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Field Survey on Concentration and Emission of Dust in Different Types of Poultry Houses of South Korea

Ki Youn Kim [1] and Han Jong Ko [2,*]

[1] Department of Safety Engineering, Seoul National University of Science & Technology, Seoul 01811, Korea; kky5@seoultech.ac.kr
[2] Department of Agricultural Sciences, Korea National Open University, Seoul 03087, Korea
* Correspondence: khjong333@knou.ac.kr; Tel.: +82-2-3668-4633; Fax: +82-2-3673-2381

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Abstract: The dust generated from poultry houses has an adverse effect on farmers and poultry in terms of hygiene and welfare problems. However, there is little information on concentration and emission of dust derived from poultry houses located in South Korea. An objective of this study is to provide fundamental data regarding particulate matters generated from the poultry houses situated in South Korea. A total 27 poultry houses, including nine broiler houses, nine layer houses, and nine layer houses with feces conveyors were surveyed. Dust was measured by gravimetric methods. Emission of dust was calculated by multiplying the mean concentration (mg/m^3) measured at the center of the poultry house by the ventilation rate (m^3 h^{-1}). Mean indoor concentrations of total and respirable dust in poultry houses were 4.39 (SD: 2.38) mg/m^3 and 2.33 (SD: 2.21) mg/m^3, respectively. Mean emission rates based on area and rearing number were estimated as 3.04 (±1.64) mg head^{-1} h^{-1} and 57.48 (±24.66) mg m^{-2} h^{-1} for total dust and 2.34 (±1.27) mg head^{-1} h^{-1} and 26.80 (±10.81) mg m^{-2} h^{-1} for respirable dust, respectively. The distribution of total and respirable dust between indoor concentration and emission rate was a similar pattern, regardless of type of poultry house. Among types of poultry house, the broiler house showed the highest levels of indoor concentration and emission rate, followed by the layer house with feces conveyor belt, and the caged layer house. In terms of seasonal aspect, indoor concentrations of total and respirable dust were highest in winter and lowest in summer, and their emission rates were the opposite at all the poultry houses. In spring and autumn, both indoor concentration and emission rate were moderate, and there was no significant difference between spring and autumn. It was assumed that the levels of indoor concentration and emission rate of dust generated from poultry houses were determined mainly by use of bedding material and ventilation rate among various environmental agents.

Keywords: poultry house; dust; concentration; emission rate

1. Introduction

Recently, social concerns and regulations regarding environmental pollution and health problems caused by the poultry industry have increased, due to intensive livestock enterprise development and implementation. In particular, air pollutants generated from poultry houses can be affected in a very wide range of fields, and the development and implementation of measures for maintaining optimal air pollutants is urgent at the present stage.

In terms of macro perspective, air pollutants released from poultry houses can provoke an acceleration of global warming by ozone layer destruction [1–3] and airborne spread of disease inducers, such as avian influenza virus [4–7]. In the case of microscopic viewpoint, they can cause a decreased productivity of chicken [8–10], increase in odor complaints in the surrounding area [11–13], and farmers' respiratory diseases such as asthma, rhinitis, and bronchitis, induced by inhalation exposure [1,14,15]. It was reported by several epidemiological studies that poultry farmers exposed to high concentrations of dust may suffer from various types of respiratory diseases such as organic dust toxic syndrome, farmer's lung disease, and occupational allergies [16–18]. Therefore, the workers in the poultry industry can be estimated to be exposed to a considerable amount of respirable dust, which implicates the occurrence potential of respiratory diseases simultaneously. In summary, air pollutants emitted from poultry houses can cause severe cardiovascular and respiratory diseases, as well as air quality decrease and living environment condition degradation. Furthermore, contributing to global warming would be one negative impact from the poultry houses, while there are more direct impacts to the atmospheric environment and public health.

Among the air pollutants, the dusts generated in poultry houses are organic particles derived from feed, feces, feathers, and litter [19,20]. Although the dust distribution according to particle size varies depending on the indoor ventilation condition and the feeding methods, it was reported that the number of particles ≤5 μm accounted for 70% to 95% of the total number of particles in poultry houses [21]. Broiler houses indoor particulate matter (PM) concentrations regularly exceed the recommended maximum concentrations of 3.4 and 1.7 mg/m^3 for inhalable and respirable PM, respectively [22].

However, the majority of most studies in South Korea on the evaluation of the work environment related to the livestock industry that have been carried out or reported focused on pig farm workplaces [5,23]. In addition, it is difficult to objectively quantify the concentration distribution of air pollutants according to the type of pig house, as these studies were conducted only in some seasons, without consideration of the seasonal climate characteristics of South Korea. Meanwhile, the South Korea government has taken steps to enhance the overall environment of poultry farms to expand eco-friendly farms.

Therefore, the objective of this study is to provide basic research data for assessing the exposure level of dust in poultry farmers, and preparing its management measures by measuring indoor concentration and emission rates of dust according to type of poultry houses in South Korea.

2. Materials and Methods

2.1. Study Details

Poultry houses of South Korea are categorized into caged layer houses, broiler houses, and layer houses with feces conveyor belts, according to the purpose of breeding (meat and egg-laying), manure handling (bedding, scraper, or feces conveyor belt), and type of ventilation (forced or natural). The caged layer house is designed to confine chickens to cages and produce only eggs. The broiler house is a vinyl house-type cage where poultry are raised from the floor with bedding material such as sawdust or chaff, for the purpose of producing chicken meat. The layer house with feces conveyor belt is a high-tech house for producing eggs that removes manure by belt transport.

The survey sites were randomly selected for each type of poultry house located in nine provinces nationwide (Gyeonggi, Gangwon, Chungbuk, Chungnam, Kyungbuk, Gyeongnam, Jeonbuk, Jeonnam, and Jeju). In order to reflect the seasonal conditions of South Korea, the survey period was set in spring (March to May), summer (June to August), autumn (September to November), and winter (December to February) for one year, 2016, and the field visit survey was conducted for each poultry house. Table 1 presents the details of the poultry houses investigated in this study.

2.2. Measurement

Dust were sampled for at least 6 h to calculate time-weighted average (TWA) concentration at 1.2 m above the floor at three locations of the central alley in the poultry houses.

Table 1. Overview of poultry houses investigated in this study.

No	Workplace Type	Manure Treatment	Ventilation		Poultry Type	Area (m^2)	No. of Poultry	No. of Worker
			Mode	Mean Airflow Rate (m^3/h)				
1	**Broiler house**	**Bedding**	**Natural**	**1.83**	**Broiler**	128	2634	3
2				0.91		109	2429	3
3				0.88		132	2376	4
4				1.27		141	2514	3
5				1.19		181	2483	2
6				1.64		153	2620	3
7				0.81		149	2504	2
8				1.13		137	2498	2
9				1.76		142	2386	3
1	Caged layer house	Scraper	Forced	0.78	Layer	231	5018	3
2				1.37		284	5089	3
3				1.32		256	5135	4
4				0.86		249	4628	2
5				1.28		276	5324	3
6				1.23		271	6294	2
7				1.42		253	6272	4
8				1.29		248	6637	4
9				1.31		254	6325	2
1	Layer house with feces conveyor belt	Manure conveyor belt	Forced/ Natural	0.79	Layer	262	5518	2
2				1.08		258	5624	3
3				0.79		249	5587	3
4				1.28		263	6262	4
5				0.85		252	5639	3
6				1.23		237	6127	3
7				0.79		238	5327	3
8				1.18		271	6528	4
9				1.26		249	5431	3

The concentration of dust was measured by the gravimetric method. The glass fiber filters (37 mm diameter, 0.8 μm pore size, Nuclepore Corp., Pleasanton, CA, USA) were dried in a desiccator for 24 h and weighed, under controlled atmosphere to avoid rehydration, before and after collecting dust with a microbalance (Ohaus model AP250D, Greifensee, Switzerland). For the correction of the concentration value, two blank samples were prepared for each sampling, and the final concentration values were calculated by reflecting the blank values.

A low-volume air sampling pump (Model71G9, Gillian Corp., West Caldwell, NJ, USA) was used for collecting dust. Its flow rate for collecting dust was calibrated to 2.0 L min^{-1} for total dust and 1.7 L min^{-1} for respirable dust, respectively. The total dust means all dust, regardless of particle size, and the respirable dust means dust with a particle size of 10 µm or less. Additionally, the proper flow rate for collecting total dust and respirable dust was a value suggested by the collection equipment. The flow rate after air sampling was measured to correct the variation of the flow rate caused by the procedure of air sampling. Total dust was collected in close-faced plastic cassette (NucleporeCorp., Pleasanton, CA, USA) and respirable dust was collected through 10 mm cyclone preselectors (Gillian Corp., West Caldwell, NJ, USA).

2.3. Emission Rate

An emission amount of total and respirable dust was calculated by multiplying the mean concentration (mg/m^3) measured in the poultry houses by the ventilation rate (m^3/h). Dust concentration measurement locations were close to a wall-mounted ventilation fan in the poultry houses, applied with forced ventilation mode apartment, and next to a winch curtain on the wall in the poultry houses, applied with natural ventilation mode. The ventilation rate was calculated by multiplying the air velocity by the area of the exhaust fan for the enclosed poultry houses operated with mechanical ventilation, and by multiplying air transfer rate by house area for the open poultry houses operated with natural ventilation. The housing area of each poultry house and the total weight of chickens were surveyed to estimate the emission rate. The housing area of the poultry houses were measured with tapeline or, in case of the poultry house not permitted to enter, with assistance of the farmer. Because it is not possible to practically measure the total weight of all the chickens that are raised in a housing room, the breeding data received from the farmer were utilized to estimate this after assuming 1.5 kg to be one chicken's weight. The rationale for setting the weight of one chicken as 1.5 kg is based on the reference values in the feeding standard as the concept of animal unit (AU).

Finally, the emission rates of total and respirable dust were calculated based on the unit number (head) and unit area (m^2). The whole applied calculation formulae are shown in Equations (1) and (2).

$$\text{Emission amount (mg/h)} = \text{mean indoor concentration (mg/m}^3) \times \text{ventilation rate (m}^3\text{/h)} \quad (1)$$

$$\text{Emission rate (mg m}^{-2}\text{h}^{-1} \text{ or mg head}^{-1}\text{h}^{-1}) = \text{emission amount (mg/h)} \div \text{housing area (m}^2) \text{ or rearing number (head)} \quad (2)$$

$$\text{Emission amount (mg/h)} = \text{mean indoor concentration (mg/m}^3) \times \text{air transfer rate (m/h)} \times \text{housing area (m}^2) \quad (3)$$

$$\begin{gathered}\text{where air transfer rate} = 5.184 \times 10^{-1} \text{ m/sec (based on mass transfer theory)} \\ \text{Emission rate (mg m}^{-2}\text{h}^{-1} \text{ or mg head}^{-1}\text{h}^{-1}) = \text{emission amount (mg/h)} \div \text{housing area (m}^2) \text{ or rearing number (head)}\end{gathered} \quad (4)$$

2.4. Data Analysis

The data obtained from this study were tested by regularity verification to confirm if it shows normal distribution. The statistical differences of indoor concentration and emission rate of total and respirable dust according to the type of poultry house were verified through multiple comparison analysis method (ANOVA and Duncan), using the SAS package program (SAS/STAT Inc., Ver 6.2, Cary, NC, USA).

3. Results and Discussions

3.1. Indoor Concentration Distribution

As indicated in Figure 1, indoor concentrations of total and respirable dust in poultry houses show the log-normal distribution and are presented as the geometric mean and geometric standard deviation (GSD). The mean concentrations of total and respirable dust were 3.66 (2.13) mg/m^3 and 1.99 (2.07) mg/m^3 for caged layer houses, 5.08 (2.64) mg/m^3 and 2.75 (2.38) mg/m^3 for broiler houses, and 4.42 (2.38) mg/m^3 and 2.25 (2.18) mg/m^3 for layer houses with feces conveyor belts, respectively. Regardless of the type of poultry house, the mean levels were estimated as 4.39 (2.38) mg/m^3 for total dust and 2.33 (2.21) mg/m^3 for respirable dust, respectively. The levels of total dust in poultry houses of South Korea cannot be compared because there is no previous research data from foreign countries. In the case of respirable dust, mean concentrations of respirable dust in caged layer houses were high [24,25], while those in broiler houses were low [1,26–29], compared with the results reported from previous foreign studies. Based on the results obtained from this study, concentration distribution patterns of total and respirable dust were different according to the type of poultry house. Both total and respirable dust were the highest in the broiler houses, followed by layer houses with feces conveyor belts, and caged layer houses ($p < 0.05$).

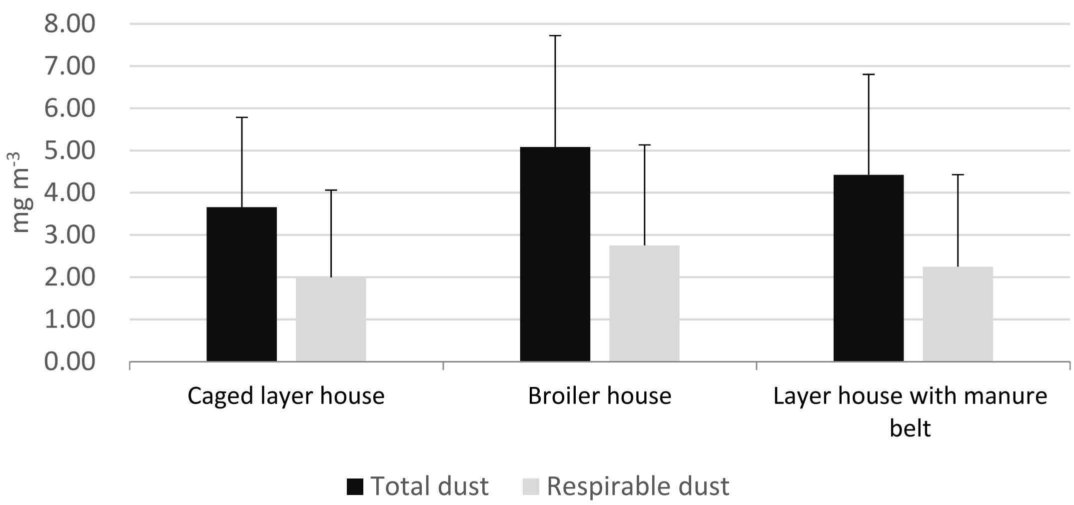


Figure 1. Mean concentrations of total and respirable dust, according to type of poultry house (the error bar represents the geometric standard deviation of the measurement data).

The reason why the levels of total and respirable dust are highest in the broiler houses among the types of poultry house is as follows. In the case of the broiler houses, the chickens were laid on a floor consisting of sawdust as a bedding material, and thus the sawdust and mixed feces would be scattered into the air every time the chickens moved. Therefore, it can be said that the level of dust generation is relatively higher in the broiler houses than in the layer houses with feces conveyor belts and caged layer houses that are operated with cage systems without using sawdust as a bedding material.

Table 2 shows the log-normal distribution of total and respirable component dust by type of poultry house according to seasonal aspect. The geometric mean concentrations and geometric standard deviation (GSD) of total and respirable dust were 4.41 (2.14) mg/m^3 and 2.35 (1.15) mg/m^3 in spring, 4.00 (1.94) mg/m^3 and 1.76 (0.84) mg/m^3 in summer, 4.16 (2.19) mg/m^3 and 1.93 (0.82) mg/m^3 in autumn, and 4.98 (2.29) mg/m^3 and 3.29 (1.68) mg/m^3 in winter, respectively. Based on the results, regardless of the type of poultry house, the mean indoor concentrations of total and respirable dust were highest in winter and lowest in summer ($p < 0.05$), while spring and fall were similar ($p > 0.05$), regardless of type of poultry house.

Table 2. Seasonal levels of total and respirable dust in poultry houses.

		Spring		Summer		Autumn		Winter	
		GM *	GSD **	GM	GSD	GM	GSD	GM	GSD
Total dust (mg/m^3)	Caged layer house (n = 9)	3.71	1.85	3.23	1.62	3.39	1.92	4.29	2.03
	Broiler house (n = 9)	5.14	2.62	4.69	2.06	4.78	2.31	5.72	2.46
	Layer house with feces conveyor belt (n = 9)	4.39	1.94	4.07	2.13	4.31	2.34	4.92	2.38
	Mean (n = 27)	4.41	2.14	4.00	1.94	4.16	2.19	4.98	2.29
Respirable dust (mg/m^3)	Caged layer house (n = 9)	1.92	0.84	1.53	0.92	1.83	0.29	2.69	1.36
	Broiler house (n = 9)	2.76	1.26	1.96	0.84	2.62	1.35	3.67	1.89
	Layer house with feces conveyor belt (n = 9)	2.37	1.35	1.78	0.76	1.33	0.86	3.51	1.78
	Mean ((n = 27)	2.35	1.15	1.76	0.84	1.93	0.82	3.29	1.68

* Geometric mean; ** Geometric standard deviation.

Seasonal difference in dust concentration is presumed to be due to variable ventilation rate. Although there were little seasonal differences in the generation of total and respirable dust, relatively high ventilation rates in summer, low ventilation rates in winter, and moderate ventilation rates in spring and autumn were applied to maintain the optimal temperature and relative humidity for rearing chickens.

The current Korea Occupational Safety and Health Act (KOSHA) recommends occupational exposure limits (OELs) of 10 mg/m^3 for total dust. The concentrations of total and respirable dust in the poultry houses measured by this study were found to be below the exposure limit, regardless of season and poultry house type. However, considering the relationship between dust exposure and the occurrence of respiratory illnesses in poultry farmers, and their suggestion that a management standard of 2.4 mg/m^3 should be applied for health protection [30], the risk of respiratory disease in poultry farmers due to dust exposure in South Korea is not low.

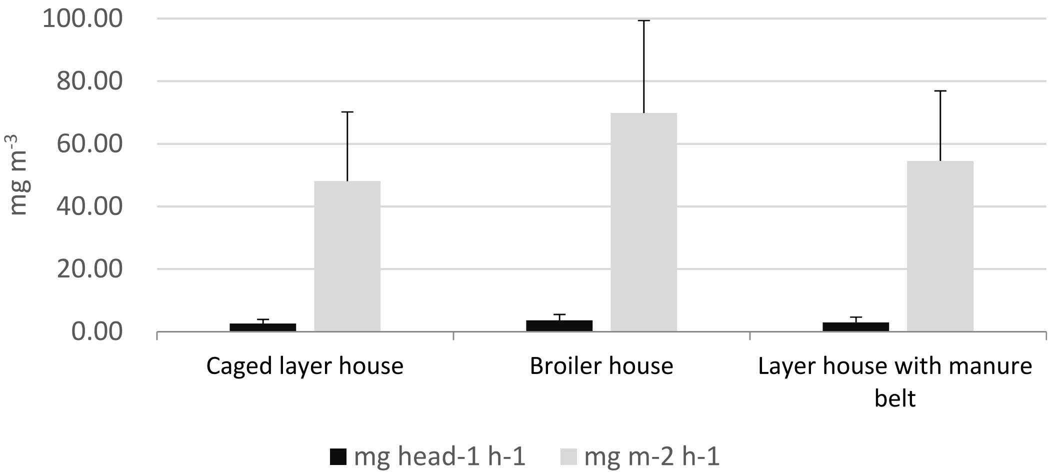
Table 3 presents the foreign data of field surveys on the concentrations of total and respirable dust in poultry houses. As a result of the overseas data related to particulate matter concentration measured in poultry houses, most of them were investigated centering on the broiler house, and the research was mainly performed on the inhalable dust corresponding to total dust ratio. As the measurements and analyses of particulate matter were applied in different ways in the case of overseas research results, and they differ in the items of the particulate pollutants, i.e., total dust, measured in this study, it is necessary to consider that a simple comparison of the numerical results reported from overseas studies with measurement data obtained from this study lacks objectivity.

Table 3. Review of particulate matter concentrations in poultry houses reported previously.

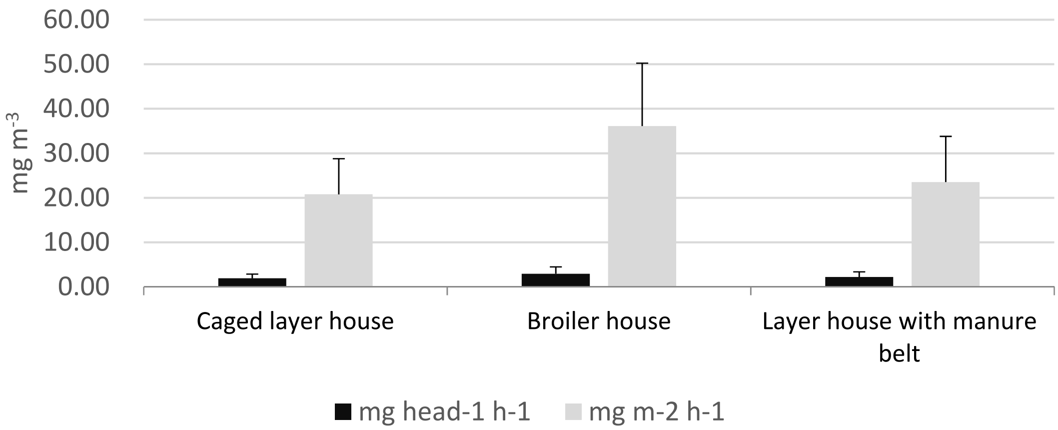
Particulate Matter	Type of Poultry House	Level	Reference
Inhalable dust	Broiler house	10.1 (7–11) mg/m^3	[1]
Inhalable dust Respirable dust	Caged layer house	0.74–1.94 mg/m^3 0.22–0.31 mg/m^3	[24]
Inhalable dust Respirable dust	Broiler house Caged layer house	0.02–81.33 mg/m^3 0.01–6.5 mg/m^3	[25]
Inhalable dust	Broiler house	7.4–11.4 mg/m^3	[26]
Inhalable dust	Broiler house	9.92 mg/m^3 (UK) 10.36 mg/m^3 (Netherlands) 3.83 mg/m^3 (Denmark) 4.49 mg/m^3 (Germany)	[27]
Respirable dust	Broiler house	7.57 mg/m^3	[28]
Respirable dust	Broiler house	0.6–1.63 mg/m^3 1.14 mg/m^3 (UK)	[29]
Respirable dust	Broiler house	1.05 mg/m^3 (Netherlands) 0.42 mg/m^3 (Denmark) 0.63 mg/m^3 (Germany)	[27]

3.2. Emission Rate

As shown in Figure 2, the emission rates of total dust by type of poultry house were 2.59 (±1.32) mg head^{-1} h^{-1} and 48.07 (±22.10) mg m^{-2} h^{-1} for caged layer houses, 3.58 (±1.91) mg head^{-1} h^{-1} and 69.83 (±29.53) mg m^{-2} h^{-1} for broiler houses, and 2.94 (±1.71) mg head^{-1} h^{-1} and 54.54 (±22.36) mg m^{-2} h^{-1} for layer houses with feces conveyor belts, respectively.



(**a**) Total dust



(**b**) Respirable dust

Figure 2. Mean emission rates of total (**a**) and respirable dust (**b**), according to type of poultry house (the error bar represents the geometric standard deviation of the measurement data).

Emission rates of respirable dust were 1.90 (±0.96) mg head^{-1} h^{-1} and 20.77 (±8.01) mg m^{-2} h^{-1} for caged layer houses, 2.93 (±1.55) mg head^{-1} h^{-1} and 36.11 (±14.14) mg m^{-2} h^{-1} for broiler houses, and 2.18 (±1.19) mg head^{-1} h^{-1} and 23.53 (±10.26) mg m^{-2} h^{-1} for layer houses with feces conveyor belts, respectively. Regardless of type of poultry house, the mean emission rates were 3.04 (±1.64) mg head^{-1} h^{-1} and 57.48 (±24.66) g m^{-2} h^{-1} for total dust and 2.34 (±1.27) mg head^{-1} h^{-1} and 26.80 (±10.81) mg m^{-2} h^{-1} for respirable dust, respectively.

Unlike the indoor concentration distribution, emission rates of total and respirable dust showed a normal distribution pattern, and hence the arithmetic means and arithmetic standard variations were calculated. The distribution patterns of emission rates of total dust were similar to those of respirable dust. Among the poultry houses, the broiler houses showed the highest emission rates of total and respirable dust, followed by layer houses with feces conveyor belts, and caged layer houses ($p < 0.05$), which were consistent with cases of indoor concentration. This finding can be explained by the fact that the sawdust used as bedding material, feces, and feathers are dispersed into the air as an organic particle when chickens raised in broiler houses are moved.

Table 4 presents the emission rates of total and respirable dust by type of poultry house according to seasonal characteristics. Regardless of type of poultry house, the mean levels of emission rates of total and respirable dust were highest in summer and lowest in winter ($p < 0.05$), while spring and fall were similar ($p > 0.05$).

Table 4. Seasonal emission rates of total and respirable dust in poultry houses.

			Spring		Summer		Autumn		Winter	
			AM *	ASD **	AM	ASD	AM	ASD	AM	ASD
Total dust	Caged layer house (n = 9)	mg head^{-1} h^{-1}	2.23	1.25	5.03	2.31	1.71	0.92	1.38	0.78
		mg m^{-2} h^{-1}	21.38	12.35	59.82	16.38	17.92	10.31	13.16	9.34
	Broiler house (n = 9)	mg head^{-1} h^{-1}	2.62	1.23	7.37	3.93	2.41	1.23	1.92	1.23
		mg m^{-2} h^{-1}	35.08	15.03	106.82	37.23	31.67	13.61	25.76	12.26
	Layer house with feces conveyor belt (n = 9)	mg head^{-1} h^{-1}	2.74	1.33	4.91	2.89	2.34	1.63	1.76	0.98
		mg m^{-2} h^{-1}	31.86	12.44	58.37	14.38	29.32	13.24	18.62	9.38
	Mean (n = 27)	mg head^{-1} h^{-1}	2.53	1.27	5.77	3.04	2.15	1.26	1.69	1.00
		mg m^{-2} h^{-1}	29.44	13.27	75.00	22.66	26.30	12.39	19.18	10.33
Respirable dust	Caged layer house (n = 9)	mg head^{-1} h^{-1}	2.14	0.92	3.13	1.62	1.54	0.83	0.79	0.48
		mg m^{-2} h^{-1}	23.52	8.67	35.34	11.37	18.13	9.34	6.08	2.63
	Broiler house (n = 9)	mg head^{-1} h^{-1}	3.46	1.53	4.72	2.64	2.53	1.32	1.02	0.72
		mg m^{-2} h^{-1}	37.28	14.06	66.21	21.04	28.62	13.24	12.34	8.23
	Layer house with feces conveyor belt (n = 9)	mg head^{-1} h^{-1}	2.36	1.34	3.64	1.63	1.94	1.14	0.79	0.64
		mg m^{-2} h^{-1}	24.37	11.03	42.51	15.31	20.74	12.31	6.51	2.39
	Mean (n = 27)	mg head^{-1} h^{-1}	2.65	1.26	3.83	1.96	2.00	1.10	0.87	0.77
		mg m^{-2} h^{-1}	28.39	11.25	48.02	15.91	22.50	11.63	8.31	4.42

* Arithmetic mean; ** Arithmetic standard deviation.

The reason for the higher emission rates in summer than in winter is the difference in the ventilation rates, unlike the distribution pattern of the indoor concentration of total and respirable dust. Due to the increased outdoor temperature, a relatively high ventilation rate was provided to poultry houses in summer to maintain the optimal temperature for raising chickens, and hence the emissions of total and respirable dust increased. On the contrary, a relatively low ventilation rate was provided in winter, and therefore the emissions of total and respirable dust were also reduced.

There is little information for previous data regarding emission rates of total and respirable dust generated from poultry houses. To the best of our knowledge, the only similar study reported inhalable dust emission rates ranging from 0.58 to 99 g h^{-1} in the broiler houses located in the United States [26]. Moreover, this value does not take into account the number of chickens kept in poultry houses and has a limitation that is simply expressed as the emission amount of inhalable dust per hour. Therefore, it is not possible at present to evaluate the comparison of emission rates of total and respirable dust between the results of this study and foreign data.

3.3. Limitations of this Study

Because there are differences in methods of measurement and analyses of particulate pollutants, discrepancies in the survey items of particulate matter, and lack of previous studies on emission rate data between this study and previous foreign studies, the fact is that it is not possible to relatively compare the results obtained from this study with the results of overseas studies that investigated the levels of exposure and emission of particulate pollutants in the poultry houses, which is one limit of this study.

Furthermore, it is necessary to interpret this measurement data on the assumption that the concentration value measured at one point in a poultry house indicates total concentration, and the ventilation effect is the same throughout the indoor areas of poultry houses for both forced and natural ventilation modes. In order to overcome this limitation, the development of an accurate dust measurement sensor and the sensor-based real time monitoring of dust at various points in poultry houses should be applied in the future. In addition, dust composition analysis should be considered, as the bedding material is one of the main reasons for dust concentration difference in poultry houses.

4. Conclusions

The distribution of total and respirable dust between indoor concentration and emission rates was a similar pattern, regardless of type of poultry house. Among types of poultry houses, the broiler houses showed the highest levels of indoor concentration (geometric mean: 5.08 mg/m^3 and 2.75 mg/m^3 for total and respirable dust) and emission rates (arithmetic mean: 3.58 mg head^{-1} h^{-1} and 2.93 mg head^{-1} h^{-1} for total and respirable dust), followed by the layer houses with feces conveyor belts, and the caged layer houses ($p < 0.05$). In terms of the seasonal aspect, indoor concentrations of total and respirable dust were highest in winter and lowest in summer ($p < 0.05$), and their emission rates were the opposite ($p < 0.05$) at all the poultry houses. In spring and autumn, both indoor concentrations and emission rates were moderate, and there was no significant difference between spring and autumn ($p > 0.05$). These field results are reasoned by the finding that the levels of indoor concentrations and emission rates of dust generated from poultry houses were determined mainly by use of bedding material and differences in ventilation rates applied to each poultry house.

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References

1. Wathes, C.M.; Holden, M.R.; Sneath, R.W.; White, R.P.; Phillips, V.R. Concentrations and emission rates of aerial ammonia, nitrous oxide, methane, carbon dioxide, dust and endotoxin in UK broiler and layer houses. *Br. Poult. Sci.* **1997**, *38*, 14–28. [CrossRef] [PubMed]
2. Hospido, A.; Sonesson, U. The environmental impact of mastitis: A case study of dairy herds. *Sci. Total Environ.* **2005**, *343*, 71–82. [CrossRef] [PubMed]
3. Adrizal, A.; Patterson, P.H.; Hulet, R.M.; Bates, R.M.; Myers, C.A.; Martin, G.P.; Shockey, R.L.; van der Grinten, M.; Anderson, D.A.; Thompson, J.R. Vegetative buffers for fan emissions from poultry farms: 2. ammonia, dust and foliar nitrogen. *J. Environ. Sci. Health* **2008**, *43*, 96–103. [CrossRef] [PubMed]
4. Alexander, D.J. A review of avian influenza in different bird species. *Vet. Microbiol.* **2000**, *7*, 3–13. [CrossRef]
5. Kim, J.A.; Cho, S.H.; Kim, H.S.; Seo, S.H. H9N2 influenza viruses isolated from poultry in Korean live bird markets continuously evolve and cause the severe clinical signs in layers. *Vet. Microbiol.* **2006**, *118*, 169–176. [CrossRef] [PubMed]
6. Malin, K.; Anders, W.; Ake, L.; Bjorn, O.; Maria, B. A real-time PCR assay for the monitoring of influenza a virus in wild birds. *J. Virol. Methods* **2007**, *144*, 27–31. [CrossRef]
7. Mayer, D.; Reiczigel, J.; Rubel, F. A lagrangian particle model to predict the airborne spread of foot-and-mouth disease virus. *Atmos. Environ.* **2008**, *42*, 466–479. [CrossRef]
8. Demmers, T.G.M.; Wathes, C.M.; Richards, P.A.; Teer, N.; Taylor, L.L.; Bland, V.; Goodman, J.; Armstrong, D.; Chennells, D.; Done, S.H.; et al. A facility for controlled exposure of pigs to airborne dusts and gases. *Biosyst. Eng.* **2003**, *84*, 217–230. [CrossRef]
9. Carey, J.B.; Lacey, R.E.; Mukhtar, S. A Review of literature concerning odors, ammonia, and dust from broiler production facilities: 2. flock and house management factors. *J. Appl. Poult. Res.* **2004**, *13*, 509–513. [CrossRef]
10. Rodenburg, T.B.; Tuyttens, F.A.; Sonck, B.; De Reu, K.; Herman, L.; Zoons, J. Welfare, health, and hygiene of laying hens housed in furnished cages and in alternative housing systems. *J. Appl. Anim. Welf. Sci.* **2005**, *8*, 211–226. [CrossRef]

11. Hilliger, H.G.; Langner, H.J.; Hilbig, V.; Heckel, U. Experiments for characterization of odour stuffs contained in the air of the interior of a laying-hen house. *Zentralbl Mikrobiol.* **1971**, *155*, 87–92.
12. Hayes, E.T.; Curran, T.P.; Dodd, V.A. Odour and ammonia emissions from intensive pig units in Ireland. *Bioresour. Technol.* **2006**, *97*, 940–948. [CrossRef] [PubMed]
13. Tymczyna, L.; Chmielowiec-Korzeniowska, A.; Drabik, A.; Skórska, C.; Sitkowska, J.; Cholewa, G.; Dutkiewicz, J. Efficacy of a novel biofilter in hatchery sanitation: II. Removal of odorogenous pollutants. *Ann. Agric. Environ. Med.* **2007**, *14*, 151–157. [PubMed]
14. Chang, C.W.; Chung, H.; Huang, C.F.; Su, H.J.J. Exposure assessment to airborne endotoxin, dust, ammonia, hydrogen sulfide and carbon dioxide in open style swine houses. *Ann. Occup. Hyg.* **2001**, *45*, 457–465. [CrossRef]
15. Venter, P.; Lues, J.F.R.; Theron, H. Quantification of bioaerosols in automated chicken egg production plants. *Poult. Sci.* **2004**, *83*, 1226–1231. [CrossRef]
16. Thelin, A.; Tegler, O.; Rylander, R. Lung reactions during poultry handling related to dust and bacterial endotoxin levels. *Eur. J. Res. Dis.* **1984**, *65*, 266–271.
17. Radon, K.; Weber, C.; Iversen, M.; Danuser, B.; Pedersen, S.; Nowak, D. Exposure assessment and lung function in pig and poultry farmers. *Occup. Environ. Med.* **2001**, *58*, 405–410. [CrossRef]
18. Rimac, D.; Macan, J.; Varnai, V.M.; Vucemio, M.; Matkovic, K.; Prester, L.; Orct, T.; Trosic, I.; Pavicic, I. Exposure to poultry dust and health effects in poultry workers: Impact of mould and mite allergens. *Int. Arch. Occup. Environ. Health* **2010**, *83*, 9–19. [CrossRef]
19. Qi, R.; Manbeck, H.B.; Maghirang, R.G. Dust net generation rate in a poultry layer house. *Trans. ASAE* **1992**, *35*, 1639–1645. [CrossRef]
20. Aarnink, A.J.A.; Elzing, A. Dynamic model for ammonia volatilization in housing with partially slatted floors, for fattening pigs. *Livest. Prod. Sci.* **1998**, *53*, 153–169. [CrossRef]
21. Ullman, J.L.; Mukhtar, S.; Lacey, R.E.; Carey, J.B. A review of literature concerning odors, ammonia, and dust from broiler production facilities: 4. remedial management practices. *J. Appl. Poult. Res.* **2004**, *13*, 521–531. [CrossRef]
22. Takai, H.; Pedersen, S. A compariosn study of different dust control methods in pig buildings. *Appl. Eng. Agric.* **2000**, *16*, 269–277. [CrossRef]
23. Kim, K.Y.; Ko, H.J.; Kim, Y.S.; Kim, C.N. Assessment of Korean farmer's exposure level to dust in pig buildings. *Ann. Agric. Environ. Med.* **2008**, *15*, 51–58. [CrossRef] [PubMed]
24. Guarino, M.; Caroli, A.; Navarotto, P. Dust concentration and mortality distribution in an enclosed laying house. *Trans. ASAE* **1990**, *42*, 1127–1133. [CrossRef]
25. Ellen, H.H.; Bottcher, R.W.; von Wachenfelt, E.; Takai, H. Dust levels and control methods in poultry houses. *J. Agric. Saf. Health* **2000**, *6*, 275–282. [CrossRef] [PubMed]
26. Redwine, J.S.; Lacey, R.E.; Mukhtar, S.; Carey, J.B. Concentration and emissons of ammonia and praticulate matter in tunnel-ventilated brolier houses under summer condition in Texas. *Trans. ASAE* **2002**, *45*, 1101–1109. [CrossRef]
27. Takai, H.; Pedeson, S.; Johnsen, J.O.; Metz, J.H.M.; Koerkamp, P.W.G.; Uenk, G.H.; Phillips, V.R.; Holden, M.R.; Sneath, R.W.; Short, J.L.; et al. Concenstrions and emissions of airborne dust in livestock buildings in North Europe. *J. Agric. Eng. Res.* **1998**, *70*, 59–77. [CrossRef]
28. Willis, W.L.; Ouart, M.D.; Quarles, C.L. Effect of an evaporative cooling and dust control system in rearing environment and performances of male brolier chickens. *Poult. Sci.* **1987**, *66*, 1590–1593. [CrossRef]
29. Conceicao, M.A.P.; Johnson, H.E.; Wathes, C.M. Air hygiene in a pullet house: Spatial homogeneity of aerial pollutnats. *Br. Poult. Sci.* **1989**, *30*, 765–776. [CrossRef]
30. Donham, K.J. The concentration of swine production: Effects on swine health, productivity, human health, and the environment. *Vet. Clin. N. Am. Food Anim. Pract.* **2000**, *3*, 559–597. [CrossRef]