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Emissions and Concentrations of Dust and Pathogens from Goat Houses

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Abstract. *The objective of this study was to determine the emissions of dust and pathogens, especially* Coxiella burnetii *(*C. burnetii*), from goat houses in the Netherlands. The study was conducted in two houses for milking goats. Furthermore, emissions of ammonia, odor, and greenhouse gases (methane and nitrous oxide) and the contribution of the different dust sources to airborne dust were determined.*

Mean emissions (in g/year per animal place) of total dust, PM10, and PM2.5 were 68.8 (s.d. 58.9), 22.4 (s.d. 14.7), and 1.02 (s.d. 0.02), respectively. Yearly emissions per animal place for ammonia were: 2.3 (s.d. 0.5) kg/year, for odour: 4.8 (s.d. 3.6) OU_E*/s, for methane: 9.4 (s.d. 0.9) kg/year, and for nitrous oxide: 167.9 (s.d. 60.0) g/year. Straw and feces largely contributed to dust in exhaust air of goat houses. Salmonella, Staphylococcus, Enterobacteriaceae and* Escherichia coli *could not be detected in the exhaust air of the goat houses. With the Andersen sampling method, mean counts of total bacteria and Enterococcus were* $2.3 \cdot 10^5$ *and* $2.5 \cdot 10^4$ *colony forming units/*m^3*, respectively. Lower concentrations were obtained using the impinger bio-sampler. DNA of* C. burnetii *was especially found in the samples of total dust and to a lesser extend in the samples of PM10 and PM2.5.*

Keywords. Goats, housing, Q-fever, micro-organisms, emissions

Introduction

The Netherlands has regions with very high animal densities. During recent decades the increasing farm size is more and more conflicting with requirements with respect to planning, environment and landscaping. In some areas there is public concern about the effects of large farms on public health and quality of living. This concern is mainly related to the exposure of humans living close to farm operations to high emissions of dust and pathogens (bio-aerosols).

The direct motive of the study described in this report was the Q-fever epidemic in the Netherlands. Dairy goats were indicated as the primary source of this zoonosis, caused by *Coxiella burnetii* (*C. burnetii*), and exposure to humans seems to be facilitated by the recent developments in dairy goat production with increasing number of farms with open naturally ventilated buildings. The small distance between farms with aborting dairy goats and dairy sheep and a large number of people living in the vicinity, seemed to be the main cause of the large Q-fever outbreak in the Netherlands (Roest et al., 2011). In a study of Schimmert et al. (2010) it was shown that people living within a radius of 2 km from a goat farm (> 400 goats) with clinical signs had a significantly higher infection risk (31x higher) than people living in a radius of 5 to 10 km of the farm. At an abortion caused by *C. burnetii,* high numbers of bacteria are shed (up to 1 billion bacteria per gram placenta (Arricau-Bouvery et al., 2005)). *C. burnetii* is also shed, but in lower numbers, via milk and feces (Roest et al., 2011).

The objective of this study was to determine the emissions of dust and pathogens from representative goat houses. The emissions, the sources and the characteristics of dust have been studied and the concentrations or presence/absence of different bacteria have been determined, including *C. burnetii*. Furthermore, emissions of ammonia, odor, and greenhouse gases (methane and nitrous oxide) were determined.

Materials and Methods

The study was conducted from November 2010 until March 2011, in two modern representative houses for dairy goats on two different locations in the South of the Netherlands, one in the province of Limburg (480 animal places, Farm 1) and the other in the province of Noord Brabant (750 animal places, Farm 2). In table 1 the main characteristics of the goat houses are given. All urine and feces of the goats were collected in a straw bed, which had a final depth of 0.70 m. Daily, 0.5 kg straw per goat was added to the straw bed. The straw bed was removed every 3 months. Both barns were naturally ventilated.

The goats have been vaccinated against *C. burnetii*. During the measurements tank milk from both farms were free from *C. burnetii*. Tank milk was analyzed every two weeks. On both farms there were no problems with abortions during the course of the study. The goats were served in the normal period (Sept – Nov).

On each farm, on four different days, the following measurements were done inside the goat house (in the exhaust air) and outside the goat house (in the incoming air), except when mentioned otherwise:

- 24 h mean dust concentrations: total dust, PM10 dust (particles < 10 µm) and PM2.5 dust (particles < 2.5 µm) by collecting dust on filters using cyclones and filter cassettes;
- 20 min sampling of the air inside and outside the goat house with a dust spectrometer. With this instrument dust mass concentrations in different size classes was determined.
- air sampling during 20 min with two different samplers (impinger and Andersen with six size classes) for determining the following bacteria concentrations: total bacterial count, *C. burnetii, Enterobacteriaceae, Escherichia coli, Salmonella, Staphylococcus* and

Enterococcus. The samples of *C. burnetii* and *Salmonella* were only analysed on presence or absence of the bacteria;
- in all 24 h dust samples, collected on filters, the presence or absence of *C. burnetii* was determined;
- ammonia concentrations were measured continuously inside the goat house and outside the goat house by impingement of the air in an acid solution; 24 h samples were taken;
- odor concentration was determined by taking a sample from the exhaust air inside the goat house from 10:00 – 12:00 h and analysed by dynamic olfactometry;
- and 24 h sample for determining concentrations of methane and nitrous oxide using gas chromatography.

To determine dust and gaseous emissions the ventilation rate was determined, as well, with the CO_2 mass balance method. Emissions were calculated per day and per animal place. The number of animal places equals the maximum number of goats that could normally be placed inside the animal house (see table 1). Calculated standard deviations are based on the variation between the mean of the different measurement days (n=8; 2 farms, 4 measuring days per farm).

For determining the contribution of the different dust sources to airborne dust inside the goat house, on one measuring day, additional air samples were taken on each farm inside and outside the animal house from dust particles < 2.5 µm (fine dust) and from dust particles sized between 2.5 and 10 µm (coarse dust). Furthermore, during this measuring day, samples were taken from potential dust sources (compound feed, silage, hay / straw in rack, straw in deep litter, fresh feces and hair). From these dust sources dust was generated in a laboratory set-up. High resolution 'Scanning Electron Microscopy' (SEM) was used to analyse particles for elemental composition. The characterized particles from the air samples were assigned to the different sources on basis of the elemental composition by using multiple linear regression. *Enterobacteriaceae, Escherichia coli, Salmonella, Staphylococcus* and *Enterococcus* were detected via culture on appropriated media. *C. burnetii* was detected via PCR.

Results and discussion

The degree of occupation of the goat houses was lower than normal, because of the Q-fever problem in the year before the measurements, varying from 75 to 82% on farm 1 and from 70 to 75% on farm 2. This study was conducted during the colder period of the year, from November until March; this means that the results of this study are not fully representative for the yearly situation. On average the goat houses were ventilated at a rate of 81.2 (s.d. 48.7) m^3/h per goat present. Mean concentrations were for total dust 0.24 (s.d. 0.17) mg/m^3, for PM10 0.075 (s.d. 0.052) mg/m^3, for PM2.5 0.016 (s.d. 0.010) mg/m^3, for ammonia 7.8 (s.d. 2.4) ppm, for methane 108 (s.d. 26) ppm, for nitrous oxide 0.50 (s.d. 0.22) ppm.

The following dust emissions were determined (in mg/d per animal place): total dust: 188 (s.d. 161); PM10: 61 (s.d. 40); PM2.5: 2.8 (s.d. 0.05). Mean emissions per animal place for ammonia were: 6.3 (s.d. 1.4) g/d, for odor: 4.8 (s.d. 3.6) OU_E/s, for methane: 25.7 (s.d. 2.5) g/d, and for nitrous oxide: 0.46 (s.d. 0.16) g/d.

While goats are milk producers, similar as cows, it is interesting to compare these two types of animals with respect to environmental emissions (table 2). An important difference between these two animal categories is the housing, goats on straw bedding and cows on concrete (slatted) floors. To be able to compare the results on a similar scale, the emissions were calculated per kg of metabolic live weight. This table shows that dust and methane emissions are lower in goats, ammonia emission comparable and nitrous oxide emission higher than in cows. It is remarkable that goat produce relatively less dust, while it was expected to be more,

because of the use of straw bedding in goats. The relatively low methane emission in goats is probably related to a different metabolism of goats. The relatively high nitrous oxide emission in goats may be caused by the difference in manure storage. In the straw bedding of the goat house manure is stored under more aerobic conditions than in the slurry pit of a cow house. Overall, the CO_2 equivalent emissions per kg metabolic weight are approximately one third in goats compared with cows. It should be noted that emissions from the cow houses were based on year-round measurements, while in the present study this was only done in a (cold) part of the year.

In table 3 the mean contribution of the different dust sources to mass of fine dust and coarse dust is given. This table shows that straw contributes for more than 50% to both dust fractions. Dust from feces and outside also contributed significantly to fine dust, while roughage, feces, and compound feed significantly contributed to coarse dust.

In table 4 concentrations of the different bacteria inside and outside the animal house are given when sampling with the impinger. Samples of *C. burnetii* and *Salmonella* were qualitatively analysed, so only the presence of these bacteria was determined. *C. burnetii* could be detected in 1 out of the 8 samples. Total bacterial count was approximately 50 times higher inside than outside the animal house. A few *Enterococci* were found in the samples, while culture samples were all negative for *Staphylococcus*, *Enterobacteriaceae*, *Escherichia coli*, and *Salmonella*. With the Andersen sampling method, mean counts of total bacteria and Enterococcus were $2.3 \cdot 10^5$ and $2.5 \cdot 10^4$ colony forming units/m^3, respectively. These counts were higher than obtained when using the impinger bio-sampler.

In table 5 the PCR analyses of *C. burnetii* in the dust samples are given. These data show that on farm 1, 6 out of 8 samples, and on farm 2, 4 out of 8 were positive. For PM10, on both farms, 2 out of 8 samples were positive, while for PM2.5 this was 2 out of 8 on farm 1 and 1 out of 8 on farm 2. Table 5 also shows that a few samples from outside air were positive for *C. burnetii*. It should be noted that the amount of air sampled for the dust samples was a lot higher than with the impinger.

From the sampling and analyzing procedure we calculated that the chance of finding a positive sample for *C. burnetii* compared to the number of positive samples in total dust is 0.75 for PM10 and 0.17 for PM2.5. In our study the number of positive samples relative to the number of positive ones in the total dust samples was 0.4 for PM10 and 0.3 for PM2.5. From these results, and considering the high variation, we did not find an indication that *C. burnetii* is concentrated in certain size fractions of dust..

In figure 1 the share of total dust mass together with the share of total bacterial count in the different particle size ranges is given. This figure shows that the division of the bacterial count over the different particle size classes is very well related to the dust mass in similar class ranges.

Conclusions

From this study the following main conclusions can be drawn:

- Compared with dairy cows, the emissions from dairy goat farms, calculated per kg metabolic weight, are relatively low for dust and greenhouse gases (based on CO_2 equivalents) and comparable for ammonia.
- Straw is the main source of dust in goat houses, but also feces, roughage, compound feed, and dust from outside contribute to dust in goat houses.

- Concentrations of total bacteria were approx. 50 times higher inside than outside the goat house. A few *Enterococci* were found in the samples, while culture samples were all negative for *Staphylococcus*, *Enterobacteriaceae*, *Escherichia coli*, and *Salmonella*.
- Despite the fact that the goats have been vaccinated against *C. burnetii* and despite the fact that *C. burnetii* could not be detected in the tank milk, *C. burnetii* could be detected in different dust samples inside the goat houses.
- Bacteria (in total count) seem to be equally divided over the mass of dust in the different particle size ranges.

Acknowledgements

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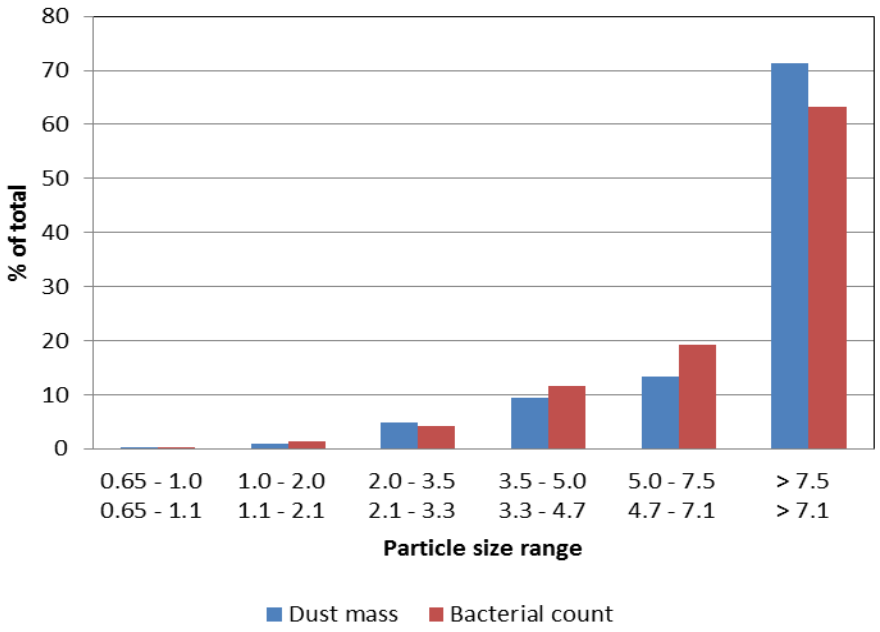

Figure 1. Share of dust (% of total mass) and bacterial count (% of total number) in the different size range classes. Note that the particle size classes are for dust (upper row) not exactly similar with the one for bacterial count (lower row).

Table 1. Main characteristics of the two goat houses

Characteristic	**Farm**	**Farm**
Number of goat places	480	750
Area per goat [m^2/animal][1)]	1.2	1.3
Area waiting room [m^2/animal place]	0.08	-
Ventilation opening of side walls [m^2/animal place] [2)]	0.12	0.17[2)]
Volume house [m^3/animal place]	10.2	12.5

[1)] *area of the bedding only*
[2)] *the ventilation openings have a limited perforation (perforated curtain)*

Table 2. Comparison between dairy goats and dairy cattle[1)] for daily emissions from the houses per kg metabolic weight ($kg^{3/4}$)[2)]

Emission ($mg/(d\ kg^{3/4})$)	Goat	Cow	Ratio goat/cow
Total dust	7.4	88.1	0.08
PM10	2.4	3.34	0.72
PM2.5	0.11	0.92	0.12
Ammonia	247	249	0.99
Methane	1011	3202	0.31
Nitrous oxide	18	5.1	3.53

[1)] Data from Mosquera et al. (2010); for ammonia the standard emission factor was taken (www.infomil.nl)
[2)] Metabolic weight dairy goat : 25,5 $kg^{3/4}$; metabolic dairy cow: 121,2 $kg^{3/4}$

Table 3. Mean contribution (in %) of the different dust sources to airborne dust mass for particles < 2.5 µm (PM2.5) and particles between 2.5 and 10 µm (PM2.5-10), with standard error of mean (SE).

Source	Contribution to fine dust (PM2.5)		Contribution to coarse dust (PM2.5-10)	
	Mean	SE	Mean	SE
Roughage	3.8	3.8	10.4	4.4
Straw	65.0	6.1	52.9	9.1
Hair	2.8	2.8	0.7	0.7
Feces	13.4	1.1	12.4	3.0
Compound feed	0.0	0.0	13.4	0.4
Outside	15.1	4.0	10.2	10.2

Table 4. Number of bacteria in the exhaust air (inside) and incoming air (outside) (in counts per m^3 air), sampled with an impinger bio-sampler. For *Coxiella burnetii* and *Salmonella* the number of positive samples is given. The volume of air sampled was 0.25 m^3. [1)]

	Number of samples[2)]		Farm 1		Farm 2	
	Inside	Outside	Inside	Outside	Inside	Outside
Coxiella burnetii, pos.	8	4	1	0	0	0
Total bacterial count	8	4	$3.0 \cdot 10^5$	$5.8 \cdot 10^3$	$7.7 \cdot 10^4$	$1.4 \cdot 10^3$
Staphylococcus	4	2	0	0	0	0
Enterococcus	4	2	$2.1 \cdot 10^4$	0	$1.3 \cdot 10^2$	0
Enterobacteriaceae	8	4	0	0	0	0
Escherichia coli	4	2	0	0	0	0
Salmonella, pos.	8	4	0	0	0	0

[1)] A zero in this table means that the bacteria could not be detected. The detection limit of the impinger sampling was approximately $5.6 \cdot 10^1$ counts per m^3 air for total bacterial count, $2.8 \cdot 10^3$ counts per m^3 air for C. burnetii, and $5.6 \cdot 10^2$ counts per m^3 air for Escherichia coli, Staphylococcus and Enterococcus. When calculating the mean, a zero was used when the bacteria could not be detected.
[2)] Number of samples per location: within the animal house samples were taken in duplicate, outside singular samples were taken.

Table 5. Number of positive dust samples for *Coxiella burnetii* of the exhaust air (inside) and incoming air (outside) for total, PM10 and PM2.5 dust. [1)]

				Coxiella burnetii, positive	
Farm	Dust fraction	m^3 air[1)]	Detection limit	Inside	Outside
1	Total dust	2.88	17.0	6	1
1	PM10	24	7.2	2	1
1	PM2.5	24	7.2	1	1
2	Total dust	2.88	17.0	4	0
2	PM10	24	7.2	2	1
2	PM2.5	24	7.2	2	1

[1)] *Amount of sampled air.*

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