Measuring particle emissions in and from a polish cattle house

T. Hinz[1], S. Linke[1], P. Bittner[1], J. Karlowski[2], and T. Kolodziejczyk[2]

Abstract

After ammonia PM comes more and more in the focus of international strategies of air pollution control. Additional PM is a factor of air quality inside the buildings related to health and welfare of farmers and animals.

One of the main sources are livestock houses of poultry and minor pigs and cattle. Annual emissions will be calculated from activity data (animal places or numbers) and emission factors. These emission factors must be determined by measurements. In contrast to ammonia there are no models available to determine particle emissions.

Effects of particles on individuals and the dispersion of particles in the ambient air strongly depend on the size that means ultimately the mass of the single particles. Various fractions are defined by different definitions. The paper gives the most important definitions and procedures how to measure particles in a size selective way.

In a project of bilateral German-Polish cooperation in agricultural research, measurements in a dairy house were carried out in summer and winter 2006. Flow rates and PM concentration were measured inside the houses and in the exhaust of a force ventilated stable.

Concentration of TSP (total dust) was below 0.6 mg/m³ with higher values in summer than in winter, whereby measures inside the stable were higher than in the exhaust flow. Emissions consist of 100 % PM10.

One aim of the studies was to give an improvement of emission factors used in emission inventory, but this spot measurements will give only the impression that dependent on the management these factors may be lower than the usually used.

Keywords: dairy cattle, PM, emissions, emission factors, air quality

Introduction

There is an increasing need to control emissions of particulate matter (PM). Agriculture is a substantial source of PM emissions. PM also reduces the air quality within livestock buildings with implications for the health and welfare of farmers and animals. Effects of particles on individuals and their dispersion in the air depend on different parameters but strongly on their size and mass. Different target–oriented definitions are used (ISO 1996, US EPA2001), figure 1.

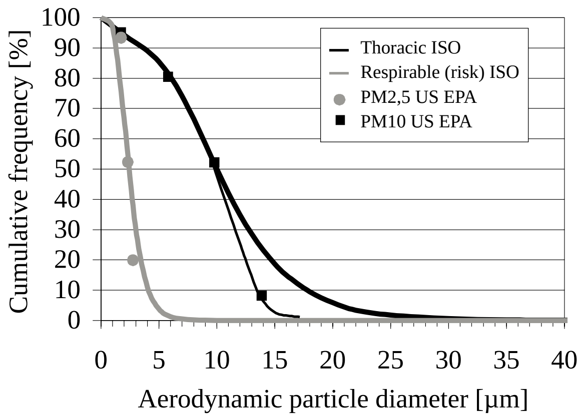

Figure 1:

Definitions of particle fractions

In a bilateral German- Polish research projects, measurements were carried out in force-ventilated building housing dairy cows. Concentration of total dust (TSP) and the PM10-fractions inside the house and the air flows through the exhaust ducts were measured and emission factors calculated. These values may be useful to estimate the size of emissions and the influencing parameters.

Materials and Methods

Investigations were done on a dairy farm in the Konin region of Poland. 64 cows with an average milk yield of 9200 kg milk per year and cow were kept in a building of 46.25m • 12 m equipped with four temperature controlled axial fans with a nominal maximum flow of 5950 m^3/h each. Figure 2 shows the floor plan of the stable and the locations of the fans in the roof.

[1] Institute for Technology and Biosystems Engineering, Federal Agricultural Research Centre, Braunschweig, Germany

[2] Institute for Buildings Mechanisation and Electrification of Agriculture, Poznan, Poland

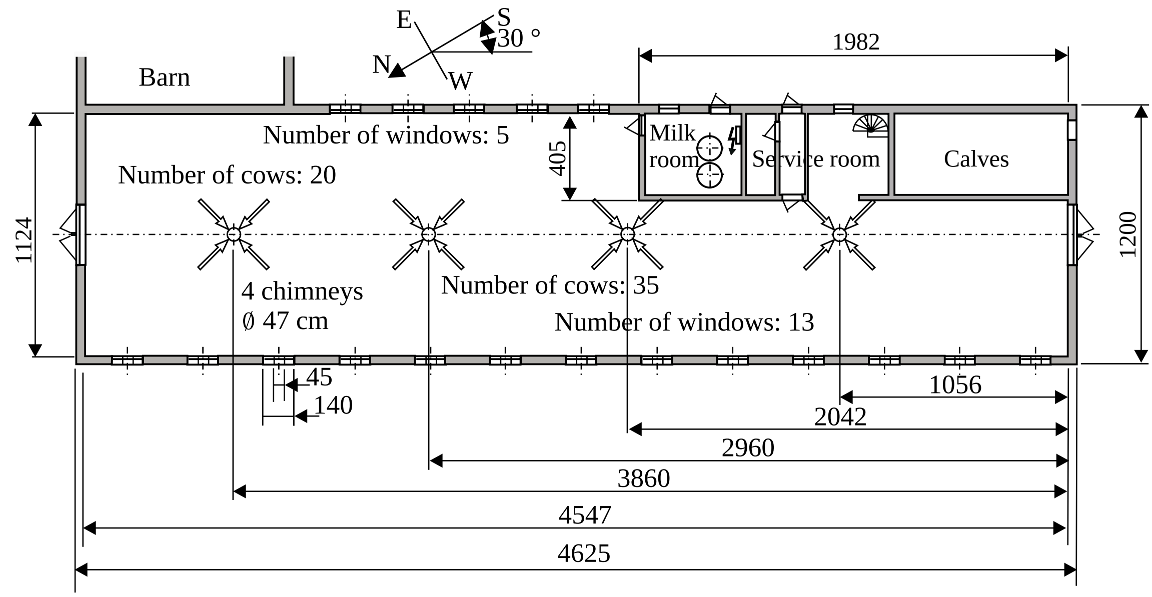

Figure 2:
Floor plan of the cattle house with exhaust openings location

There was a passage in the corridor used for forage distribution. On both sides of it were forage tables and two rows of chained cows' boxes with straw bedding. Straw manure is removed by mechanical grabbers of an electrically-powered machine once a day.

Fresh air entered the cow house through windows with variable openings. The degree of declination of the windows was adjusted manually upon evaluation of atmospheric conditions as given in figure 3.

Measuring particle emissions from force ventilated stables requires isokinetic sampling in the duct to get the

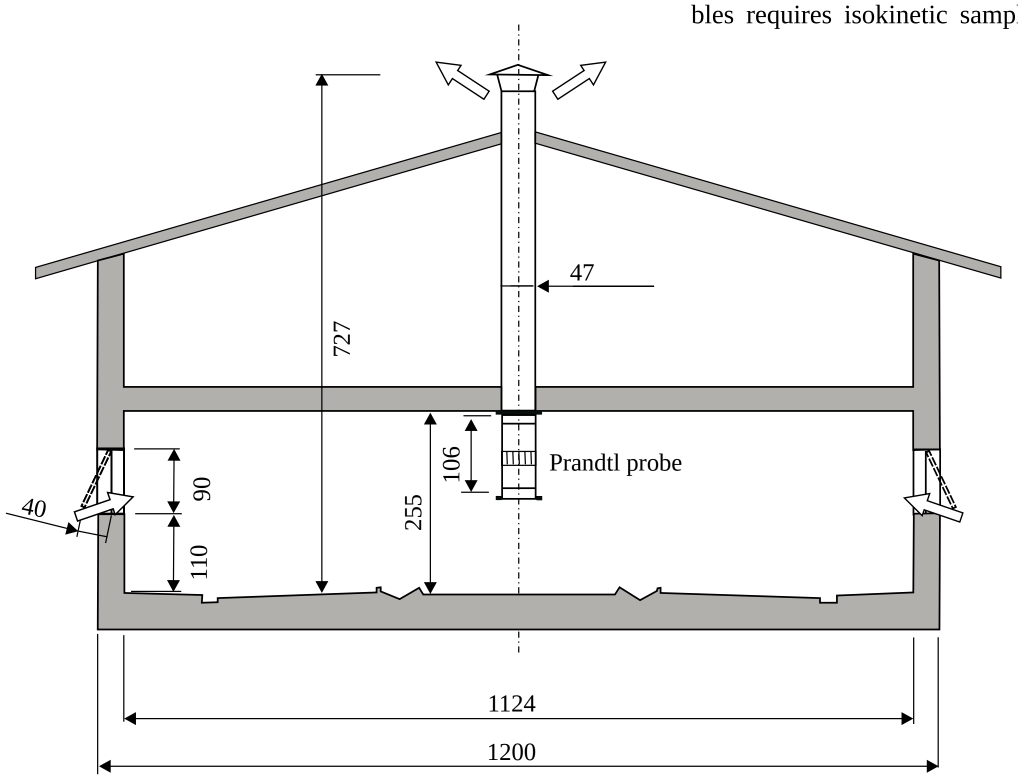

Figure 3:
Cross section of the cattle house

representative information about particle mass concentration in the balance area; figure 4 (Hinz T. 2005).

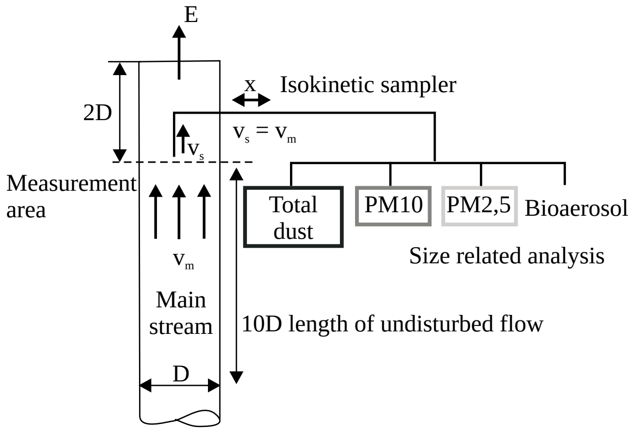

Figure 4:
Scheme of isokinetic sampling

To ensure the isokinetic condition at each measuring location, flow velocity was monitored using a hot wire anemometer.

To asses the emissions actual flow rates through all the ducts must be known. It was not possible to do so during the measuring campaign. Pre- investigations were carried out to get knowledge about flow distribution in the four ducts. For this purpose air velocity profiles were measured using a Prandtl-probe. The measuring positions inside a duct, which were also basically used to arrange the PM sampler, are given in figure 5.

At eight positions in two cross sections each grid measurements of air veloctiy were used to calculate average air flow rates and to calibrate voltage control of the ventilation system.

Samples inside the buildings were collected with a sampling velocity of 1.25 m/s according to the conditions at working place.

In both cases inside the stable and in exhaust a conventional gravimetric filter procedure served as reference of total dust. To determine the complete size distribution a high-volume sampler was used with a pre-separator to separate large particles. The coarse fraction was analysed with light diffraction method. A scattering light monitor was installed in the flow behind the cyclone separator in order to determine the passing through of fine particles. For control and calibration purposes an absolute filter collected the fine particle fraction. Figure 6 shows the complete ensemble of inside measurements.

Figure 6:
Set of instruments to measure concentration and particle size inside the stable

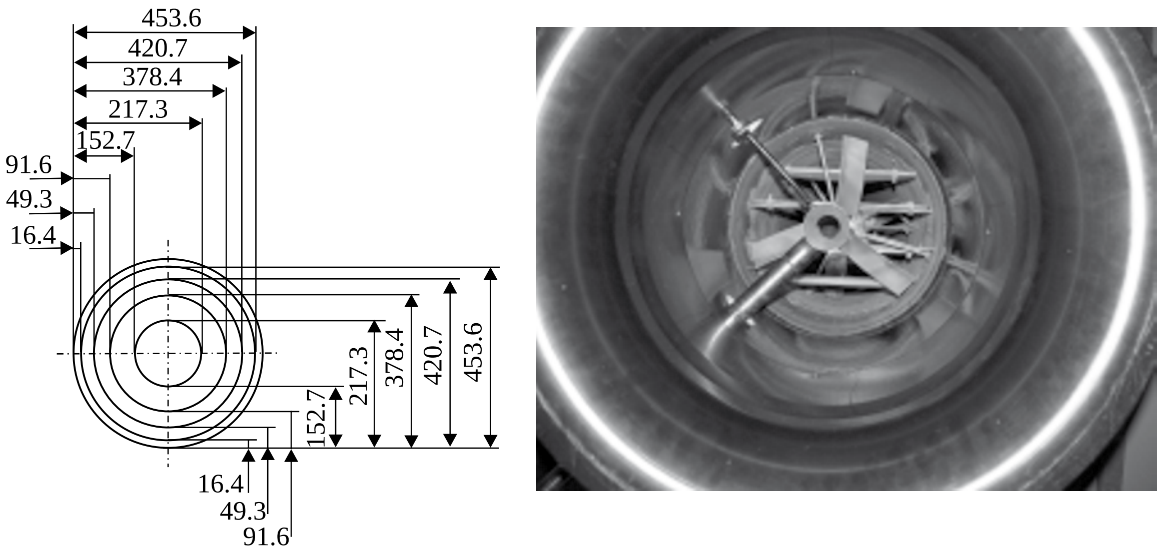

Figure 5:
Array of measuring locations to calculate exhaust air flow

Results and Discussion

Results will be presented for the pre- investigations to calibrate the ventilation system, the air flow rates and the measurements of concentration and particle size inside the stable in comparison with the emissions.

Monitoring of air flow rate in the ventilation system has been replaced by monitoring of the supplying voltage of the fans after previous assessment of air flow in each chimney separately. The sum of capacities of all four chimneys represents total running capacity of the ventilation system that is a function of supplying voltage delivered by the speed controller.

Table 1.
Air flow through the chimneys as a function of supplying voltage

Fan	Flow rate	Supplying voltage [V]								
		70	90	110	130	150	170	190	210	230
K-1	[m^3/h]	1 858	1 768	2 358	2 537	2 865	3 353	3 459	3 213	3 279
K-2	[m^3/h]	1 440	1 745	2 256	2 565	2 787	3 096	3 291	3 412	3 478
K-3	[m^3/h]	1 290	1 624	2 167	2 524	2 742	2 893	3 039	3 204	3 342
K-4	[m^3/h]	1 628	1 823	2 260	2 518	2 756	2 967	3 099	3 205	3 302
Total	**[m^3/h]**	**6 217**	**6 960**	**9 041**	**10 144**	**11 150**	**12 308**	**12 888**	**13 034**	**13 402**

Total performance of the ventilation system is shown in the diagram below, figure 7.

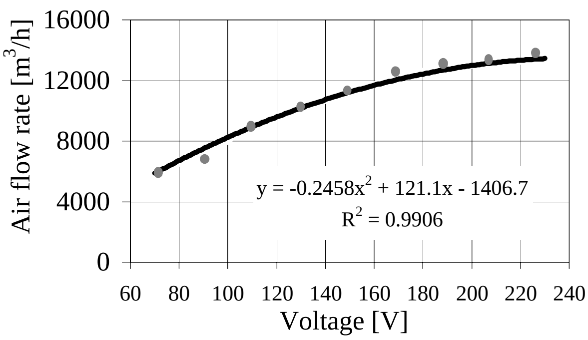

Figure 7:
Calibration of the ventilation control, total air flow rate of the 4 fans

Thus performance of the ventilation system is presented by the equation:

$$V = -0.246 \cdot U^2 + 121.1 \cdot U - 1406.7 \qquad [m^3\ h^{-1}]$$

The coefficient of determination R^2 = 0.9906 is sufficient. The function was used in further calculations for estimating the air exchange in the stable.

From March 2006 to 2007 the ventilation rate changed between approximately 8000 m^3/h and 12000 m^3/h measured in the hot July 2006. The columns of figure 8 give the course of the year.

The investigations in dust concentration and dust emissions were carried in July and November 2006. Figure 9 shows the measured airflows for the respective days, which do not differ widely from the monthly averages.

In July the air exchange raised up to approximately 11000 m^3/h while in November an average of 9000 m^3/h was measured caused by the lower temperature.

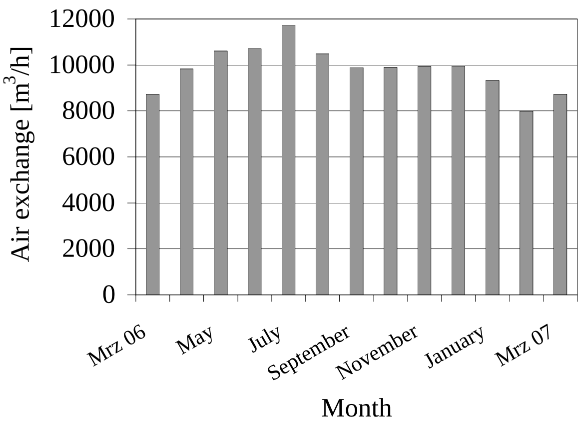

Figure 8:
Air exchange in the cow stable in the period from March 2006 until March 2007

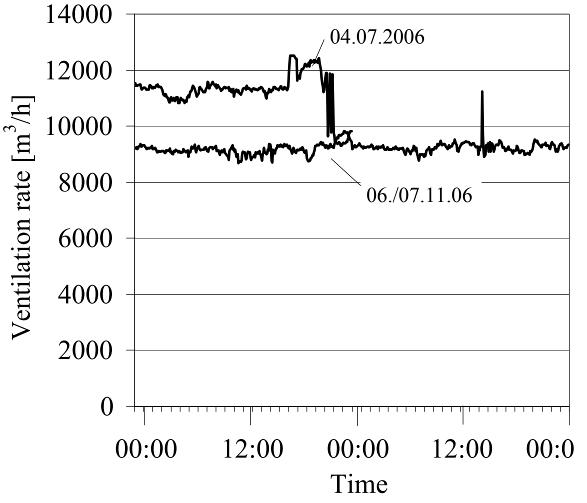

Figure 9:
Air exchange in the cow stable at 04.07.2006 and 06./07.11.2006

The concerned concentration of total dust (TSP) inside the stable, in the exhaust and the resulting emissions of TSP and PM10 are given in table 2.

Table 2:
Concentration and emissions in and from the stables

Type of animal / season / litter	C_{inside} [mg/m³]	$C_{exhaust}$ [mg/m³]	M_{TSP} [g/(animal/h)]	M_{PM10} [g/(animal/h)]
cow / summer / straw	0.550	0.188	0.033	n.a.
cow / winter / straw	0.198	0.064	0.009	0.008

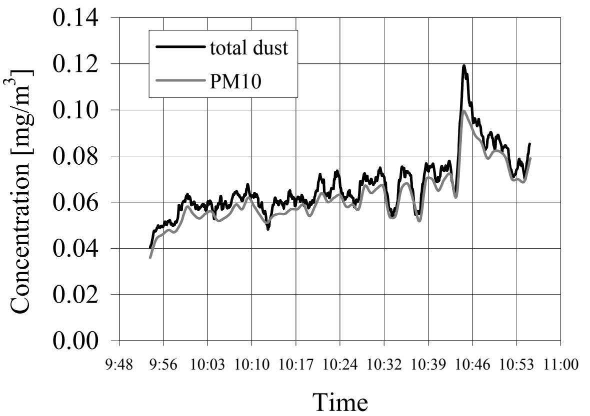

Figure 10:
TSP and PM10 concentration in the exhaust flow

In the cow stable the concentration was generally low with values <1 mg/m³. Depending on the climate conditions PM concentration and emissions were lower in November than in June. In both cases the concentration inside the stable at 1.5 m above ground was 3 times higher than the concentration in the exhaust flow.

Particle size distribution and with this the ratio of PM10 differ essentially between the air inside the stable and the exhaust flow, figure 10 and figure 11.

PM emissions consist of the fraction PM10 only. In contrast to this TSP concentration inside the building was much higher than for PM10, figure 11.

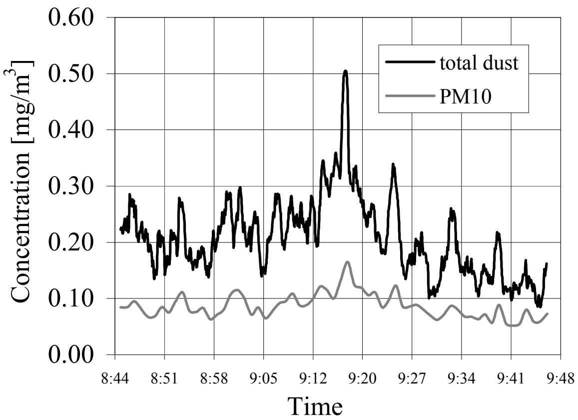

Figure 11:
TSP and PM10 concentration inside the stable

Depending on the principle the used light scattering monitor is not able to classify coarse particles >20 µm. By cyclone separation TSP was split to 5 % fine and 95 % coarse fraction. Particle size analyses of the coarse fraction show a wide distribution with particle sizes up to 300 µm and only a little proportion of approximately 15 % of PM10, figure 12. In total only 20 % of TSP form PM10 in the stable.

The differences between concentration and size distribution confirm the necessity to measure in the exhaust flow to get the right emissions.

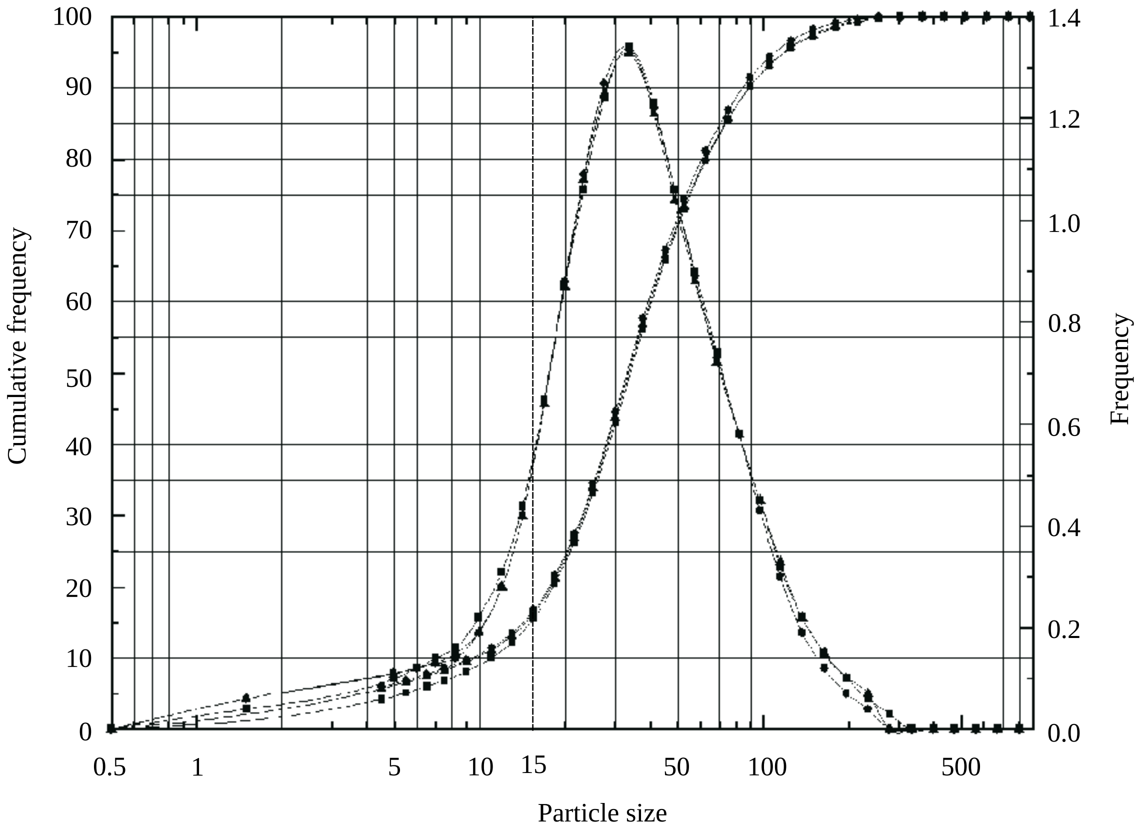

Figure 12:
Size distribution of the separated coarse fraction in the stable air

Conclusion

On a dairy cattle farm in Konin, Poland, PM emissions in and from a cattle house were investigated. Instrumentation was used to measure total dust and PM10 by gravimetric procedure and online monitoring.

An excellent management strategy by the farmer resulted in a very clean dairy house with very low concentration and emissions, which may be not the normal case.

In summer concentration was higher than in winter.

Concentration inside the building was higher than in the exhaust flow.

The ratio PM10/TSP was nearly 100 % in the emission flow, but 20 % only in the stable air.

References

Hinz T. (2005). Particulate matter emissions as a part of air pollution control in agriculture. Definitions, sources, measurements, 63-70. In (eds.) Kuczynski T., Dämmgen U., Webb J., Myczko A.(1996). Emissions from European agriculture.Wageningen Academic Publishers

ISO 7708 Publication date: 1996-01 Air quality- Particle size fraction definitions for health- related sampling.

US EPA: Code of Federal Regulations; PM10, 2001a PM2.5, 2001c