Influence of Temperature, Humidity and Ventilation Rate on the Release of Odour and Ammonia in a Floor Housing System for Laying Hens

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ABSTRACT

The air in floor housing systems for laying hens may be more polluted than in traditional cage systems since gases are emitted from large exposed surfaces of manure and litter. In order to study odour and ammonia concentrations and emissions at different climatic conditions a small scale poultry house (climate chamber) was equipped with a floor housing system were 356 laying hens were kept. Temperature was set to about 12, 15, 20, and 25° C and ventilation rate was set to values between 0.9 and 5.3 m^3 h^{-1} hen^{-1}. Temperature, humidity, and ventilation rate were measured as well as odour, ammonia, carbon dioxide and dust concentration. The ammonia concentration was high and exceeded 25 ppm in many of the measurements. Odour emission showed a significant increase with temperature at similar ventilation rate. Both odour and ammonia emissions showed a significant increase with water vapour pressure. In the experiment, odour and ammonia emissions were more strongly correlated to water vapour pressure than to relative air humidity. The results suggest that control of temperature and humidity may decrease concentrations and emissions of odour and ammonia.

Keywords: Poultry, odour, ammonia, pollution, emissions, ventilation, Sweden

1. INTRODUCTION

Odours (odorants) and gases produced in livestock and poultry production may affect the animals, the workers and people living nearby as well as the ecosystem. Ammonia contributes to large scale eutrophication and acidification of ecosystems and may cause toxic injuries on the vegetation near the source (Fangmeier *et al.*, 1994). Some years ago 92% of the ammonia emission in Western Europe was estimated to come from agriculture (ECETOC, 1994). Odour emission is a major issue for poultry production as well as for pig production and dairy operations.

Regarding laying hens, floor housing systems are being re-established in Sweden since animal welfare legislation stipulates that systems for laying hens must include laying nests and perches and provide access to litter. Compared to traditional cage systems the air in floor housing systems may be more polluted since gases are emitted from large exposed surfaces of manure and litter. Measurements at commercial Swedish operations with low density floor systems for laying hens have shown that ammonia concentrations exceeded the legislated maximum of 25 ppm (Swedish National Board of Occupational Safety and Health, 2000; Swedish Board of Agriculture, 2003) in a majority of 18 randomly selected houses and concentrations up to 80 ppm were measured (von Wachenfelt *et al.*, 2002). These concentrations are bad for the workers as well as for the animals, and there is a need to reduce the levels.

In order to study emissions and concentrations of odour and ammonia and their correlation to climatic factors a small scale poultry house (climate chamber) at the university research station Alnarps Södergård was equipped with a loose housing system were 356 layers were kept.

The hypothesis of the study was that different ventilation and climate control strategies for poultry houses may result in differences in odour and ammonia concentrations inside the houses as well as differences in odour and ammonia emissions. Furthermore, correlation between pollution factors like ammonia and odour may exist and actions decreasing ammonia may also decrease odour. The objective of the study was to evaluate the influence of temperature, humidity and ventilation rate on odour and ammonia release, and further to study the correlations between odour, ammonia and carbon dioxide.

2. MATERIALS AND METHODS

Odour, ammonia, carbon dioxide and dust concentrations as well temperature, humidity and ventilation rate were measured in a loose housing system in a small scale poultry house (climate chamber) at the SLU research station Alnarps Södergård. The chamber is placed inside a building and surrounded by a space where the temperature can be controlled. The design of the chamber is shown in Figure 1. The floor housing system contained equipment manufactured by Fienhage GmbH (Germany). The housing system contained a bedding area, a manure bin area with manure conveyors below a draining floor and laying nests placed close to one of the walls. Automatic feed conveyors, water nipples and perches were placed in the manure bin area with the draining floor. The total area of the chamber including walking alleys is 87 m^2 and the area where the laying hens were kept was 47 m^2. Before start of the experiment the chamber was equipped with new litter. The litter used in the experiment consisted of small pieces of recycled paper and the amount used was about 3.2 kg/m^2.

The hens were fed *ad libitum* and had free access to water. The daily feed intake was 117 g/hen on average during the experiment. The metabolic energy content of the feed was 11.2 MJ/ kg and the crude protein content was 15.5%. The daily egg yield was 50 g/hen on average for the hens being 71 weeks old at the start of the experiment. An average weight of 1.72 kg/hen was found for 30 hens that were randomly selected and weighed on each of three different days. The stocking density was about 7.6 hens per m^2 available floor area. At the start of the experiments the chamber contained 359 laying hens of the LSL (Lohmann Selected Leghorn) hybrid. Some hens died during the experiment, and the chamber contained 356 hens on average during the experimental period starting in September and ending in November 2002.

The manure on the manure conveyors was removed daily. A problem with the equipment made this impossible for four days during the experimental period. The ventilation system was mechanical and the design is shown in Figure 1. Two rows of air inlets in the ceiling provided the chamber with supply air from the climate controlled space surrounding the chamber. An exhaust fan removed air at floor level close to the manure conveyors via a slit in a duct below the laying nests.

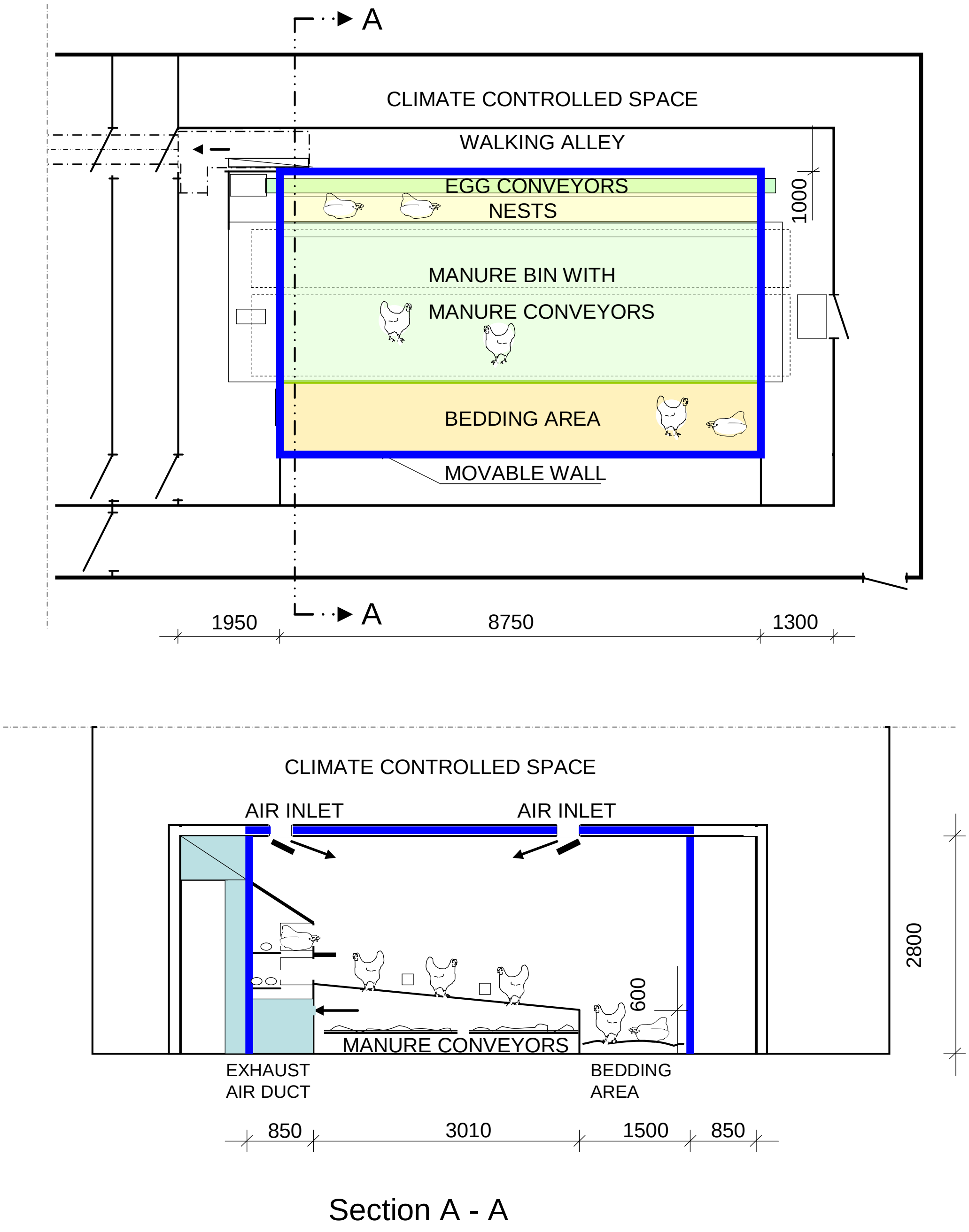

Figure 1. Design of the chamber equipped with a floor housing system for laying hens.

2.1 Control of Room Temperature and Air Flow Rate

The room temperature was adjusted by control of the temperature in the space surrounding the chamber (control of supply air temperature). This space was heated or cooled in order to obtain different set point temperatures. Temperatures in this space were set to achieve chamber

temperatures of about 12, 15, 20, and 25° C. Differences in animal activity and windy conditions outside caused some variation of the temperature inside the chamber.
The air flow rate was manually adjusted with a damper in an exhaust air duct. The ventilation rates were set to values of about 1, 2, 3, and 5.3 $m^3 h^{-1} hen^{-1}$. After adjustment of the damper the air flow rate in the duct was measured. The air flow rate was calculated from air velocities measured in 5 points in a circular duct (Φ 400 mm). The air velocities were measured by using a hot-wire anemometer (Alnor, GGA-65P).

Temperatures and ventilation rates were kept to a specific set point value for three or four days in order to get steady state conditions during days used for evaluation. Air flow rates and temperatures during these days are shown in Table 1.

Table 1. Air flow rates and exhaust air temperatures during days of the experiment

Day	Air Flow Rate Chamber	Temperature in the Exhaust Air Mean	 Minimum	 Maximum	 SD
No.	m^3/h	° C	° C	° C	
0	374	20.2	19.9	20.7	0.282
3	1909	20.4	19.6	21.4	0.622
4	1909	21.0	20.1	21.8	0.473
8	1020	18.4	17.4	19.3	0.601
11	727	19.7	18.9	20.2	0.434
15	334	15.6	14.1	16.9	0.960
18	338	12.6	11.1	14.0	0.964
22	338	11.0	9.6	12.0	0.761
25	422	11.8	10.5	12.9	0.765
29	422	20.2	19.3	21.0	0.568
31	427	21.1	20.3	21.9	0.505
35	427	20.8	19.8	21.6	0.625
37	402	20.3	19.2	21.2	0.747
45	383	25.0	24.2	25.7	0.538

2.2 Measurements

Temperature, relative air humidity (RH), ammonia and carbon dioxide concentrations were recorded using sensors and instruments connected to a logger and a computer. Data was recorded each minute and average values for every 30 minutes were stored on a computer and used for evaluation.

Temperature and relative air humidity were measured in the exhaust air and in the supply air. Temperatures were measured using 5 thermocouples (type T) in the exhaust air duct and 4 in the supply air. Two Hygromer®-C80 sensors were used for measuring RH in the exhaust air and two were used for measuring RH in the supply air. Ammonia and carbon dioxide concentrations were measured in the exhaust air. The gas analyzer used for measurement of ammonia was an infrared (IR) spectrophotometer (Miran 203, Foxboro Analytical, UK). Carbon dioxide was measured using an optical analyzer (RI-221) manufactured by Rieken Keiki Co. Instruments were calibrated regularly. Ammonia and carbon dioxide were also measured in the mornings by the use of Kitagawa detection tubes.

The total amount of dust was measured in the middle of the chamber and above the manure bin close to the walking alley. Measurements were made by the help of vacuum pumps (1.9 l/min) and 37 mm Millipore filters. Sampling time for the measurements were 3-4 days. The filters were analyzed at the Department of Occupational and Environmental Medicine at Lund University and the average concentration during the period was calculated.

Odour samples were collected at about 9 a.m. before the manure on the conveyors was removed. Sampling was made using a vacuum sampling device manufactured by ECOMA (Honigsee, Germany). Samples were taken in the exhaust air duct, about 0.3 m above the litter in the bedding area, and about 1.1 m above the draining floor (1.7 m above the solid floor) in the manure bin area. Samples were taken to the laboratory at the JBT Department and were analyzed following procedures described in European guidelines (CEN, 1999). A standardized panel and an ECOMA (Honigsee, Germany) TO7 olfactometer was used for the measurements of odour concentration (OU_E) in the samples.

Odour and ammonia emissions were calculated from measured concentrations in the exhaust air and measured air flow rates. Values of water vapour pressure (VP) and water vapour deficit (VD) i.e. the difference between water vapour pressure at saturation (100% RH at actual temperature) and at actual RH were calculated from measured temperatures and measured RH following standard equations.

The statistic software package MINITAB was used for evaluation of the data.

3. RESULTS

Ammonia concentrations varied from 1 up to about 45 ppm_v and measured odour concentrations varied from about 50 OU_E/m^3 up to 1100 OU_E/m^3. Values for specific days are shown in Table 2 together with ventilation rates, temperatures, RH, and average dust concentrations for 3-4 days.

Table 2. Odour and ammonia concentrations at odour sampling about 9 a.m. and average dust concentration during 3-4 days

Day	Ventilation Rate per Hen	Temperature	RH	Pollution Concentration				
				Odour	Odour	Odour	Ammonia	Dust
		Exhaust Air	Exhaust Air	Exhaust Air	Above Manure Bin	Above Litter	Exhaust Air	Average
No.	$m^3\ h^{-1}\ hen^{-1}$	° C	%	OU_E/m^3	OU_E/m^3	OU_E/m^3	ppm_v	mg/m^3
0	1.04	20.7	- [2]	1122	707	630	18.0	1.35
3	5.32	20.0	- [2]	108	57	71	3.6	1.35
4	5.32	21.3	- [2]	108	102	102	3.8	1.35
8	2.85	18.4	- [2]	215	194	308	4.8	3.26
11	2.03	19.4	47	588	357	418	5.8	4.46

15	0.93	15.1	61	561	1122	669	8.8	2.31
18	0.94	12.2	61	327	58	375	7.9	1.24
22	0.94	11.0	64	354	1160	595	10.0	0.99
25	1.19	11.7	65	256	135	120	16.5	1.10
29	1.19	20.3	71	854	944	969	39.6	1.85
31	1.21	21.3	67	707	1171	944	36.5	2.03
35	1.21	20.7	62	425	476	364	24.8	2.52
37	1.15	20.1	61	707[1]	944[1]	530[1]	20.7	1.91
45	1.10	25.0	59	891	401	530	21 [3]	- [2]

[1] After removal of manure
[2] Instrument failure. No value
[3] Value from Kitagawa detection tube

Measured ammonia emissions per m^2 floor area were in the range of 11-69 μg m^{-2} s^{-1} and odour emissions per m^2 floor area were in the range of 0.6-2.5 OU$_E$ m^{-2} s^{-1}. Ammonia and carbon dioxide concentrations showed daily variations and average, minimum and maximum values are presented in Table 3.

Table 3. Concentrations of ammonia and carbon dioxide during days of the experiment

Day	Ammonia Concentration				Carbon Dioxide Concentration			
	Mean	Minimum	Maximum	SD	Mean	Minimum	Maximum	SD
No.	ppm$_v$	ppm$_v$	ppm$_v$		ppm$_v$	ppm$_v$	ppm$_v$	
0	16.8	15.8	18.0	0.64	2262	2081	2595	197
3	4.3	1.8	7.5	1.63	844	653	994	88
4	6.4	3.6	7.9	1.05	762	596	944	89
8	3.9	0.7	6.8	1.83	1241	1026	1382	125
11	8.4	4.8	11.4	1.74	1389	1138	1553	157
15	10.1	6.9	13.5	2.17	2262	1658	2679	339
18	9.6	5.8	13.0	2.27	2179	1828	2518	247
22	7.7	4.6	10.7	1.82	2418	1825	2924	323
25	18.1	13.5	22.4	2.95	2258	1813	2543	227
29	40.1	34.3	45.5	4.15	2241	1787	2576	284
31	37.7	32.4	43.7	3.61	2164	1724	2526	283
35	28.1	22.0	33.5	3.89	2096	1598	2526	320
37	22.3	17.3	26.8	3.52	2227	1816	2533	244
45	33.5[1]	[1]	[1]	[1]	1737	1243	2274	305

[1] Only 2 values because of instrument failure. Values for day 44 were: Mean 33.2 ppm$_v$; Min 30.4 ppm$_v$; Max 37.0 ppm$_v$; SD 1.87

Reducing the number of factors affecting pollution levels may lead to easier evaluation and a better understanding of the effect of each single factor. Therefore, values measured at about the same air flow rate were used to evaluate effects of temperature and values measured at about the same temperature were used to evaluate effects of different air flow rates.

3.1 Temperature and Humidity Influence on Odour and Ammonia

Measurements at a ventilation rate of about 1 m^3 h^{-1} hen^{-1} were used to evaluate the influence of temperature and humidity on odour and ammonia. Different variables describing the humidity i.e. RH, VP and VD in the exhaust air was studied and the correlation coefficients are presented in Table 4. Increased temperature was found to significantly increase odour concentration in the exhaust air (p=0.004) and odour emission (p=0.002) as well as ammonia concentration in the exhaust air (p=0.043). Increased temperature was also found to increase the ammonia emission (p=0.052). Odour and ammonia concentrations and emissions plotted against temperature are shown in Figure 2. No significant correlation was found between the temperature in the exhaust air and the odour concentration above the manure bin or above the litter in the bedding area.

Table 4. Correlation coefficients and significance levels found at ventilation rates ranging from 0.93 to 1.21 m^3 h^{-1} hen^{-1}

	Odour Concentration Correlation	Odour Emission Correlation	Ammonia Concentration Correlation	Ammonia Emission Correlation
Temperature	0,851**	0,880 **	0,683*	0,662*
RH	N.S.	N.S.	0,694*	0,702*
VD	0,724*	0,704*	N.S.	N.S.
VP	0,869**	0,918***	0,796**	0,775**

N.S. = Not Significant;
* = Significance level p≤0.05; ** = Significance level p≤0.01; *** = Significance level p≤0.001

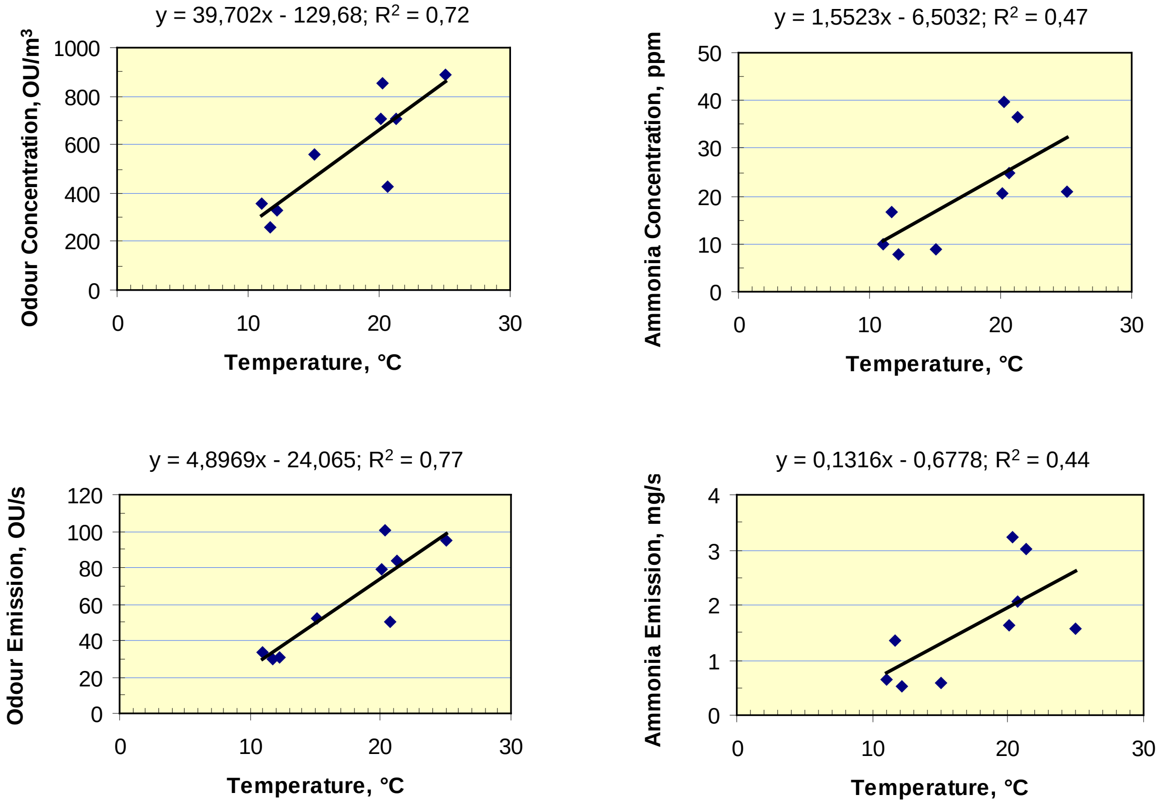

Figure 2. Odour and ammonia concentrations and emissions vs. exhaust air temperature for ventilation rates ranging from 0.93 to 1.21 m^3 h^{-1} hen^{-1}.

Also an increase of the humidity was found to increase odour and ammonia concentration as well as odour and ammonia emission. Regarding odour emission significant increase was found for VP (p=0.000) and VD (p=0.034), but not for RH. Significant positive correlations were also found between odour concentration in the exhaust air and VP (p=0.002) and VD (p=0.028). No significant correlation was found between humidity and odour concentration above the manure bin or above the litter. Increase of RH in the exhaust air was found to significantly increase ammonia emission and ammonia concentration in the exhaust air. The same but somewhat higher significance (lower p-values) was found for VP. Odour and ammonia concentrations and emissions plotted against VP are shown in Figure 3.

Ammonia concentrations at temperature levels of 11-13° C and 19-21° C are plotted against water vapour pressures (VP) in Figure 4 for all measured values between 8 a.m. and 11 a.m. The regression lines were different for different temperatures.

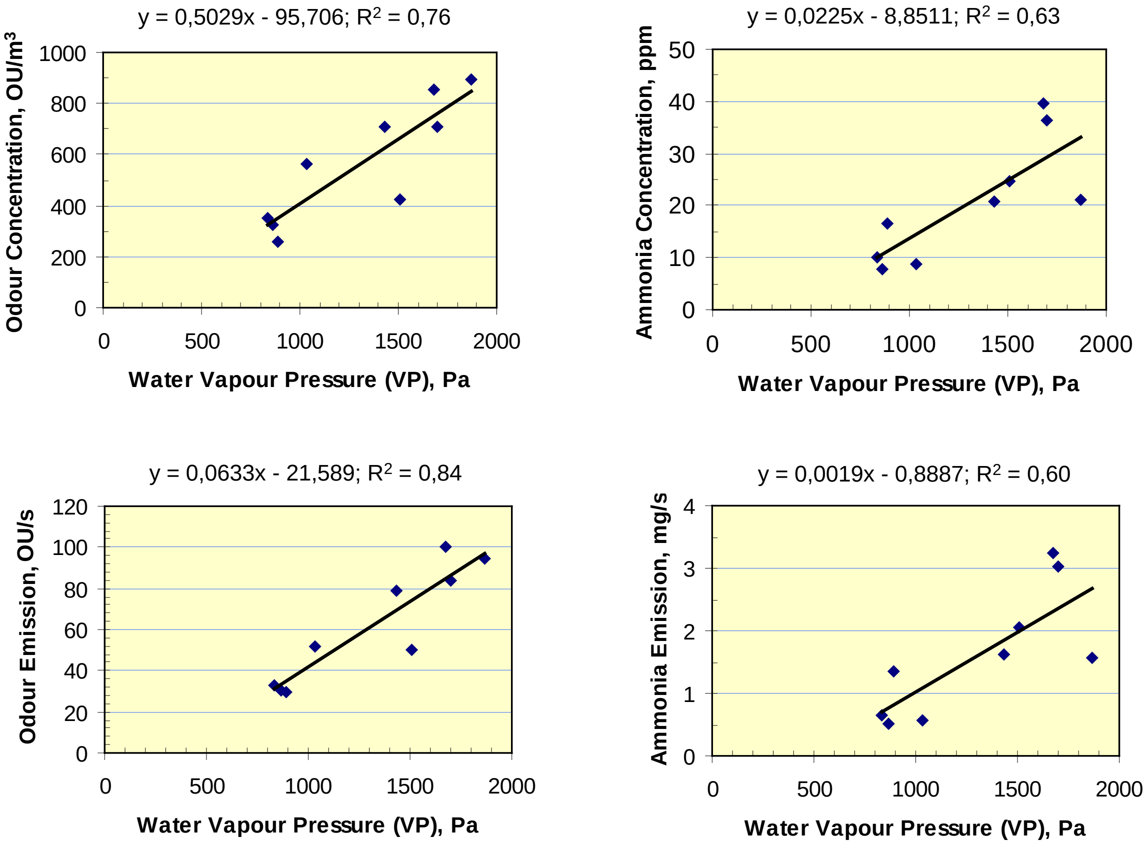

Figure 3. Odour and ammonia concentrations and emissions vs. water vapour pressure for ventilation rates ranging from 0.93 to 1.21 m^3 h^{-1} hen^{-1}.

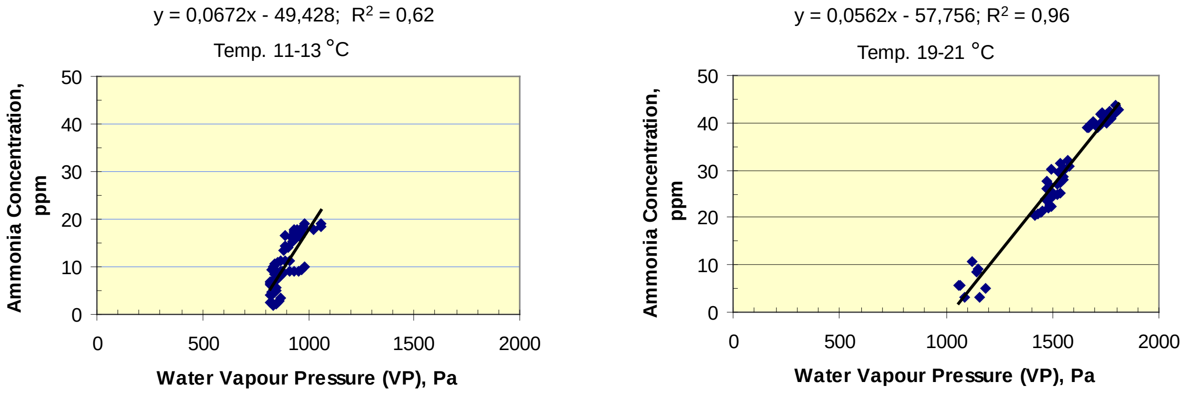

Figure 4. Ammonia concentrations measured in the exhaust air vs. water vapour pressure for exhaust air temperatures 11 to 13° C and 19 to 21° C for all values between 8 a.m. and 11 a.m. during the experimental period.

3.2 Air Flow Influence on Odour and Ammonia Concentrations and Emissions

The air flow rate showed as expected a significant influence on concentrations of odour, ammonia and carbon dioxide in the exhaust air. Correlation coefficients for temperatures ranging from 18.4 to 21.3° C are shown in Table 5. Concentration values measured at 9 a.m. during the experimental period are plotted against ventilation rate per hen in Figure 5. The concentrations followed roughly an expected decline with the ventilation rate for constant generation of a pollutant indicating no change of emission by change of ventilation rate. No significant correlation between emissions of odour, and ammonia and ventilation rate was found. Further, no influence of the ventilation rate could be seen on dust concentrations.

Table 5. Correlation coefficients and significance levels found at temperatures ranging from 18.4 to 21.3° C

	Odour Concentration Correlation	Odour Emission Correlation	Ammonia Concentration Correlation	Ammonia Emission Correlation	Carbon Dioxide Concentration Correlation
Air Flow Rate	-0,828**	N.S.	-0,725*	N.S.	-0,943***

N.S. = Not Significant;
* = Significance level p≤0.05; ** = Significance level p≤0.01; *** = Significance level p≤0.001

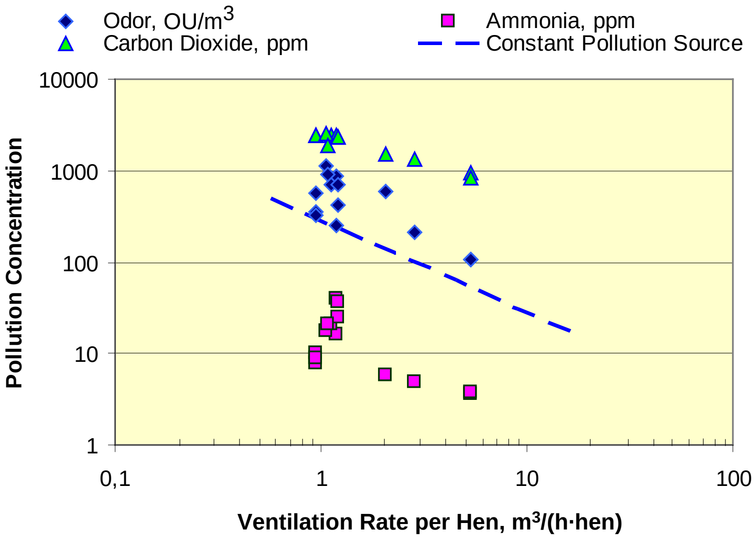

Figure 5. Concentrations of odour, ammonia and carbon dioxide vs. ventilation rate. Theoretic dilution of a pollutant with constant production shows the expected decline by increase of the ventilation rate if no increase or decrease of the generation occurs by this change.

3.3 Correlation between Pollution Factors

Regarding the values measured at about 9 a.m. an increase of odour concentration was positively correlated to ammonia concentration (p=0.052) and to carbon dioxide concentration (p=0.030). Values are plotted in Figure 6. Further, there was a tendency (p=0.091) of positive correlation between odour emission and dust concentration.

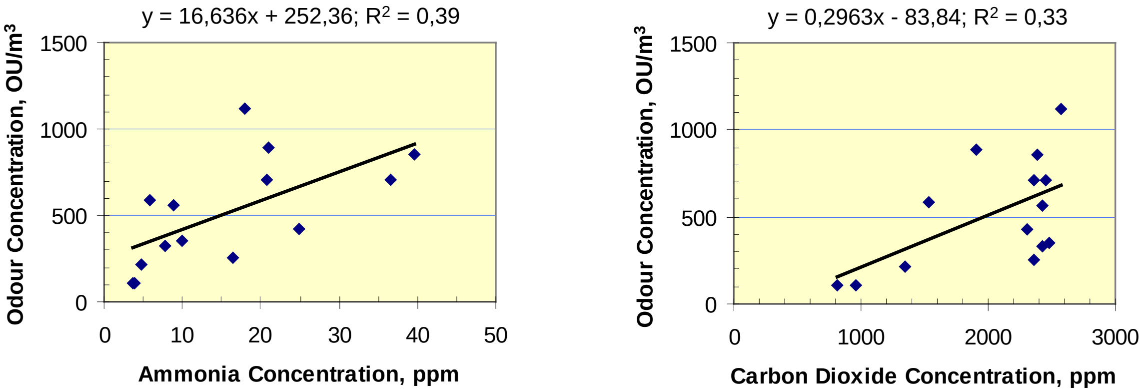

Figure 6. Odour concentration in the exhaust air vs. ammonia and carbon dioxide concentrations in the exhaust air.

4. DISCUSSION

The measured odour concentrations were similar to concentrations measured at broiler farms in Australia (Jiang and Sands, 1998) with chickens on litter, but the emissions (0.6-2.5 $OU_E\ m^{-2}\ s^{-1}$)

where lower. The daily removal of manure from the manure bin area and the small amounts of manure deposited in the litter which had a good consistency during the experiment may have reduced the emission. Daily removal of manure on manure belts has been found to considerably reduce the ammonia concentration (Groot Koerkamp *et al.*, 1995; von Wachenfelt *et al.*, 2002). The measured ammonia emissions would if the emissions were constant during the year result in an emission of 46-280 g year^{-1} hen^{-1} which can be compared to values reported by Müller, *et al.*, (2003) who report values of 17-63 g year^{-1} hen^{-1} for battery cages, 50-136 g year^{-1} hen^{-1} for aviary systems and 296-389 g year^{-1} hen^{-1} for systems with grid floor and manure cellar.

Ammonia emissions are measured for a large number of animal production systems (see e.g. Wathes *et al.*, 1997; Groot Koerkamp *et al.*, 1998a; Demmers *et al.*, 1999). Values found in a number of studies are put together by the Iowa State Univ. and The Univ. of Iowa Study Group (2002). It has been reported that temperature, air flow rate, and air velocity around the manure affect the amount of ammonia released in poultry houses beside factors like animal weight, stocking density, size of manure area exposed, time for exposure of manure before removal, and pH and moisture content in manure (Gustafsson and von Wachenfelt, 2004). Ammonia emissions from laying hens have in experiments been shown to increase with air temperature (Groot Koerkamp *et al.*, 1995). Ammonia emission is also considered to increase with the water content of the litter (Groot Koerkamp *et al.*, 1999). In experiments with broilers, increased levels of relative air humidity resulted in increased litter moisture and caking, and generally also in increased ammonia levels (Weaver and Meijerhof, 1991). A significant increase of ammonia emission with temperature and with water vapour pressure in the air was found in the present study.

Change of temperature and humidity in the environment may lead to change of odorant emission e.g. by affecting the volatilization or by affecting the activity of micro-organisms producing odorous compounds. It is reported (Jacobs, 1994; O'Neill and Phillips, 1991) that reducing the moisture content reduces the odour production in manure, and this effect may be explained by less anaerobic conditions at low moisture levels (O'Neill and Phillips, 1991). Jongebreur, *et al.*, (2003) have reported that increased temperature and increased air exchange rate lead to increased odour emission and the air velocity above the manure is meant to be important. Odour and ammonia emission increased in the present study by temperature and by humidity but no significant correlation to the air flow rate could be found. This might depend on less good correlation between air flow rate and air velocity above the manure or it might depend on decreased moisture content in the manure at increased air velocities. Increased ventilation rate might have limited effect on air speed above the manure in the present system where the main part of the manure was located below the hens and below the draining floor in the manure bin area. However, supply air from the inlets was observed to drop from the inlets down towards the manure bin area at occasions. These air movements may have influenced samples taken above the manure bin area and may explain why odour samples taken inside the chamber differed from samples taken in the exhaust air. Increase in air flow rate should increase the air velocities and the emissions of ammonia, but it should also decrease the moisture content of the litter and the manure. In a study drying the litter in an aviary system for laying hens with air sucked from the top of the room and blown through holes in ducts at floor level the ammonia concentrations were kept low (Groot Koerkamp *et al.*, 1998b). It was meant that low moisture content minimized the degradation of nitrogenous compounds into ammonia and that the possible increase of ammonia volatilization at higher air velocities was of minor importance.

A number of studies (e.g. Verdoes and Ogink, 1997; Heber, *et al.*, 1998) have shown that no correlation between ammonia and odour seems to exist. However, other studies have shown a correlation and e.g. for measurements at a large number of farms in Minnesota a significant positive correlation (0.486) between odour and ammonia emission was found (Wood, *et al.*, 2001). Jongebreur, *et al.* (2003) refer to findings that pig houses with low ammonia emissions also have low odour emissions. During some periods in the present study both odour and ammonia emissions were low which might explain why a positive correlation between odour and ammonia was found.

Odorous compounds adhere to dust particles and removal of dust can reduce the odour in air from swine houses by 65% or more (Hartung, 1986; Hoff *et al.*, 1997). Animal activity, type of ventilation and type of housing system are important for generation of dust and sprinkling with water and oil is a way to reduce the concentrations of dust (Gustafsson, 1999). Since sprinkling decrease dust concentration and since humidity seems to be important for odour a correlation between dust and odour might exist. However, no significant correlation could be found between odour and dust in this experiment.

5. CONCLUSIONS

The following conclusions can be drawn from the experiments in the loose housing system for laying hens:

- Ammonia concentrations sometimes exceeded hygienic threshold limit values and the concentration of 25 ppm considered to be the highest tolerated concentration for poultry kept on litter in Sweden.
- Decrease of temperature and decrease of humidity decreased odour and ammonia concentrations and emissions.
- Water vapour pressure had a stronger correlation to odour and ammonia than relative air humidity (RH).
- The air flow rate affects concentrations of odour and ammonia but had a limited effect on emissions.
- Control of temperature and humidity potentially decreases generation and emission of odour and ammonia.

Release of odour and ammonia depends on a large number of factors and the present study indicates a need of further research regarding effects of single climatic factors as well as for combinations of factors.

6. ACKNOWLEDGEMENTS

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