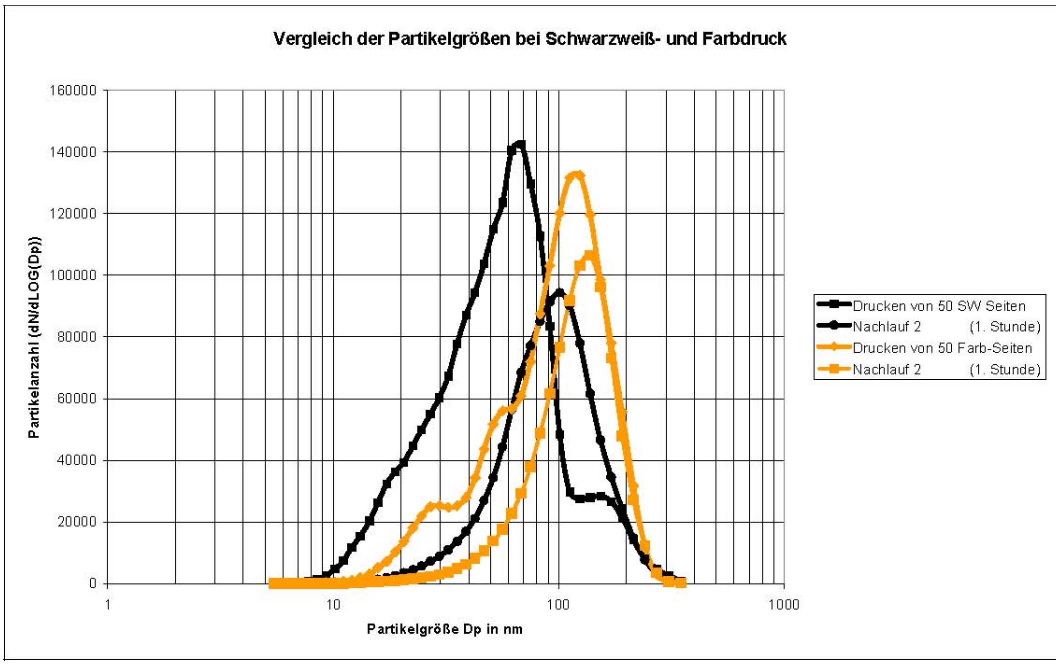
Left side
Increase factor of concentration of particle numbers

underneath
Number of pages

Source: Federal Environment Agency

A difference between monochrome printing and colour printing can also be seen in the ranges of particle sizes. Figure 7 shows that the maximum particle size for colour printing is around 110 nm, while the figure for monochrome printing is around 65 nm. A different chemical composition of the particles, which we were not able to investigate in any more detail in this study, may be an influencing factor here.

Fig. 7: Comparison of ranges of particle size during monochrome and colour printing (printer G)



Comparison of particle sizes for monochrome and colour printing

Left side
Number of particles

Right side (from up to down)
Printing 50 monochrome pages
After-running 2 (1st hour)
Printing 50 colour pages
After-running 2 (1st hour)

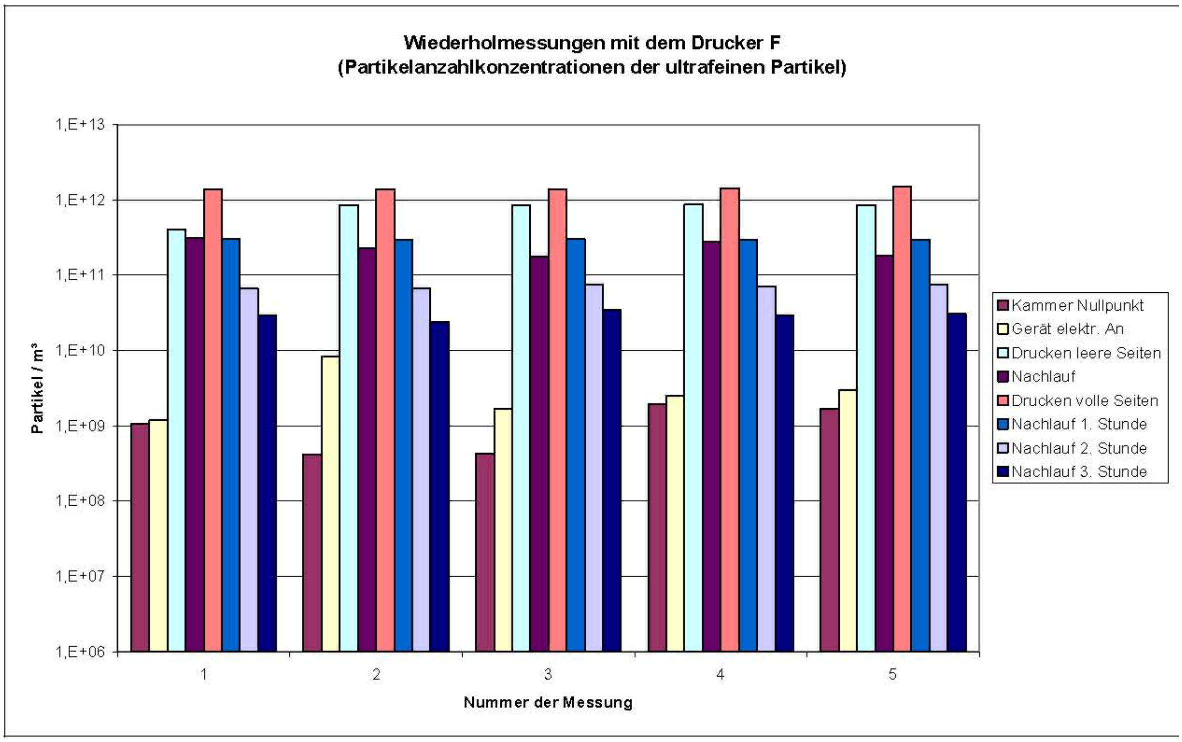
Particle size Dp in mm

Source: Federal Environment Agency

However, in both cases the same situation applies whereby, during the after-run period, the ranges of particle sizes move towards the larger particles. This allows us to conclude that the particles are agglomerating (concentrating).

The issue of reproducibility of measurements is considered taking the example of printer F (see Fig. 8). Five measurements taken on different days show a good correlation between repetitions of the test. Similar results can be seen for the other printers. A sufficient degree of reproducibility can therefore be assumed.

Fig. 8: Reproducibility of measurements taking the example of printer F (test chamber measurements)



Repeat measurements with printer F
(concentrations of particle numbers for ultra-fine particles)

Left side
Particles/m³

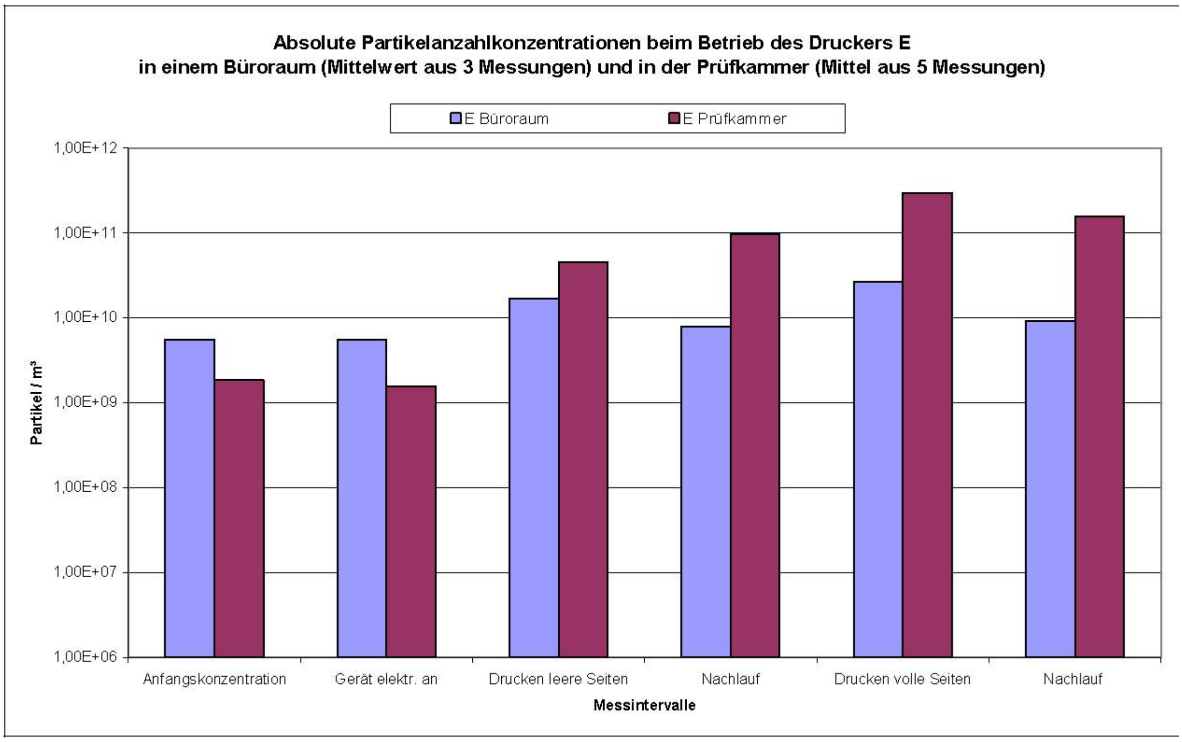
Right side (from up to down)
Chamber datum point
Device elec. power supply on
Printing empty pages
After-running
Printing full pages
After-running, 1st hour
After-running, 2nd hour
After-running, 3rd hour

underneath
Number of measurement

Source: Federal Environment Agency

The measurements taken on printer E in an office environment show that the concentrations of particle numbers when printing are lower than those obtained in the test chamber measurements (see Fig. 9). This can be attributed to the effect of dilution in a larger and moving volume of air. However, here we can also note increases in the particle numbers in comparison with background loads.

Fig. 9: Absolute concentrations of particle numbers for ultra-fine particles during measurements with printer E in an office; the measurements obtained in the test chamber are shown by way of comparison



Absolute concentrations of particle numbers when using printer E
in an office (mean value from 3 measurements) and in the test chamber (mean of 5 measurements)

E office ***E test chamber***

Left side
Fine particles/m³

Underneath (from left to right)
Initial concentration
Device elec. power supply on
Printing empty pages
After-running
Printing full pages
After-running

Measurement intervals

Source: Federal Environment Agency

4. Summary

The investigations have shown that using laser printers may result in the emission of fine and ultra-fine particles. The levels of particle emission differ greatly. The results vary depending on machine manufacturer and machine age. Newer machine types do not necessarily achieve better results than older ones. Quite the opposite is true: in some cases, a higher emission of ultra-fine particles was found with newer machines than with older machines (in terms of year of manufacture and amount of use). It is conceivable that the thermal processes in new machines are designed differently from those in older printers. The higher emission levels perhaps resulted from the higher printing speeds often experienced with new machines and different types of toner composition.

We know that the thermal process probably generates ultra-fine particles from the fact that some older machines start to emit particles as soon as they are switched on. In some cases, these levels were so high that the emissions from subsequent printing processes were of very little significance. However, this also varied from printer to printer.

Increases in concentrations of particle numbers could also be seen in printing processes and it should be noted that these increases differed greatly between the different printer types. The inkjet printer (H) investigated for comparative purposes also showed an increase in concentrations of particle numbers during the printing process. This figure was however smaller than those of the laser printers.

Since the FEA was only able to investigate a limited number of printer models and since the number of tests per machine was also limited due to capacity (max. 7 repeat tests per machine), the results initially only relate to the printers investigated and can only be generalised in the form of the opening statement of this section (printed in bold).

The tests were undertaken in a test chamber because this was the only way of achieving standardised comparative measurements. In reality, the printers are however used in considerably larger offices and working spaces. Sink effects, such as particles being absorbed by plants, room sizes, air circulation etc. also affect the level of the concentrations of particle numbers. However, the concentrations of particle numbers still increased during the tests in an office environment. The core statement therefore also applies under real conditions.

The results do not provide any information on possible health risks caused by the particle emissions. In terms of mass, the particle emissions are low.
To more accurately gauge the health risk, a pilot project organised by the Federal Institute for Risk Assessment with the involvement of the Federal Environmental Agency is currently being carried out at the University of Giessen by the chair of interior and environmental toxicology (Prof. Mersch-Sundermann). The results of this FEA study were taken into account in the planning of the project.

Investigations into particle emissions from office printers are also currently been undertaken by the Federal Institute for Materials Research and Testing as part of a research project conducted on behalf of the Federal Environmental Agency.