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AMMONIA, DUST AND BACTERIA IN WELFARE-ORIENTED SYSTEMS FOR LAYING HENS

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Abstract: The use of litter and manure in welfare-oriented systems for laying hens may negatively affect the air quality and the work environment. The objective of the current case study was to compare concentrations of ammonia, dust and bacteria in 3 such systems: 1) a floor housing system, 2) a multilevel system, and 3) a system with furnished cages. Data was collected from 3 houses of each type, and 1 house of each type was selected for detailed measurements for 1–2 weeks. Daily average concentrations of ammonia were 3–12 ppm in the house with furnished cages, 21–42 ppm in the multilevel system, and 66–120 ppm in the floor housing system. Total dust concentration was 2.0–2.5 $mg \cdot m^{-3}$ in the house with furnished cages, 0.71–2.4 $mg \cdot m^{-3}$ in the multilevel system, and 6.8–18 $mg \cdot m^{-3}$ in the floor housing system. The number of bacteria cells per m^3 was $1.1–2.2 \cdot 10^7$ in the house with furnished cages, $2.2–3.4 \cdot 10^7$ in the multilevel system, and $8.0–9.6 \cdot 10^7$ in the floor housing system. In the system with furnished cages, concentrations of ammonia and dust were of the same magnitude or below concentrations found to reduce pulmonary function in poultry workers in other studies. Concentrations of ammonia in the multilevel system and concentrations of both ammonia and dust in the floor housing system were above these levels.

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Key words: poultry, laying hens, air quality, work environment, pollutants, ammonia, dust, bacteria.

INTRODUCTION

European consumers show growing concerns regarding the welfare of domestic animals [17]. This is reflected in the animal welfare legislation in the European Union (EU). An example is Council Directive 1999/74/EC, setting the minimum standards for the protection of laying hens. This directive prohibits conventional battery cage systems in the EU by the year 2012 for all installations. Therefore, systems with perches, nests and litter facilities have been developed with the aim of improving poultry welfare. However, there are strengths and weaknesses inherent in any rearing system, and air quality is an area of concern in alternative housing systems. The use of litter and, in particular, storage of manure inside such houses may cause high concentrations of air pollutants. This may have consequences for human health as well as for bird health and productivity. Decreased respiratory health already appears to be a problem among persons working with poultry [28, 55, 56, 59]. Diseases such as asthma, chronic bronchitis and organic dust toxic syndrome are more prevalent among poultry workers than other workers [61, 68]. Studies of poultry workers have shown high rates of acute and chronic respiratory symptoms and changes of expiratory flows, indicating decreased pulmonary functions [29, 41]. Effects in workers exposed to pollutants at a hatchery may be less compared to effects in workers exposed at poultry farms [62]. Many health problems are likely related to high

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levels of ammonia and dust in poultry houses. Eye irritations are common among poultry farmers [48], and a main clinical symptom found in poultry exposed to ammonia is keratoconjunctivitis [35]. Ammonia, known to irritate skin, eyes, nose, throat and lungs [46], is recognized as one of the most prominent air pollutants in poultry houses. High water solubility allows it to be absorbed in dust particles and litter, as well as in mucous membranes [73, 74]. Such mechanisms allows it to be deposited in the upper as well as the lower respiratory tract [66]. Several countries have introduced threshold limit values (TLV) of 25 ppm ammonia for 8 hours work. However, already at this concentration, ammonia has been shown to have deleterious effects on the respiratory tract in poultry [3, 4, 42], including the loss of tracheal cilia and histopathological changes to the tracheal epithelium in the respiratory tract [44, 45]. This reduced effectiveness of the mechanical defence mechanism of the respiratory system may increase the frequency of respiratory diseases. Thus, concentrations around 60–70 ppm seem to predispose birds to respiratory diseases and secondary infections [70]. At high ammonia concentrations the liver and kidneys also can be affected [10], as well as feed intake and growth rate [6, 30, 32, 57, 75]. Exposure of laying hens to 100 ppm ammonia for 4 weeks resulted in fewer eggs, decreased egg weight, reduced body weight, and reduced food and water intake [2]. Humans are not the only ones who prefer fresh air. In a study where hens were given the choice of selecting compartments with 0, 10, 20, and 40 ppm ammonia, the hens preferred the fresh air [71].

High dust concentration is another major problem in poultry houses. The dust particles originate from animal feed and litter material (pollen and fragments), animals (skin scales, faeces, urine and feathers), soil, microorganisms (bacteria and fungi), insects, and mites. Dust in poultry houses is mainly of organic origin, and components of the dust can be biologically active and cause hypersensitivity reactions [18, 58] as well as respiratory diseases [11]. Many particles are antigenic and can activate the innate and the adaptive immune systems, causing inflammation. Antigens inducing allergic reactions (so-called allergens) in farm environments include mites, pollen, and animal, bacterial (thermophilic actinomycetes, some Gram-negative bacteria and others) and fungal allergens [13, 59, 54]. Bacterial endotoxin, a potent non-specific immunostimulant, is an important pathogenic agent in animal houses [36, 54, 60]. Airborne microorganisms frequently are attached to dust particles and may be directly pathogenic or may release toxins.

The effect of poultry house microorganisms on human health has been investigated in a number of studies [14, 15, 33, 38, 39]. It has been shown that dead and partially decomposed bacteria may cause inflammation in the respiratory organs, and antigens and allergens may activate the immune system, leading to allergic reactions [13, 59]. It may be difficult to relate symptoms and function in humans and animals to a single pollution or production parameter, and pollutants may have additive or synergistic effects. Studies have shown that the number of infections in broilers and turkeys increases with increased dust concentrations [34, 75], and normally harmless *Escherichia coli* bacteria had pathogenic effects on the respiratory system of 4-week-old chicks when combined with sterile dust [51]. Dust may impair lung clearance mechanisms of exposed animals and humans and depress immune response to infections [18].

Few studies have so far been published on how new, welfare-oriented systems affect air quality. Michel *et al.* [40] found that dust levels in aviaries are 5–14 times higher than in conventional cage systems for layers, and a review by Guillam *et al.* [23] indicates that workers in loose housing systems usually are exposed to poor air quality regarding ammonia and dust (including endotoxins) compared to workers in systems with cages. In birds, a higher incidence of lung damage was found in broilers raised on litter compared with a system with a netting floor [34].

In order to prevent expected problems, it is important to gain more knowledge regarding the effect of these new welfare-oriented systems on air quality. In this paper, a case study of the air quality in 3 alternative housing systems is presented: 1) a system with furnished cages, 2) a multilevel system and 3) a floor housing system. The hypothesis was that concentrations of ammonia, dust and bacteria in houses for laying hens are affected by the system design, including the litter and manure handling systems. The objective of the study was to compare the air quality in different systems that allow a more natural behaviour for laying hens, specifically, the occurrence of ammonia, dust and bacteria in the air inside the buildings.

MATERIALS AND METHODS

Farms. Nine farms representing 3 different rearing systems were visited once, and information about the systems was collected. The characteristics of the farms are shown in Table 1. All farms except No. 6 and No. 8 have exhaust air ventilation, and all have wall mounted air inlets. At farm No. 8 inlets were also mounted in the ceiling.

Direct reading measurements of ammonia and carbon dioxide were made at all farms during the visits. Three farms were selected for longer-term (1–2 weeks) measurements: i.e. farms No. 3 (furnished cages), 4 (multilevel system), and 7 (floor housing). Selection was based on an evaluation of the representativeness of the farms for the respective housing systems as well as typical size for Norwegian egg producers. All 9 farms were visited during winter (20 January–7 February). The longer-term measurements were made during the period 28 February–3 April.

Measurements. Direct reading measurements of ammonia and carbon dioxide were made using Kitagawa® (105SC, 105SD, 126SF, Komyo Rikagako Kogyo K.K., Kanagawa, Japan) or Dräger® (100/a, 2/a, 5/b, Dräger Safety AG, Lübeck, Germany) gas detection tubes.

Table 1. Characteristics of the animal houses for laying hens.

Farm No.	Stock size	Building		Equipment/System	Stock density [hens·m^{-2}]	Manure Removal	Litter	Ventilation/ Heat	Hen age at visit [weeks]
		Type	Insulation						
Furnished cages									
1.	7 500	Concrete[1]	wall 15 cm ceiling 25 cm floor 0 cm	TAPE-cage – 3 cage levels – 7 hens per cage	10.1	2 times/week		Exhaust vent/–	57
2.	7 500	Concrete[1]	wall 15 cm ceiling 35 cm floor 5 cm	Victorsson, Trivselbur[2] – 4 cage levels – 7 hens per cage	14.3	2 times/week		Exhaust vent/–	61
3.	7 500	Concrete[1]	wall 14 cm ceiling 30–35 cm floor 5 cm	Big Dutchman – 3 cage levels – 9 hens per cage	11.5	5 day intervals		Exhaust vent/–	65
Multilevel system									
4.	13 500	Concrete[1]	wall 10 cm ceiling 15 cm floor 0 cm	Vencomatic	18.1	1 time/week	Wood carvings	Exhaust vent/–	60
5.	8 000	Wooden structure	wall 15 cm ceiling 15 cm floor 0 cm	Big Dutchman, NaturaNova	9.6	1 time/week	Wood carvings	Exhaust vent/–	43
6.	7 500	Concrete[1]	wall 15 cm ceiling 30 cm floor 10 cm	Oli-free	8.8	Regular + storage[3]	Gravel + wood carvings	Balanced vent[5]/–	35
Floor housing system									
7.	5 400	Wooden structure	wall 15 cm ceiling 20–25 cm floor 5 cm	Vencomatic floor system	7.4	Storage of manure inside the house	Wood carvings	Exhaust vent/–	47
8.	5 300	Plastic walls	wall 15 cm ceiling 20 cm floor 0 cm	Vencomatic floor system	8.4	Storage of manure inside the house	Sand/ gravel + straw	Balanced vent[6]/–	69
9.	10 000[4]	Wooden structure	wall 10 cm ceiling 25 cm floor 0 cm	Fienhage, 2 levels of nests	9.1	Storage of manure inside the house	Sand + saw dust	Exhaust vent/ Supply heat	61

[1]Elements of concrete, [2]Norwegian system, [3]No manure removal 60 cm in front of nests, [4]No. of hens in 2 departments, [5]Air supply through a 40 m long ceiling mounted "stocking", [6]Air supply from ceiling mounted fans with mixing units and diffusors.

Temperature was measured by a hot-wire instrument (Alnor®, Compuflow GGA-65P, Shoreview, MN, USA). Longer-term measurements were mainly made close to an exhaust air fan or 1.6–1.8 m above the floor (human breathing height) at a central place in the poultry house. During longer-term measurements, temperature and relative humidity (RH) were measured and logged by Tinytag® Plus mini-loggers (Gemini Data Loggers Ltd., Chichester, UK). Data was recorded every 10 min. The gas analyzer used for continuous measurement of ammonia was an infrared (IR) spectrophotometer (Miran® 203, Foxboro Analytical, Redhill Surrey, UK). Carbon dioxide was measured using an optical analyzer (RI-221) manufactured by Riken Keiki Co (Tokyo, Japan), or a Siemens CO_2-Controller (M52080-A, Munich, Germany). Output voltages from the instruments were logged every 10 min by Tinytag voltage mini-loggers. Instruments were calibrated by standard gas before and after the measurements. For determination of mean concentrations of ammonia and carbon dioxide over prolonged periods (longer-term registrations) Dräger diffusion tubes (20/a-D and 1%/a-D, Dräger Safety AG, Lübeck, Germany) also were used.

Total dust was sampled by battery powered pumps with an air flow rate of 1.9–2.2 ℓ·min^{-1} and polycarbonate filters with pore size 0.8 µm. The sampled dust was weighed in a room with RH 40 ± 2% and temperature 20 ± 0.5ºC at the National Institute of Occupational Health, using a Sartorius MC5 microbalance (Göttingen, Germany). A subset of the dust filters were selected for microbial analysis. Particles were resuspended, stained with a fluorochrome and

Table 2. Ammonia and carbon dioxide concentrations in the different systems for laying hens.

System	Direct reading measurements/Performed during visits							Longer-term measurements						
	Farms	Ammonia, ppm			Carbon dioxide, ppm			Farms	Ammonia, ppm			Carbon dioxide, ppm		
	No	Mean	(SD)	N[1]	Mean	(SD)	N[1]	No	Mean	(SD)	N[2]	Mean	(SD)	N[2]
Floor housing	2*	57	(10)	3	1900	(1100)	3	1	85	(17)	12	1800	(300)	12
Multilevel system	3	38	(13)	6	2000	(690)	6	1	32	(6.5)	12	1900	(270)	20
Furnished cages	3	2.5	(0.37)	5	1500	(840)	5	1	5.2	(4.1)	5	2500	(300)	5

*One farm with supplemental heat is not included in the average values. Here, concentrations were only 6-7 ppm, measured at 3 different locations in the human breathing zone, and 40 ppm just above the litter area. [1]No. of measurements. [2]No. of days with measurements.

bacteria were counted by fluorescence microscopy (FM) as described in [26].

Carbon dioxide ratios and temperature ratios. Carbon dioxide ratios (CR) were calculated as the ratios of heightened pollutant concentrations (C) to heightened carbon dioxide concentrations (C_{CO2}) following Equation [1] where index 1 refers to the outdoor concentrations, and index 2 refers to the indoor concentration:

$$CR = \frac{(C_2 - C_1)}{C_{CO2,2} - C_{CO2,1}} \quad [1]$$

Temperature ratios (TR) were calculated similarly as the ratios between heightened pollutant concentrations (C) and heightened temperature (T) following Equation [2] where index 1 refers to the outdoor concentrations, and index 2 refers to the indoor concentrations:

$$TR = \frac{(C_2 - C_1)}{(T_2 - T_1)} \quad [2]$$

Concentrations of pollutants inside a building are largely influenced by the ventilation rate, which in a poultry house varies with the outside climate. The major sources of carbon dioxide and heat in a poultry house are the animals. A constant release of a pollutant and a constant release of carbon dioxide means a constant CR value, also when the ventilation rate varies. Hence, CR values may provide better values for comparisons between systems and buildings than measured concentrations. Temperature varies similar to carbon dioxide concentrations in animal houses where ventilation rates for cooling the house are regulated by the inside temperature. Also, TR values can be used for comparison between systems and houses.

Ammonia emission. The ammonia emissions from the different systems were estimated using measured ammonia concentrations and ventilation rates calculated from the mass balance of carbon dioxide according to equations derived by Pedersen and CIGR [8, 9, 53]. In these equations, the amount of carbon dioxide produced by the hens is calculated from the total heat they produce and this varies with body weight; in calculations the weight of a laying hen was set to 1.7 kg.

Carbon dioxide concentrations outdoors. During the last century the concentration of atmospheric carbon dioxide has increased. Due to exchange with vegetation, sea water and marine life there is also a seasonal variation in atmospheric carbon dioxide [63]. In 2005, atmospheric CO_2 levels was estimated to 381 ppm. In this study, the outdoor concentration of CO_2 was set to 380 ppm in all calculations.

Table 3. Dust and bacteria concentrations in samples from different days.

Location	Date	Dust	Bacteria
		mg · m^{-3}	10^7 cells · m^{-3}
Floor housing system			
Breathing zone*, Central	28 Feb–1 Mar	6.84	
Breathing zone*, Central	29–30 Mar	17.65	9.6
Breathing zone*, Central	30–31 Mar	11.33	8.0
Floor zone**, Central	28 Feb–1 Mar	7.98	
Multi level system			
Breathing zone*, Central	1–2 Mar	0.71	
Breathing zone*, Central	7–8 Mar	1.72	
Breathing zone*, Central	28–29 Mar	1.87	2.2
Breathing zone*, Central	29–30 Mar	2.38	
Breathing zone*, Central	30–31 Mar	1.81	2.9
Breathing zone*, Central	31 Mar–1 Apr	1.96	
Breathing zone*, Central	1–2 Apr	1.47	
Breathing zone*, Central	2–3 Apr	2.35	3.4
Floor zone**	7–8 Mar	0.79	
Upper zone***	1–2 Mar	0.40	
Furnished cages			
Breathing zone*, Central	6–7 Mar	2.05	2.2
Breathing zone*, Central	7–8 Mar	2.48	1.6
Breathing zone*, Central	8–9 Mar	2.23	1.1
Cage front	8–9 Mar	2.30	
Breathing zone*, Wall	6–7 Mar	0.60	0.69
Breathing zone*, Wall	8–9 Mar	1.19	

*1.6–1.8 m above the floor; **Approx. 0.3 m above the floor; ***Approx. 1.0 m below the ceiling; Central At a central place in the house; Wall Close to the wall at a short end of the building.

Statistics. The statistic software package MINITAB was used for evaluation of data. The following statistical tests were used: Kruskal-Wallis test, ANOVA, pairwise comparisons, regression analysis, and descriptive statistics.

RESULTS

Ammonia and carbon dioxide concentrations. Ammonia and carbon dioxide concentrations measured at all 9 farms and average values for longer-term measurements at 1 farm of each type are shown in Table 2. The instant measurements in the 2 houses with floor housing and no heat supply showed an average ammonia concentration of 57 ppm. The third floor housing system was equipped with a heat supply. Here, concentrations were only 6–7 ppm, measured at 3 different locations in the human breathing zone, and 40 ppm just above the litter area.

Average daily values of ammonia, carbon dioxide, temperature and humidity during different periods of the longer-term measurements are shown in Table 4. Ammonia concentrations (average during a day) varied from 3–12 ppm in the house with furnished cages, from 21–42 ppm in the multilevel house, and from 66 to 120 ppm in the floor housing system. Carbon dioxide concentrations of 2,700–2,900 ppm (average during a day) were measured in the house with furnished cages during 2 days when the average outside temperature fell below -8°C. On all other days, carbon dioxide concentrations were below 2,500 ppm in all 3 systems.

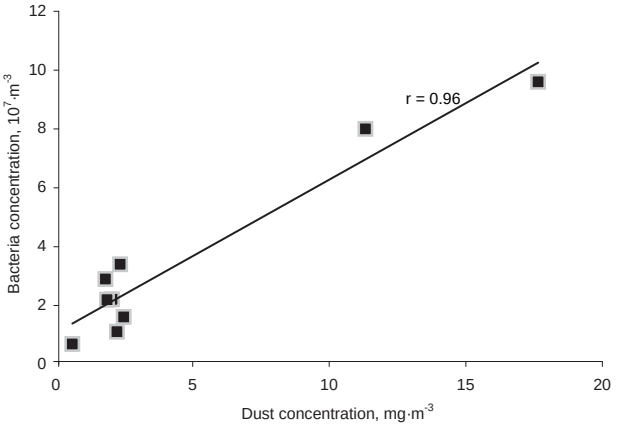

Figure 1. Bacteria concentration versus dust concentration in samples from 3 farms with different housing systems.

Dust and bacteria concentrations. Concentrations of dust and bacteria in samples from the 3 selected farms are shown in Table 3, and average concentrations of dust and bacteria in samples from the human breathing zone at the 3 selected farms are shown in Table 5.

Most samples from the human breathing zone (1.6–1.8 m above the floor) at central places in the building with a

Table 4. Average daily values of temperature, relative humidity, carbon dioxide concentration and ammonia concentration for longer-term measurements during different periods in houses with different systems.

Period	Temperature						Relative Humidity, RH			CO_2			NH_3		
	Inside the House			Outdoors			Inside the House			Exhaust Air			Exhaust Air		
	Mean °C	(SD)	N[1]	Mean °C	(SD)	N[1]	Mean %	(SD)	N[1]	Mean (Range) ppm	(SD)	N[1]	Mean (Range) ppm	(SD)	N[1]
Floor housing system															
28 Febr–5 March	19.7[E]	(0.34)	6	– [-8.6	(–) (2.74)	0 6][G]	59[E]	(0.5)	6	1800[IR] (1514–2084)	(191)	6	71.7[IR] (66–79)	(4.8)	6
29 March–3 April	21.4[H]	(0.09)	6	2.5 [0.8	(1.20) (1.15)	6 6][G]	58[H]	(2.1)	6	1750[DIFF] (1224–2143)	(401)	6	98.2[DIFF] (85–117)	(14.1)	6
Multilevel system															
1 March–9 March	17.9[E]	(0.79)	9	-7.9 [-10.0	(1.48) (2.66)	3 9][G]	64[E]	(3.2)	9	2066[IR] (1637–2417)	(281)	9	30.0[TUBE] (–)	(–)	1
28 March–7 April	16.1[H]	(0.44)	11	2.1 [0.7	(0.60) (1.13)	11 11][G]	65[H]	(2.5)	11	1723[IR] (1550–1963)	(123)	11	32.3[IR] (21–42)	(6.8)	11
Furnished Cages															
6 March–10 March	14.5[H]	(2.01)	5	-6.1 [-11.4	(4.34) (1.80)	5 5][G]	–*	(7.2)	5	2499[IR] (2244–2878)	(303)	5	5.2[IR+DIFF] (2.5–12)	(4.1)	5

[1]N = No. of days with measurements; * No values because of instrument failure; [E] Exhaust air inside the house; [H] Approximately 1.8 m above the floor inside the house; [G] Outdoor temperatures registrated at Gardemoen airport, Oslo; [IR] Measurement using IR-instrument; [DIFF] Measurement using diffusion tubes; [TUBE] Detection tubes, average for 2 measurements

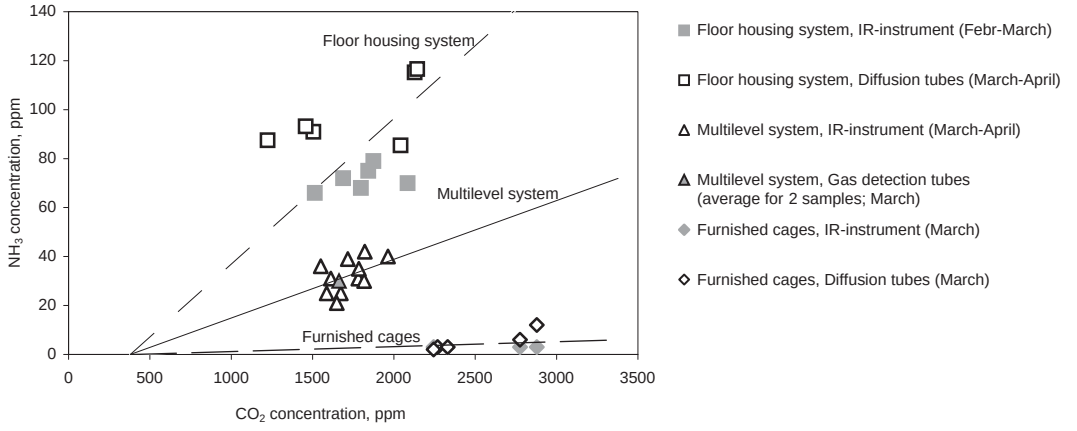

Figure 2. Ammonia concentrations versus carbon dioxide concentrations for separate days, measured at three farms with different housing systems.

multilevel system and the building with furnished cages contained about the same amount of dust (1.5–2.5 mg·m^{-3}). In one sample from the house with a multilevel system the concentration was lower (0.71 mg·m^{-3}). Dust concentrations between 6.8 and 18 mg·m^{-3} were found in the house with floor housing. A significant increase in dust concentration over time (3–4 weeks) was found in the floor housing system and the multilevel system (ANOVA, log transformed dust concentrations, $p<0.05$ for different periods). Two samples taken from the egg packing room in the floor housing system indicated that dust concentration here was less than 1% of the concentration inside the poultry house (0.04 and 0.05 mg·m^{-3}).

In the house with the multilevel system, concentrations were lower at the floor and at the upper zone of the house than at human breathing height. In the house with furnished cages, concentrations were lower in samples collected close to the wall than at the centre of the house.

Table 5. Average concentrations of dust and bacteria in the breathing zone at central places in the buildings.

System	Dust, mg · m^{-3}						Bacteria, 10^7 cells · m^{-3}					
	N[1]	Mean[2]	(SD)	(Range)	GM[3]	(GSD)[4]	N[1]	Mean[2]	(SD)	(Range)	GM[3]	(GSD)[4]
Floor housing	3	12	(5.4)	(6.84–17.65)	11	(1.5)	2	8.8	(1.1)	(8.0–9.6)	8.8	(1.1)
Multi level system	8	1.8	(0.53)	(0.71–2.38)	1.7	(1.4)	3	2.8	(0.60)	(2.2–3.4)	2.8	(1.2)
Furnished cages	3[5]	2.3	(0.22)	(2.05–2.48)	2.2	(1.1)	3	1.6	(0.55)	(1.1–2.2)	1.6	(1.3)
All systems	14	4.1	(4.8)	(0.71–17.65)	2.7	(2.3)	8	3.9	(3.1)	(1.1–9.6)	3.0	(2.0)

[1]N = No. of days with measurements; [2]Mean = Arithmetic mean; [3]GM = Geometric mean; [4]GSD= Geometric standard deviation; [5]Samples taken close to the wall are not included.

Table 6. CR and TR values for ammonia in the different systems.

	Instantaneous measurements during visits							Longer-term measurements						
System	Farms	CR NH_3			TR NH_3			Farms	CR NH_3			TR NH_3		
		Average	(SD)	N[1]	Average	(SD)	N[1]		Average	(SD)	N[2]	Average	(SD)	N[2]
	No.	ppm · ppm^{-1}		No.	ppm · °C^{-1}		No.	No.	ppm · ppm^{-1}		No.	ppm · °C^{-1}		No.
Floor housing	2*	0.0500	(0.0246)	3	2.6	(0.70)	3	1	0.063	(0.018)	12	5.2	(0.73)	6
												[3.7	(1.3)	12][G]
Multilevel system	3	0.0250	(0.0064)	6	1.9	(0.56)	6	1	0.024	(0.0043)	12	2.3	(0.40)	11
												[2.0	(0.53)	12][G]
Furnished cages	3	0.0037	(0.0027)	5	0.12	(0.022)	5	1	0.0023	(0.0015)	5	0.23	(0.11)	5
												[0.19	(0.13)	5][G]

*One farm with supplemental heat is not included in the average values; [G]TR ammonia calculated from outdoor temperatures measured at Gardemoen airport, Oslo; [1]No. of measurements; [2]No. of days with measurements.

Table 7. CR and TR values for dust in the breathing zone during measurements in the different systems.

System	CR Dust			TR Dust		
	Average	(SD)	N[1]	Average	(SD)	N[1]
	mg · m^{-3} · ppm		No.	mg · m^{-3} · °C^{-1}		No.
Floor housing	0.011	(0.0058)	3	0.63	(–)	1
Multilevel system	0.0014	(0.0004)	7	0.13	(0.036)	7
Furnished cages	0.0011	(0.0001)	3[2]	0.13	(0.006)	3[2]

[1]N = No. of days with measurements; [2]Samples taken close to the wall are not included.

Table 8. Ventilation rates and ammonia emissions calculated from carbon dioxide balances in the different systems.

System	Ventilation rate		Ammonia emission per unit area		Ammonia emission per hen	
	Average (SD)	N[1]	Average (SD)	N[1]	Average (SD)	N[1]
	m^3 · h^{-1}	No.	mg · m^{-2} · s^{-1}	No.	g · day^{-1} · hen^{-1}	No.
Floor housing	7800 (1900)	12	0.18 (0.051)	12	2.1 (0.60)	12
Multilevel systems	20000 (1700)	12	0.16 (0.029)	12	0.78 (0.14)	12
Furnished cages	6900 (940)	5	0.010 (0.006)	5	0.075 (0.048)	5

[1]N = No. of days with measurements

Bacterial concentrations differed significantly among samples from the different systems (Kruskal-Wallis test, p=0.04; Fisher's pairwise comparisons, 95% CI). Using Tukey's pairwise comparisons (95% CI), bacteria concentrations were found to be significantly higher in the floor housing compared to the multilevel house and the house with furnished cages. Bacterial concentrations increased with increasing dust concentrations, $r_{Pearson} = 0.96$, $p < 0.001$ (Fig. 1).

Carbon dioxide ratios and temperature ratios. CR and TR values for ammonia measured at all 9 farms and in the longer-term measurements at 1 farm of each type are shown in Table 6. CR values for ammonia were significantly higher in the floor housing than in the multilevel system, and CR values were significantly higher in the multilevel system than in the system with furnished cages (Kruskal-Wallis test, $p < 0.001$; Tukey's pairwise comparisons, CI 95%).

Ammonia concentrations plotted against carbon dioxide concentrations during different days of the longer-term measurements are shown in Figure 2. Trend lines are also shown for the different systems, assuming zero ppm ammonia when the indoor concentration of carbon dioxide is equal to an outside concentration of 380 ppm.

CR and TR values for dust in the human breathing zone at the 3 selected farms are shown in Table 7. Dust concentration (CR dust) in the human breathing zone was significantly higher in the floor housing than in the multilevel system and the system with furnished cages (Kruskal-Wallis test, p=0.02; Tukey's pairwise comparisons, 95% CI).

Ammonia emission. Ammonia emissions calculated from carbon dioxide balances during longer-term measurements at the three selected farms with different systems are shown in Table 8.

DISCUSSION

Daily average concentrations of ammonia were 3–12 ppm in the house with furnished cages, 21–42 ppm in the multilevel system, and 66–120 ppm in the floor housing system. Concentrations of total dust at representative places were 2.0–2.5 mg·m^{-3} in the house with furnished cages, 0.71–2.4 mg·m^{-3} in the multilevel system, and 6.8–18 mg·m^{-3} in the floor housing system. The concentration of bacteria at the same places was 1.1–2.2·10^7 cells per m^3 in the house with furnished cages, 2.2–3.4·10^7 cells per m^3 in the multilevel system, and 8.0–9.6·10^7 cells per m^3 in the floor housing system. A study of dose-response relationships for poultry workers showed that exposure levels associated with significant pulmonary function impairment were as follows: 2.4 mg·m^{-3} total dust, 0.16 mg·m^{-3} respirable dust, 614 EU·m^{-3} endotoxin, and 12 ppm ammonia [12]. Total dust and ammonia were the most important because these agents showed the strongest associations with decline in FEV_1 (Forced Expiratory Volume, 1 second) and $FEF_{25–75}$ (Forced Expiratory Flow rate between 25–75% vital capacity), respectively. Ammonia concentration in the house with furnished cages was well below these values (on average 5.2, SD 4.1), and total dust concentration was of the same magnitude or lower. In contrast, in the multilevel system ammonia concentration was considerably higher, and in the floor system both ammonia and dust concentrations were very much higher than these values. The indoor air appears to be considerably healthier in the house with furnished cages than in the other systems.

Ammonia. Ammonia concentrations showed large differences between the 3 systems. Highest concentrations (on average 85 ppm) were found in the system with most manure stored inside the building (floor housing), lower concentrations (on average 32 ppm) was found in the system with smaller amounts of manure inside (multilevel system), and the lowest concentrations (on average 5 ppm) were found in the system with furnished cages where the smallest amount of manure was stored inside. This is in agreement with other studies where it has been suggested that manure, litter and temperature are crucial factors for ammonia concentrations in poultry houses [1, 50], although several other factors like ventilation rate, air velocity, animal weight and animal

density have been shown to affect the concentration [21, 24]. Manure from the whole production period was stored in the floor housing system, while the manure was removed by conveyer belts every 5 days in the system with furnished cages. In systems with frequent manure removal, ammonia emissions are usually low [21, 67, 76]. For example, in a study of traditional battery cages and daily removal of manure, a value of 2–6 ppm was recorded [49]. Similar to findings here, other researchers also have found high ammonia concentrations in loose housing systems. In a study of Swedish loose housing systems for laying hens, the threshold of 25 ppm was exceeded during the winter in the majority of houses, and concentrations up to 80 ppm were observed [76].

The ammonia emission in the current study, calculated per hen, was 0.075 g·day^{-1} (27.2 g·hen^{-1}·year^{-1}) in the system with furnished cages, 0.78 g·day^{-1} (283 g·hen^{-1}·year^{-1}) in the multilevel system, and 2.05 g·day^{-1} (750 g·hen^{-1}·year^{-1}) in the floor housing. Thus, emissions were about 10 times higher in the multilevel system and about 25 times higher in the floor housing, compared with the system with furnished cages. Such large differences have also been found in another study, where systems with indoor composting of manure had a more than 10-fold increased ammonia production than systems with battery cages and daily removal of the manure by manure belts under the cages [20].

The temperature inside the house with furnished cages was low compared with the other 2 systems, which may have contributed to reduced emissions, since ammonia release increases with temperature and humidity [50] as well as with moisture content in the litter [22]. In experiments with broilers, an increase in air humidity was correlated with increased moisture in the litter and with litter caking [72]. A fast drying rate of the manure is considered important for reduction of ammonia release in poultry houses [20]. This can be achieved by a heat supply, and floor heating should lead to a specifically fast drying rate. It is worth noting that the measurements in the house with floor housing and supplemental heating showed ammonia concentrations below 10 ppm. In the multilevel house, litter caking was observed, which may have increased the ammonia release. According to the farmer, the caking was related to the feed composition where wheat was included. Less wheat and a better balance of salt, fat and enzymes was meant to decrease the problems. Another reason might be insufficient floor insulation [76].

Moist litter is not only a problem for air quality; it may also result in breast burns and foot lesions in the birds [72]. Decreased thickness of the litter layers has been observed to decrease the amount of foot lesions in broilers. Thick layers of litter may lead to decreased floor temperature and increased moisture content from a changed moisture balance and condensation. In the floor housing system, much of the ammonia most likely originated from large amounts of moist manure in the manure bin. However, the thick litter bed (estimated thickness 30 cm) also may have significantly contributed to the high ammonia concentration.

For animal welfare reasons the Norwegian egg industry has set a goal that ammonia levels in poultry houses should not exceed 20 ppm. The occupational exposure limit (OEL) value for 8 hours work in Norway is 25 ppm. These exposure limits were exceeded in the multilevel and floor housing systems, although the concentrations occasionally were below the OEL in the multilevel system. Mean ammonia concentrations in the floor housing greatly exceeded the OEL during all days of the study, and the maximum value during part of a day, 160 ppm, was unacceptably high at 6 times the OEL. Such high ammonia concentrations not only pose human and animal welfare problems, but also reduce production [2]. If hens could chose they would probably avoid the floor housing and multilevel systems. Following the results of Kristensen *et al.* [31], the concentration acceptable to the birds is likely somewhere between 0–25 ppm. Thus, only the air in the system with furnished cages may be endurable for birds as well as for workers.

Dust and bacteria. Dust concentrations in the breathing zone were considerably higher in the floor housing (12 mg·m^{-3}) than in the multilevel system (1.8 mg·m^{-3}) and the system with furnished cages (2.3 mg·m^{-3}). Total dust concentrations in the floor housing system was high, up to 18 mg·m^{-3}, but in another study of poultry houses an even higher concentration was found, 21 mg·m^{-3} [19]. High concentrations of dust have been found in animal houses with much litter [27]. In a study of Swedish floor housing systems, concentrations below 3 mg·m^{-3} were observed at most farms, with concentrations at a few farms of 5–6 mg·m^{-3}, probably because of moulting or large litter areas [76]. The high concentration in the floor housing system in the present study was probably caused by the litter area with deep and dry litter, where many hens also laid their eggs. Hen activity may also have increased dust concentrations [47, 52]. Compared with the floor housing, dust concentrations were low in the multilevel system and in the system with furnished cages, probably because there was less dry litter in these systems. It is interesting that the dust concentrations in the present study (geometrical mean 2.7 mg·m^{-3} with a geometrical standard deviation of 2.3) were of the same magnitude as concentrations found in an earlier study of Norwegian poultry farmers and their work environment (geometrical mean of 5 mg·m^{-3} with a geometrical standard deviation of 2.9) [37].

In Sweden, the maximum allowed concentration of dust in poultry houses is 10 mg·m^{-3} [64]. This was exceeded in the floor housing system (6.8–18 mg·m^{-3}), but not in the other systems, where concentrations were clearly below 5 mg·m^{-3}, the OEL for organic dust for 8 hours work in Sweden and Norway [5, 65]. It has been argued that the total amount of dust in poultry houses can be decreased by the use of various techniques but not the amount of respirable dust, i.e. particles smaller than 5 μm [16]. However, it should be possible to decrease the amount of these particles in the breathing zone by the use of a different ventilation

technique, e.g. low velocity inlets placed in the lower zone of the house. In specific cases, biofilters might be an option to reduce airborne dust, bacteria and odorants [7, 69].

The microbial component in the organic dust is a reason for keeping concentrations of organic dust low (preferably less than 5 mg·m^{-3}). In the present study, most samples contained 10^7–10^8 bacteria cells per m^{-3}. The highest concentrations were observed in the floor housing system. Similar findings were reported for endotoxin, a cell wall component of Gram-negative bacteria, that was present with higher concentrations in an aviary system than in a house with traditional cages [43]. The bacterial concentrations showed a strong positive correlation with total dust concentration, which seems plausible considering the origin of the dust. Such a correlation was also found in another Norwegian study [14]. The bacteria concentration in the present study (geometrical mean $3.0 \cdot 10^7$ bacteria cells per m^{-3} with a geometric standard deviation of 2.0) was of the same magnitude as concentrations during poultry tending found in another study of Norwegian farmers ($4.8 \cdot 10^7$ bacteria cells per m^{-3} with a geometric standard deviation of 8.6) [37].

Although pollutant concentrations were low in the system with furnished cages, the air in this system may still contain to high concentrations of certain compounds. For example, endotoxin concentrations in the airborne dust in poultry houses may reach 860 ng·m^{-3} which can be compared to proposed OEL of 5 ng·m^{-3} [25]. Endotoxin levels were not measured in the present study.

Carbon dioxide ratios and temperature ratios. The ventilation rate has a significant impact on the concentrations of pollutants inside animal houses, and problems with high ammonia levels are greatest in winter. As expected, the highest ammonia levels occurred on very cold days when the ventilation rate was decreased to keep the indoor temperature on the setpoint value. CR and TR ratios may provide reliable information when comparing ammonia concentrations in different housing systems, and perhaps also when comparing dust concentrations, although dust is thought to vary less with ventilation rate than does ammonia. In the present study, significant differences among these values were found for the different systems.

CONCLUSIONS

Pollutant emissions and concentrations in different systems vary with management procedures and available technical equipment, e.g. the use of supplemental heat. The number of farms included in the current study and the number of samples taken in each building was limited; thus, it is not possible to generalise conclusions about differences in air quality between different housing systems. However, the findings in this study are in accordance with other studies. The following conclusions, although limited, can be drawn from this study:

• CR values for ammonia (ammonia concentrations) were significantly higher in the floor housing than in the multilevel system and the system with furnished cages, and significantly higher in the multilevel system than in the system with furnished cages.

• Ammonia concentrations higher than 25 ppm were frequently observed in the multilevel system, and concentrations much higher than 25 ppm were frequently observed in the floor housing system.

• Dust concentrations in the human breathing zone were significantly higher in the floor housing than in the multilevel system and the system with furnished cages.

• Dust concentrations in the floor housing system exceeded 5 mg·m^{-3} (the Swedish and Norwegian occupational exposure limit).

• Bacteria concentrations in the human breathing zone were significantly higher in the floor housing than in the multilevel system and the system with furnished cages.

• Bacteria concentration increased with increasing dust concentration.

• Both ammonia and dust concentrations in the house with furnished cages were of the same magnitude or lower than values previously found to impair the pulmonary function of poultry workers.

In the floor housing system, concentrations of ammonia, dust and bacteria were all high; the high ammonia concentration was in itself a reason for improvements considering both animal welfare and the work environment. Considering synergistic effects that may occur, the actual situation may be even more critical. Supplemental heat can be a way to decrease the gas concentrations inside the house when outside temperatures are low. The high concentrations of air pollutants found in the present study indicate the need for further technical development and research regarding welfare-oriented systems for laying hens. It is important to develop preventive measures and solutions to air quality problems before the EU ban on conventional cages comes into force in 2012.

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