Abstract

The enhancement in the productivity of the Korean poultry industry has had a positive effect on its competitiveness in exports. However, the expansion and overproduction for providing the needed amount of supply increase the rearing density and create an inferior environment within the broiler houses. Especially, a crowded rearing environment generates a vulnerable dust environment within the broiler houses, which acts as a factor for inducing respiratory diseases in the broilers and workers, such as bronchitis and occupational asthma and so on. Despite such harms, however, not only is the periodic monitoring and study of the dust environment within broiler houses unsatisfactory but also the legal regulations for the permissible standards within them yet to be established. Thus, this study has conducted a periodic monitoring of TSP, PM10 and inhalable and respirable dust in a naturally-ventilated broiler house according to the season and the age and activity of the broilers, while assessing the air quality within the broiler house according to the threshold limit as proposed by Donham *et al.* (2000) and CIGR (1994).

When the TSP and PM10 were measured at different points of time, different concentrations were found across the seasons: the average dust concentration was found to be highest in the winter, followed by autumn and summer. The difference between the concentration of PM10 and that of TSP was relatively small, and the ratio of PM10 to TSP increased with the age of birds, implying that the rate of production of PM10 increases with the age of birds. Also, it is thought that most of the dust at the height of the respiratory system of the workers has the size that is

either same as or smaller than that of PM10.

When the concentrations of inhalable and respirable dust were measured across the seasons, different schematic amounts of ventilation were found to contribute to a considerable level of difference in the dust concentration in different seasons. When the activity of the broilers increased by the entry and exit of the workers to manage in the broiler house, inhalable dust increased by up to 769.6% (28-day old, summer) and respirable dust by up to 882.4% (28-day old, summer) compared to when the broiler's activity were stable. Such differences significantly increased with the age of broilers ($p < .05$). Also, the dust concentrations were higher than the threshold limit for human lung function as proposed by Donham *et al.* (2000) and the threshold limit for the lung function of broilers as proposed by CIGR (1994) when the entry and exit of the workers induced the activity of the broilers. Especially, the concentration of respirable dust was over the threshold limits even when the broilers were stable, indicating that a dust environment that is harmful for the workers and the broilers had already been created within the broiler house. Thus, protective devices such as masks should be recommended when working within broiler houses.

A physicochemical analysis of the dust collected from the air confirmed N, K, F, S, Mg, Cl and Na as its components. Particularly, it seems that airborne dust within a broiler house is largely affected by the feathers of broilers and the bedding material.

A correlational analysis between the dust concentrations and the internal and external environmental parameters found a strong negative correlation when the broilers were young. As they grew older, however, the correlation with the external

environment mostly disappeared, while there was a strong negative correlation with the internal temperature. This implies that the appropriate rearing temperature decreases as the broilers grow older, and that the amount of dust produced by the older broilers, including feathers and skin fragments, may have an effect on the dust concentration. This study provides preliminary data for the assessment of air quality within a naturally-ventilated broiler house based on its dust concentration and investigate the sources of the dust. The results of this study is hoped to help with further studies for dust reduction within broiler houses by aiding in the estimation of the main sources of dust and the control of dust production from the sources.

Keyword: Broiler house, Dust monitoring, Inhalable dust, PM10, Respirable dust, Total suspended particle (TSP)

Student Number: 2013-23260

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Chapter 1. INTRODUCTION

1.1. Research Background

The total production of agroforestry in 2014 was 47,292.2 billion wons; livestock and sericulture industry, at 18,874.6 billion wons (39.9%), constituted a large portion of the total production value. The production of livestock industry is on the rise since 2011; for example, the rise in the price of goods including Korean beef, pork and milk brought a 15.7% increase in livestock industry production compared to the last year (Figure.1) (Ministry of Agriculture, Food and Rural Affairs, 2015). Moreover, the recent MOU agreed upon with United Arab Emirates (UAE) regarding agricultural products and halal food means that the possibility for the relevant food businesses, including chicken, one of the meat products recognized as halal, to expand into the Middle Eastern market is higher than ever. Especially, the halal food market is expected to show a steady growth from 1,088 billion dollars in 2012 to 1,626 billion dollars in 2018 (Ministry of Agriculture, Food and Rural Affairs, 2015); thus, the volume of export of Korean broiler industry into the halal market is expected to grow even further (Research Center for Export of Poultry Product, 2012).

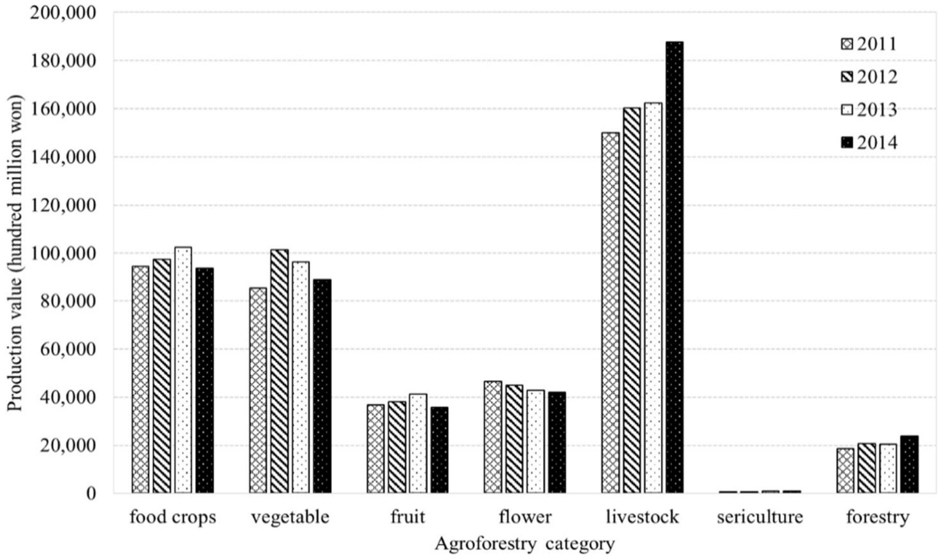


Figure 1 Total production value according to the agroforestry category in Korea (2011～2014) (Ministry of Agriculture, Food and Rural Affairs, 2015)

However, in order to secure the amount of supply needed to assure the companies a higher market share, farms lend themselves to indiscriminate expansion and overproduction, which creates a higher rearing density which in turn lowers the quality of the broiler products (Dozier *et al.,* 2006; Chae *et al.,* 2009). Especially, the closed rearing environment creates a vulnerable dust environment within the facilities, which threatens not only the poultry but also the workers' health (Takai *et al.,* 1998; Banhazi *et al.,* 2008; Wilson *et al.,* 2008; Cambra-López *et al.,* 2010). Dust within poultry rearing facilities originates mainly from skin particles of broiler, to which either bacteria or endotoxins, which causes respiratory diseases, are adsorbed. These are reported to enter the respiratory tract and lungs when the broilers and workers breathe (Steven *et al.,* 1984; Jerez *et al.,* 2013). Notably, it is reported that the workers feel chest pain and irritations in eyes, nose and neck, exhibit decreased lung function and suffer from diseases related with bronchial inflammation (Pearson *et al.,* 1995; Malmberg *et al.,* 1993). Thus, In Europe and other countries around the world, a threshold limit for dust within facilities has been proposed regarding the lung functions of workers within broiler houses (Donham *et al.,* 2000). Also, a constant effort to establish a standard for air quality within livestock facilities has been undertaken in order to enhance the public awareness regarding the effects of dust within livestock houses. In Korea, however, while the air quality standards regarding cotton and grain dust within agricultural facilities has been proposed in accordance to the Occupational Exposure Standard (OES) as proffered by ASAE in 1994, no legal regulation regarding air quality standards appropriate for workers and livestock within livestock facilities and suitable for domestic circumstances has been proposed yet (Kwon *et al.,* 2013). Moreover, Korean studies that focused on within-house monitoring that could be presented as evidentiary material for a tentative air quality standard have mostly been limited to short-term monitors regarding exposure to organic materials (Shin *et al.,* 2004; Choi *et al.,* 2005); foundational researches for long-term monitoring are lacking. Especially, while the investigation results for construction types of Korean broiler houses show a high proportion of naturally ventilated houses at 47.7% (19.8% are vinyl and 19.0% are windowless) (Ministry of Agriculture, Food and Rural Affairs, 2007), monitoring studies for dust within livestock facilities have mostly been conducted within windowless houses. Therefore, it is important to procure fundamental data regarding dust environment within broiler houses that is in accordance with the domestic circumstances.

1.2. Research Objectives

This study is a foundational research for dust reduction by improving indoor air quality within livestock facilities. This is hoped to not only act as a measure against occupational diseases of the workers and thereby enhance industrial public health but also create a suitable environment for livestock in order to enhance the animas' productivity and welfare. For this, the periodic monitoring of dust concentration according to various environmental parameters within facilities is essential. Thus, this study has conducted a within-house dust monitoring in naturally ventilated broiler houses. Through such monitoring, the levels of dust production and the effects of environmental parameters on them are evaluated.

The monitor study and evaluation of air quality within broiler house have been conducted as the following.

(1) Dust monitoring is conducted for inhalable dust and respirable dust as well as total suspended particles (TSP) and PM10, the parameters used for the evaluation of air quality, with experimental parameters including ages of birds, season, the broilers' activity according to the entry and exit of workers, temperature and humidity, and the results are analyzed.

(2) Based on the results as well as the threshold limit as proposed by Donham et al. (2000) and CIGR (1994), the air qualities within naturally ventilated broiler houses are evaluated.

(3) The main sources of dust are determined through the physical and chemical analyses of the collected dust and the dust's components are qualitatively and quantitatively analyzed.

(4) A correlation analysis is performed for the environmental parameters that have an effect on dust concentration (e.g. temperature, bedding water content).

Chapter 2. LITERATURE REVIEW

2.1. The effect of dust for human and animal health

A large number of people in the domestic agriculture and livestock field are found to suffer from farming-related incidents; the prevalence of acute and chronic farming-related diseases is found to be 72.3 cases out of 1,000 people, which is 70 times higher compared to the total industry (0.63 cases). Among them, over 90% are found to be musculoskeletal diseases; however, the prevalence of circulatory diseases is much higher than the general industry. Especially, the prevalence of respiratory diseases has rapidly increased in 2014 in comparison to that in 2012.

Table 1 The number of worker-related disease in agriculture filed (Statistics Korea, 2014)

Type of disease	2012 year	2014 year
Circulatory system	3,960	3,395
Musculoskeletal system	128,789	98,213
Respiratory system	925	2,500
Endocrine system	196	31
Alimentary system	1,141	3,313
Genitourinary system	1,028	492
Neuropsychiatric	145	0
Eye	582	292
Ear	351	0
Nervous system	103	48
Infectious diseases	870	2,148
Skin ailment	1,110	1,293
Tumor	80	31

Moreover, the prevalence of chronic obstructive pulmonary disease (COPD) in large cities was found to be 16.9%, while that in rural areas was 26.7%; that is, the prevalence was reported to be higher in farming regions (Lee *et al.*, 2011).

Since the 1960s, there has been a multitude of studies in various fields regarding the side effects suffered by workers, which is caused by dust produced within livestock houses. Especially, the number of workers who contract respiratory diseases by either allergic or hypersensitivity reactions is increasing each year; the inhalation of dust and gas produced within broiler houses is indicated as a reason (Simpson *et al.*, 1998; Donham *et al.*, 2000; Iversen *et al.*, Iversen *et al*., 2000; Vucemilo *et al*., 2008; Viegas *et al*., 2013; Rees *et al.,* 1998).

Dust produced in livestock houses includes a large amount of organic matter. It may have a potential effect on the health of humans and animals; particulate matter (PM), especially, has a significant effect on respiratory diseases (HSE, 2008; Lee, 2010; Anderse *et al*., 2004; Alencar *et al*., 2004; Government of Saskatchewan, 2007). Microbes are adsorbed on the surface of dust, which then moves through the respiratory system via respiration (Hauser *et al*., 1993; Pickrell *et al*., 1993; Vučemilo *et al*., 2008).

During this process, the various chemical substances contained in the dust irritates the respiratory tract. When the dust arrives at the lungs, it is reported that the particles may cause inflammation in bronchial epithelial cells and increase cardiopulmonary toxicity (Welthagen *et al*., 2003; Pope *et al*., 2002).

Especially, livestock houses provide an environment suitable for the growth of microbes such as gram-negative bacteria and thermophilic bacteria in the dust particles. A multitude of studies have confirmed that the endotoxin produced by these microbes is one of the chief causes of respiratory diseases (Radon *et al*., 2002; Seedorf *et al*., 1998; Hagmar *et al*., 1990; Vučemilo *et al*., 2008).

Notably, airborne dust includes bacteria that can cause common allergic diseases such as Penicillium sp, Aspergillus sp, Fusarium sp, Coletotrichum sp, etc.; by provoking respiratory diseases it may weaken immune resistance (Alencar et al., 2004), and serve as the medium for the transmission of diverse viruses, pathogenic and non-pathogenic bacteria and harmful gas (Harry *et al.,* 1978; Qi *et al*., 1992; Choi *et al*., 2006; Jerez *et al*., 2014).

Acute and chronic diseases reported to be related with labor within broiler houses induce symptoms such as cough, phlegm, eye irritation, dyspnea, chest tightness, fatigue nasal congestion, wheezing, sneezing, nasal discharge, headache, throat irritation, fever and Toxic organic dust syndrome (Homidan *et al*., 2003; Donham *et al*., 2000; HSE, 2008; Shin *et al*., 2004; Pearson *et al*., 1995).

Respiratory diseases frequently occur in the animals as well. Livestock, like humans, inhale dust by respiration; it is reported that in the case of chickens, dust particles with particle size as small as 7~10㎛ may reach the lungs with inhalation. The dust, as well as the toxic substances exudated by microbes within the dust, causes inflammation within the respiratory system. Respiratory diseases of chickens include *blastomycosis*, *Mycoplasma gallisepticum* infection, *Infectious Bronchitis*, *AvianRhinoTracheitis virus (ART)* and *Infectious LaryngoTracheitis virus (ILT)*, which lead to symptoms such as sneezing, wheezing, rhinorrhea, swollen sinuses, foamy eyes and lung disease (Richard, 2011). These diseases reduce the rate of gain and, if colibacillosis follows as a respiratory sequele, may lead to decreased productivity and cause significant financial damage of the poultry industry (Yang *et al*., 2012).

2.2. The research of dust in the broiler house

2.2.1. The level of dust in the broiler house.

Particulate matter (PM) within livestock house should be treated seriously because 1) their concentration is 10~100 times higher than in other types of environment; 2) they carry foul odor and gas; and 3) they carry a large amount of bacteria and organic matter which can undergo biological reactions (Cambra-López *et al.,* 2010).

In the case of Netherlands, a report has shown that 25% of PM10 in the country is produced from livestock houses (Chardon et al., 2002). Among the PM10 produced from livestock houses in Europe, 50% are produced from broiler houses and 30% are from swine houses (EMEP-CORINAIR, 2007). In United Kingdom, a study has shown that 9 kton of PM is produced per year from labor in broiler houses (EPR 9.09).

Many studies have confirmed that livestock facilities produce a large amount of dust in Korea as well. The amounts of emission from agricultural, livestock and fishing industry in 2012 were found to be 442, 405 and 246 ton/year for TSP, PM10 and PM2.5, respectively (National Air pollutants emission, National institute of environmental research, 2015). When the sources of dust is classified by livestock species, chickens (broiler and layer chicken) produces the highest amount of PM10 (52%) (Jang *et al*., 2008). Thus, dust monitoring studies within broiler houses are being conducted in order to decrease the financial impact of dust on poultry industry and establish preventive measures.

Several countries have seen efforts to sample and measure dust in broiler houses in order to assess the dust environment: the concentration distribution according to the types of dust is listed in Table 2.

Table 2 Dust concentration reported in literature in the chicken farm

Dust type	Mean Concentration (range) (mg/m^3)	Country	Reference	Ventilation type	Chicken type
Total dust	1.1-3.7		Clark (1983)		
	1.8-11.5		Louhelainen (1987)		
	7.9	England	Carpenter et al, (1986)	mechanically	broiler
	3.2 (1.8-4.8)	Croatia	Vučemilo et al. (2007)	mechanically	broiler
TSP	10.1	England	Wathes et al. 1997	mechanically	broiler
	2.0 (spring: 1.3/summer:0.9/winter:3.7)	Korea	Choi et al. (2005)	mechanically	broiler
PM10	1.0 (spring:0.7/summer:0.3/winter:2.1)	Korea	Choi et al. (2005)	mechanically	broiler
PM2.5	0.2 (spring:0.2/summer:0.02/winter:0.3)	Korea	Choi et al. (2005)	mechanically	broiler
Inhalable dust	4.8 (1.3-9) (summer:4.12 /winter:4.8)	Germany	Saleh et al, (2005)	mechanically	broiler
	8.2-9		Ellen et al. (1999)		
	3.6 (summer:3.03/ winter:3.88)	North Europe	Takai et al. (1998)	mechanically	broiler, perchery
	3.9 (summer:1.8/autumn:4.6/winter:5.3)	Korea	Kwon et al. (2014)	mechanically	broiler

	1.2	England	Wathes et al. (1997)	mechanically	broiler
Respirable dust	0.82 (0.07-4.07)	America	Jerez et al. (2014)	mechanically	broiler
	0.26 (0.07-4.07)	America	Jerez et al. (2014)	mechanically	broiler
	1.4-1.9		Ellen et al. (1999)		
	0.45 (0.35: summer/0.48: winter)	North Europe	Takai et al. (1998)	mechanically	broiler, perchery
	0.8 (0.3-1.5) (summer:0.65/winter:0.86)	Germany	Saleh et al. (2005)	mechanically	broiler
	0.4 (summer:0.2/autumn0.5/winter:0.6)	Korea	Kwon et al. (2014)	mechanically	broiler
	0.3	England	Wathes et al. (1997)	mechanically	broiler

Dawson (1990) has reported that the outdoor dust concentration in the vicinity of broiler houses is usually 0.1-0.2 mg/m^3, while the concentration within broiler houses is found to be much higher. Carpenter (1986) measured the total dust concentration according to the age of birds; the average concentration, measured within two rooms of control groups, were: 1.1 mg/m^3 at 1 week old; 7.9 mg/m^3 at 2 weeks old; 10.2 mg/m^3 at 3 weeks old; 12.63 mg/m^3 at 4 weeks old; 6.8 mg/m^3 at 5 weeks old; and 8.7 mg/m^3 at 6 weeks old. Overall, the concentration increases from 1 week old up to 4 weeks old and then decreases in chickens 5 and 6 weeks old. The average dust concentration in a common broiler house was reported to be about 7.9 mg/m^3. Jerez *et al.* (2014) have measured the concentrations of respirable dust at worker-exposure and broiler heights by collection through personal monitoring, which were reported to be 0.82 mg/m^3 and 0.26 mg/m^3, respectively. Vučemilo *et al.* (2007) have measured the dust concentration according to the age of broilers to be: 1.8 mg/m^3 at 1 week old; 4.3 mg/m^3 at 2 weeks old; 4.8 mg/m^3 at 3 weeks old; 2.6 mg/m^3 at 4 weeks old; 3.6 mg/m^3 at 5 weeks old; and 2 mg/m^3 at 6 weeks old. The total average concentration was reported to be 3.18 mg/m^3.

Taylor *et al.* (2007) have compared the PM10 concentration between the summers and winter seasons; when the broilers were younger than 14 days old, the similar ventilation rates led to little difference in concentration between the seasons. The total concentration was higher in the winter by approximately 46% compared to that in the summer. Takai *et al.* (1998) have measured the average concentration of inhalable and respirable dust in England, Netherlands, Denmark and Germany and found them to be 3.6 mg/m^3 and 0.45 mg/m^3, respectively. When the dust concentrations were compared across the seasons, inhalable dust and respirable dust were 28% and 37% higher, respectively, in the winter than in the summer. Saleh *et al.* (2005) conducted a study where the inhalable and respirable dust concentrations were measured with the age of broilers in summer and winter as well as the heights of the respiratory systems of the broilers and workers, 0.3 m and 1.5 m respectively, in consideration. At workers' height in the summer, the average concentration of inhalable dust was 4.12 mg/m^3 and that of respirable dust was 0.67 mg/m^3. In the winter at the same height, inhalable dust was measured to have an average concentration of 5.46 mg/m^3 while that of respirable dust was 0.98 mg/m^3. At broilers' height in the summer, the average concentrations of inhalable and respirable dust were found to be 4.36 mg/m^3 and 0.63 mg/m^3, respectively. In conclusion, the dust concentration was higher at the workers' height, where the concentrations of inhalable and respirable dust were higher in the winter than in the summer by approximately 33% and 46%, respectively.

In Korea, Choi *et al.* (2005) have measured the concentrations of TSP, PM10 and PM2.5 with the season and age of birds in consideration. While the dust concentration was varied according to the age, the average concentrations of the different types of dust were found to be 2.0 mg/m^3, 1.0 mg/m^3 and 0.2 mg/m^3, respectively. In the study of Kwon *et al.* (2014), the average dust concentrations showed a considerable difference across the seasons; the average concentrations of inhalable and respirable dust were found to be 3.9 mg/m^3 and 0.4 mg/m^3, respectively.

2.2.2. Origination of dust

The airborne dust within broiler houses consists mostly of inhalable and respiratory dust, which, according to a number of studies, are produced from feathers, excrement, feed particle, bacteria, fungi, litter and bedding mold spores (British columbia, 1999; Dawson *et al.,* 1990; Banhazi *et al.,* 2008; Anderson *et al.,* 1966; Qi et al., 1992; Anderson et al., 1966; Takai *et al.,* 1998; EPR 6.09; Cambra-López *et al.,* 2010).

In particular, the bedding material is a main source of dust within broiler houses and its concentration is reported to vary according to the water content and composition of the bedding (Banhazi *et al.,* 2008). Dawson *et al.* (1990) confirmed that 92% of dust within broiler houses consisted of dry matter, among which 60% was protein, 4% was fat and the rest was cellulose. Components from feed, such as calcium, were detected, while a high portion of the protein was formed from either the feathers or the epithelial tissue of birds. Aarnnink *et al.* (1999) conducted a chemical analysis of PM dust found within swine and broiler houses and found a large amount of dry matter (DM) and N; the N value was especially high in the broiler house. Since the feed has a high N content, it can be deduced that the feed had a considerable effect on the production of PM. Cambra-López *et al.* (2010) conducted a SEM-EDX analysis for dust within broiler houses. Morphological and chemical analyses revealed a substantial amount of featherlike morphology in the collected dust. Chemical analysis found a significant disparity of composition between different types of particles: the mineral components, such as feed and external substances, were rich in Al, Si and Ca while organic particles were rich in N, Na, S, Cl and Ca. The study expected this result to be convenient in discriminating Ca-rich feed and other external particles (mineral) from the residual materials including organic matter. Also, Choi *et al.* (2005) conducted a component analysis of the collected dust and feed and found that dust had 3.1 times more protein compared to feed; skin particle and feathers of animals, which have high protein content, supposedly contributed to the production of dust.

Chapter 3.   MATERIALS AND METHODS

3.1. Experimental period and site

The broiler house used for the experiment is in a farm situated in Ongdong-myun, Jeongeup-shi, Jeollabuk-do and is constituted of two mechanically-ventilated broiler houses and a single naturally-ventilated broiler house. The naturally-ventilated broiler house was selected for this study for a real-time monitoring of dust. Kwon et al. had already conducted a monitor study for the mechanically-ventilated broiler houses of the same farm. The experiment was conducted from September 2013 to September 2014; the farm was visited regularly for three times every season, with the ages of the broilers (7, 14 and 28 days old) in consideration. In December 2013, however, the experiment was conducted for broilers 5, 12 and 22 days old due to the farm’s circumstances. Moreover, due to the HPAI outbreak near the experimental farm from January 2014 to May 2014 a temporary standstill order was issued by the government in order to defend against HPAI and put an early end to it, limiting the travel of diseased livestock, workers in the field and vehicles. Because of this the experiment had to be halted, and could only be restarted on June 2014. A naturally ventilated broiler house can accommodate approximately 25,000 broilers. It is 11 m wide and 1.5 m and 4.5 m high in the eaves and ridge, and has a total length of 85.5 m. Two layers of winch curtains are installed on each side wall of the broiler house and when they are opened to the maximum the total area is equal to 101.7 m^2. Also, four 20-inch, 5,000-CFM ventilation fans are installed in the frontal wall, and four ventilation fans of the same specifications are installed in the back wall as well. In the summer, a hybrid method of ventilation is employed: that is, natural ventilation is achieved by the full opening of winch curtains while the ventilator fans are operated for additional ventilation. The ratio of opening of the winch curtains is adjusted for the insulation within the broiler house and the discharge of pollutants with the age of birds and external temperature, which changes along with the seasons, in consideration. In the winter, the winch curtains are fully shut in order to block the influx of external airflow, while negative-pressure ventilation was conducted through the eight ventilation fans installed in the frontal and back walls and external air enters through the inlet pipes installed along the slope beneath the roof. Each inlet pipe has a diameter of 0.1 m and a length of 1.9 m. 90 pipes are installed on the left and 91 on the right, as seen from the entrance. The entrance is a sliding door that is 0.9 m wide and 1.6 m tall; it is used only when the broilers are either moving in or being shipped out and the workers use the back entrance to enter and exit and perform work. Table 3 shows the basic data including the rearing capacity and measured area of the selected broiler house.

Table 3 Specification of naturally ventilated broiler house

Factor (Unit)	Value
Width (m)	11.0
Side height (m)	1.5
Ridge height (m)	4.5
Total length (m)	85.5
Inlet pipe diameter (m)	0.1
Inlet pipe length (m)	1.9
Sliding door width (m)	0.9
Sliding door height (m)	1.6
Total winch curtain opening area (m^2)	101.7
Fan size (inch)	20

Figure 2 is an exterior view of experimental broiler house and Figure 3 is a schematic view of the naturally ventilated broiler house.

(a) Exterior view of experimental site

(b) Frontal view of experimental broiler house

(c) Winch curtain-opened broiler house in the summer

(d) Winch curtain-closed broiler house in the winter

Figure 2 Exterior view of experimental broiler house

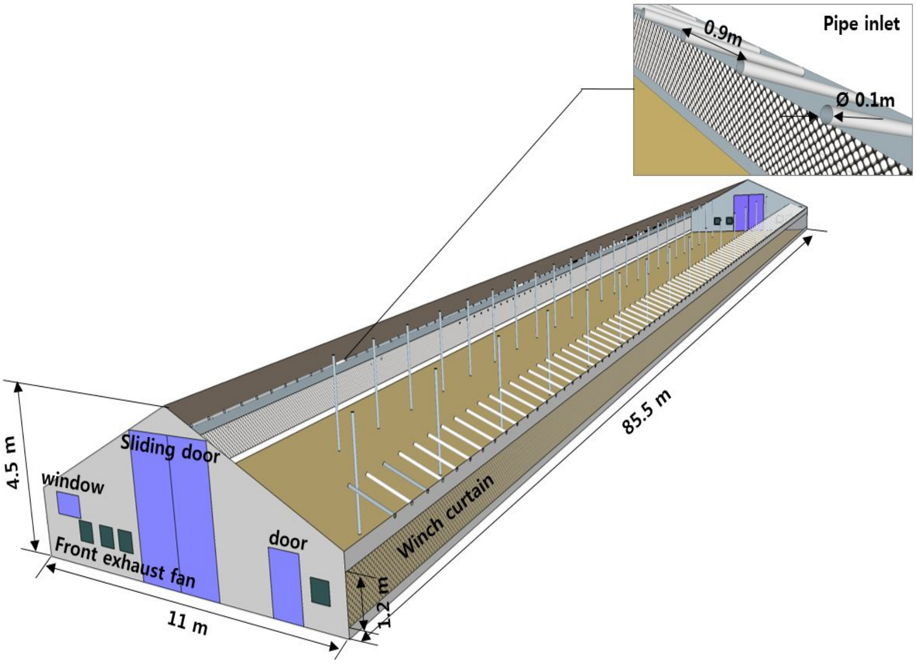


Figure 3 Schematic view of the naturally ventilated broiler house (Jo et al., 2015)

3.2. Airborne collectible specimen

3.2.1. Total suspended particle (TSP) and PM10

Dust refers to the collection of particles that float in the atmosphere until they settle by the effect of gravity. Also called aerosol, the size of the particle ranges approximately from 0.5 to 1,000 ㎛ (Pearson *et al.,* 1995). When expressing the concentration of dust, it is generally classified into categories such as total suspended particles (TSP) and particulate matter (PM). These expressions are mainly used as measures for assessing air quality in the field of atmospheric environment. PM is further classified according to the cut-off diameter of the collecting equipment as PM10, PM2.5 and so on. The definition may either refer to a collecting efficiency of 50% for that diameter or (Cambra-López *et al.,* 2010), as declared in the Environmental Policy Act Enforcement Ordinance in Korea, to PM with an aerodynamic diameter less than either 10 ㎛ or 2.5 ㎛ for PM10 and PM2.5, respectively.

PM is the assortment of airborne particles with various sizes and chemical and biological properties which can cause not only environmental but also health problems (Dawson *et al.,* 1990; EPA 2004). Particularly, fine PM whose size is smaller than 2.5 ㎛ may enter the human body through the bronchi and into the lungs where it may cause diverse respiratory diseases even in small amounts (EPA 2004; 2010). According to a Korean study regarding PM, at PM2.5 concentration of 36~50 ㎛/m^3 the prevalence of acute lung disease increases by 10%, while that of chronic asthma increases by 10% when the concentration of PM2.5 is 51~80 ㎛/m^3. The study also estimated that a 10 ㎛/m^3 increase in the PM10 concentration in Seoul, the capital of Korea, will bring about a 0.3% increase in the daily early mortality rate and a 0.4% increase in the case of PM-sensitive groups such as older people with the age over 65 (National Institute of Environmental Research, 2009).

In order to protect human health and maintain and improve an agreeable environment, an environmental standard is set as a criterion for determining and predicting the level of contamination so that it could be used as the administrative goal for environmental policies. In Korea, especially, the management of PM10 as a part of the atmospheric environmental standards began in January 1995.

When the standards saw reinforcements such as the introduction of PM2.5 surveillance system in the United States and WHO, Korea also established new standards for PM2.5 in addition to preexisting ones for the atmospheric environment via the Amendment to the Environmental Policy Act Enforcement Ordinance in March 2010. The revised standards are currently being applicated to environmental policies as of 2015. The atmospheric environmental standards of the nations are as the following (National Institute of Environmental Research, Annual report of Ambient air quality in Korea, 2015).

Table 4 Atmospheric environmental standards of the nations

Unit: mg/m^3

Category	Reference time	Korea	USA	Japan	Canada	Australia	Hong Kong	China	United Kingdom	EU	WHO
PM10	1hr			200							
	24hr	100	150	100	25	50	100	150	50	50	50
	year	50					50	70	40	40	20
PM2.5	24hr	50	35	35	15	25	75	75			25
	year	25	12, 15	15		8	35	35	25	25	10

However, the environmental standard of Korea is somewhat more lenient compared to what is recommended by WHO. Also, since the forecast-warning system is employed according to short-term outdoor measurements, the regulations for reducing health damages suffered by indoor workers who experience the health risk of long-term dust exposure remain lacking. Moreover, the 3rd Article “Recommended Standards for Indoor Air Quality” in the “Indoor Air Quality Management Law Enforcement Regulation” sets forth only the maintenance standards for business facilities including multiuse facilities; the standards for specific occupations as well as agricultural and livestock facilities are yet to be established.

Table 5 Recommended Standards for Indoor Air Quality (Ministry of Environment, 2015)

Category	PM10 (㎍/m^3)
underground subway station, underground shopping center, bus terminal waiting room, museum, art museum, funeral hall, public bath, store	≤150
medical institution, nursery facility, public care facility, postpartum care center	≤100
Indoor Parking Lot	≤200

3.2.2. Inhalable dust, thoracic dust and respirable dust

Large-size particles with the particle size distribution of over 70 μm settle down in the atmosphere. Particles smaller than 70 μm, however, may move through the respiratory tract of humans and animals. The American Conference of Governmental Industrial Hygienists (ACGIH) have classified dust into three groups, based on the size of dust and the location of deposit within the human body: inhalable, thoracic and respirable dust. Inhalable dust refers to dust with the particle size of 0～100 μm, and is deposited in the upper respiratory tract, including nose and throat. Thoracic dust is dust that is deposited in the upper and lower respiratory tracts; its particle size ranges from 0 to 25 μm and it has the average particle size 10 μm. Respirable dust, whose size ranges from 0 to 10 μm with the average size of approximately 4 μm, can reach the alveoli, where gas exchange occurs. Also, inhalable, thoracic and respirable dust show 50% deposit rate at 100 μm, 10 μm and 4 μm, respectively (Kwon *et al.,* 2014). According to the Notification Regarding Working Environment Measurement and Designated Measurement Institution Evaluation, as announced by the Ministry of Employment and Labor, inhalable fraction is defined as dust that displays toxicity regardless of the location of deposit; meanwhile, respirable fraction is defined as dust whose size is such that it may enter the respiratory system to be accumulated in the alveoli (Ministry of Employment and Labor, 2013).

Meanwhile, the Occupational Exposure Standard (OES), proposed by ASAE (1994), reports that a broiler manager working 8 hours a day is exposed to 10 mg/m^3 of total inhalable dust and 5 mg/m^3, while the legal regulatory standards for airborne dust within an ordinary workplace in the United Kingdom is set as 10 mg/m^3 for inhalable dust and 4 mg/m^3 for respirable dust for a time span of 8 hours and 20 mg/m^3 of inhalable dust for short-term exposure (15 minutes). The German Ordinance on Hazardous Substances (GetStoffV), has set the short-term exposure standards as 10 mg/m^3 for inhalable dust and 3 mg/m^3 for respirable dust. In the case of dust regulatory standards for rural areas or agricultural facilities, many countries have not established any regulatory standard at all; and even in countries that do have such standards, they are not accordant with one another. The threshold limits for airborne dust within broiler houses and organic dust that takes the decrease in the workers' lung function into consideration has been proposed at 2.4 mg/m^3 for inhalable dust and 0.16 mg/m^3 for respirable dust (Donham *et al.,* 2000).

3.3. Equipment for dust collection within experimental broiler houses

Adequately desiccated 37 mm Teflon filter (PTFE, SKC. Inc., US A, pore size: 2.0 μm) was used for the collection of TSP and PM10. In the case of TSP, the filter was inserted into a three-stage cassette (SKC. Inc., USA). In the case of PM10, the filter was attached to a single-stage impactor PEM (Personal Environmental Monitor, SKC. Inc., USA) and then connected to a portable pump (AirChek XR500, SKC. Inc., USA) via a Tygon tube. For the experiment the suction airflow was set as 2 L/min and 4 L/min, respectively. The PEM used in this experiment, with the cut-point diameter set as 10 μm, was used to collect PM10. Dust particles that has a size larger than the cut-point diameter is attached to the surface of the porous impaction ring, which is coated with oil before the experiment, by inertial force. PM10 particles whose size is smaller than the cut-point diameter will ride the air current formed within the equipment to be collected in the innermost filter. Aerosol Spectrometer (Grimm Inc., Germany), which utilizes light-scatter measurement method to measure the number and concentration of airborne dust according to its particle sizes, was used to measure inhalable and respirable dust. The concentration data of each type of dust was recorded in the memory card every 6 seconds.

(a) Air sampler,
PEM monitor and cassette sets
(XR5000, SKC. Inc., USA)

(b) Aerosol spectrometer
(EN 1.108 dust-check5 TM,
Grimm Inc., Germany)

Figure 4 Experimental equipment for dust concentration and indoor thermal environment monitoring

3.4. Instrument for monitoring interior and exterior environmental parameters

In order to secure fundamental data for the investigation of correlation between dust production and different environmental parameters inside and outside the broiler houses, 7 thermocouples (T-type) were installed at 7 points 1.5 m high from the floor of the broiler house. The data was saved to a data logger (GL820, Graphtec Inc., USA) every minute. To measure the interior and exterior temperature and humidity, two HOBO sensors (UX100-003, Onset Inc., USA) were installed 1.5 m high from the floor. To obtain the outdoor meteorological data a portable weather station (Watchdog, Spectrum Tech. Inc., USA) was installed on a rooftop near the experimental broiler house. The direction and velocity of the wind, amount of solar radiation, precipitation, temperature and humidity were recorded every minute. Additionally, a portable camera (MS Lifecam VX-5000, FUJITSU AMERICA Inc., USA) installed at the entrance of the broiler house recorded a real-time video for confirming the activity of broilers, the entry and exit of workers, the hours of operation of the ventilation fan, etc.. The measurement location of each equipment for the monitoring of thermal environment is as shown in Figure 6.

(a) Data logger
(GL820, Graphtec Inc., USA)

(b) HOBO sensor
(Onset Inc., USA)

(c) Portable camera
FUJITSU AMERICA Inc., (USA)

(d) Data logger box

Figure 5 Experimental equipment for indoor thermal environment monitoring and installation view

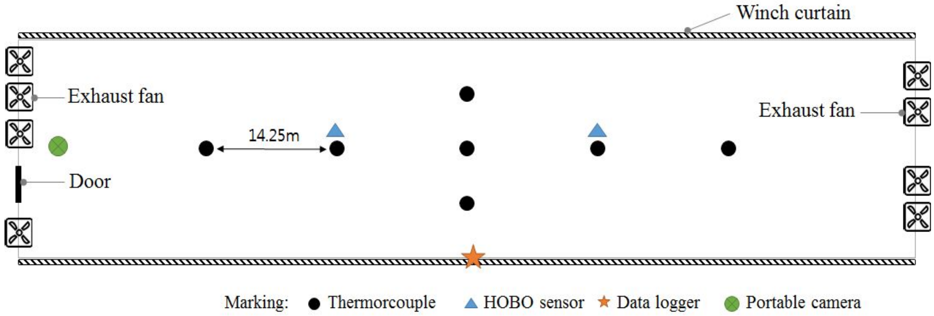


Figure 6 Installation position for collecting a thermal environment data

3.5. Dust monitoring and analysis

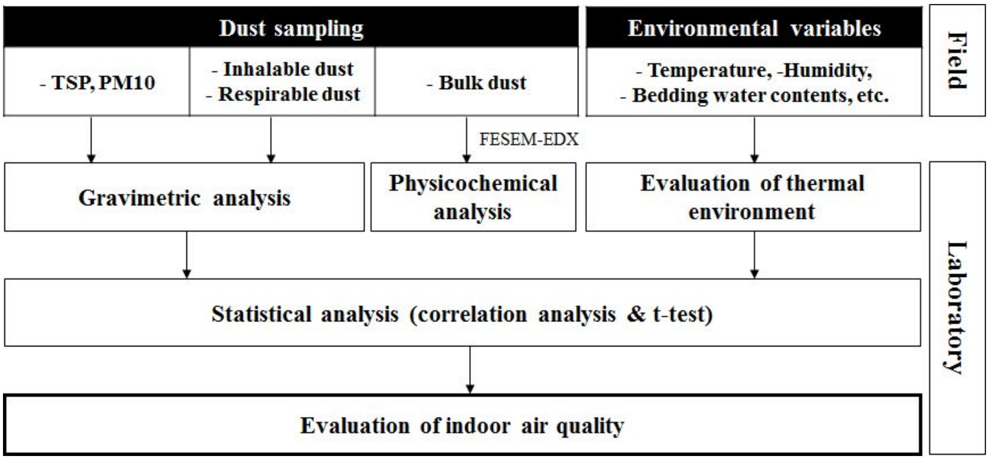


Figure 7 Flow chart of this study to conduct a periodic monitoring and correlation analysis in the naturally ventilated broiler house

Figure 7 shows the flow chart of the study for the assessment of air quality, analysis of thermal environment and correlation analysis of the results of the periodic monitoring of a naturally-ventilated broiler house. In order to monitor dust concentration within the experimental broiler house, dust sampling was conducted for TSP and PM10; inhalable, respirable dust were logged real-time using an aerosol spectrometer; and bulk dust collection was carried out. The internal environmental parameters such as the temperature, humidity and bedding water content within the broiler house were monitored as well. The concentrations of the collected TSP and PM10 as well as inhalable and inhalable dust were estimated through gravimetric measurement, while physical and chemical analyses were done for the bulk-collected dust with FESEM-EDX so to assess the components of the dust. Later, the air quality was assessed based on the threshold limit for the calculated dust concentrations and the internal thermal environment was assessed using the information for the temperature and humidity suitable for the growth and development of livestock, as provided by the Rural Development Administration. Also, a correlation analysis and a paired t-test were conducted with SPSS version 23 to determine the relationship between the dust concentrations and environmental parameters.

3.5.1. Monitoring of TSP and PM10

For the monitoring of dust within experimental broiler houses, the collection and analysis of TSP and PM10 was conducted according to the NIOSH Manual of Analytical Methods. Both samples were area-monitored; the locations of collection are as shown in Figure 8. In order to assess the width direction propensity according to the influx of external air current through the winch curtain in the summer, three longitudinal locations were selected with the center of the broiler house as the reference point, along with one additional location each on the left and the right of the center point in the direction of the winch curtain, so that a total of five points are arranged in the shape of a cross. Since ventilation is achieved in the longitudinal direction through the exhaust fans installed in both sides walls in the winter, 5 equally spaced points were arranged in a row in the longitudinal direction of the broiler house. The experiment instruments for the collection of TSP and PM10 dust samples were installed in each selected point for a long-term collection over an average time-span of 8 hours. 37 mm PTEE filter adequately desiccated in the laboratory was connected to either a cassette (for TSP) or a PEM (for PM10), and then connected to a portable pump via Tygon pump at a flow of 2 and 4 LPM, respectively. The collection instruments were installed 1.5 m high from the floor with the height of the workers' respiratory system in consideration by hanging the pump sets on the guideline installed on the pipes that support the broiler houses

(Figure 9). After the end of the experiment, the used filters were sealed in the cassettes and transported to the laboratory. There, the filters were adequately desiccated and the dust concentration collected in each sample was gravimetrically measured. The weight of a blank sample as well as the flux through each sampler before and after the experiment were measured for calibration so that experimental errors were minimized. Blank sample refers to a sample that is not exposed to the air that is to be collected; it is managed, transported and analyzed in the same way as the experimental samples except for the fact that it is not exposed to hazardous materials.

The amount of air collected is determined by multiplying the length of time of collection to the arithmetic average of the flux through the samplers before and after the experiment (Equation 1).

$$C = \frac{[(WS_p - WS_i) - (WB_p - WB_i)]}{V} \times 10^3 \qquad (1)$$

Here, refers to the dust concentration (mg/m^3), the weight of the filter paper after collection (mg), the weight of the filter paper before collection (mg), the weight of the blank sample after collection (mg), the weight of the blank sample before collection (mg) and the amount of air collected (L).

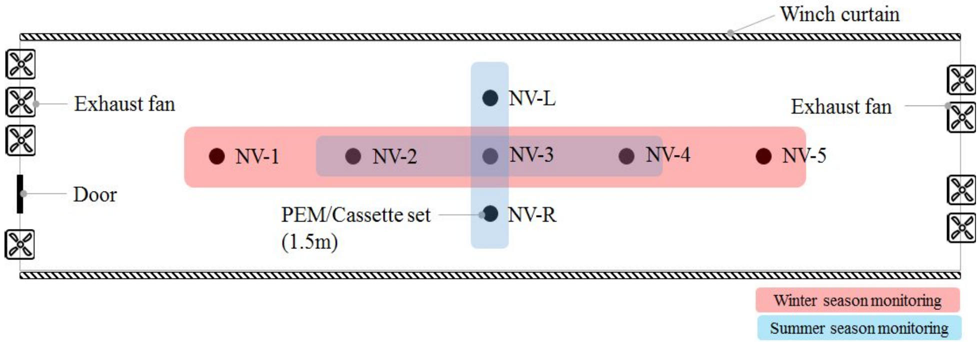
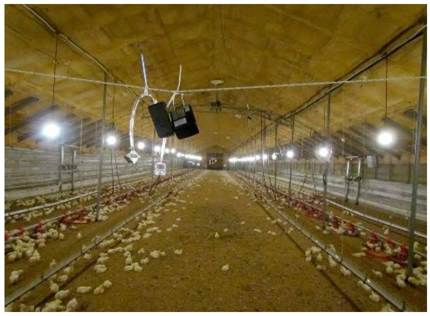


Figure 8 Measurement point for periodic monitoring of TSP and PM10 in a naturally ventilated broiler house

(a) Installation of TSP/PM10 sampler at the worker's nose height



(b) Measuring of TSP and PM10 concentration at the worker's nose height

Figure 9 Experimental views of TSP and PM10 dust sampler in the natural ventilated broiler house

3.5.2. Monitoring of inhalable and respirable dust

Inhalable and respirable dust monitoring was done separately the time when broilers show a high level of activity due to the entry and exit of workers and the time when broilers show a relatively stable movement in order to demonstrate the contrast in dust concentration according to the activity of the broilers. Inhalable and respirable dust monitoring was used for a short-term sampling. The short-term sampling is mainly used when the sample measurement can’t be continuously measured of full-period sample due to the limited measurement.

Figure 10 shows the locations of inhalable and respirable dust collection and Figure 11 shows the real-time measurement in different locations. The entrance area and the center of the broiler house, where primary chores such as the manipulation of ventilation fans and winch curtains occur, were chosen as locations for collection. Monitoring was conducted at the height of 0.15 m from floor, the height of the broilers’ respiratory system, and 1.5 m, the height of that of the work. For inhalable, and respirable dust, an aerosol spectrometer was used to measure the concentration of each type of dust in real time, for every 6 seconds for each sample for a total of 3~5 minutes. While the experiment was being conducted, the real-time dust concentration data saved in the memory of the instrument was analyzed to determine the change in the concentration with time; an arithmetic average was obtained to compute the dust concentration at that timeframe.

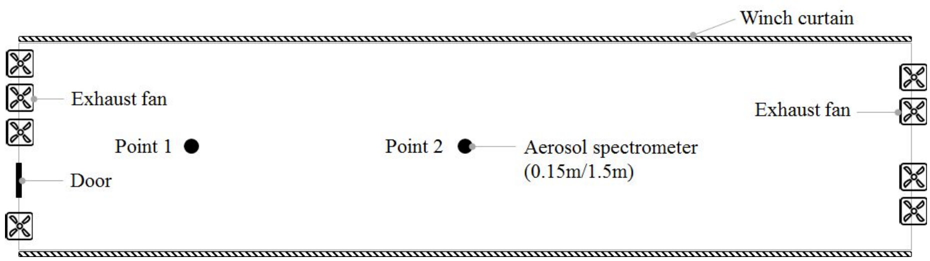


Figure 10 Measurement point of inhalable and respirable dust monitoring in the broiler house according to worker's activity

(a) Measurement of inhalable and respirable dust at broiler's nose height

(b) Measurement of inhalable and respirable dust at worker's average nose height

Figure 11 Experimental views of inhalable and respirable dust monitoring using aerosol spectrometer according to respiratory height in the natural ventilated broiler house

3.5.3. Monitoring of bedding water content

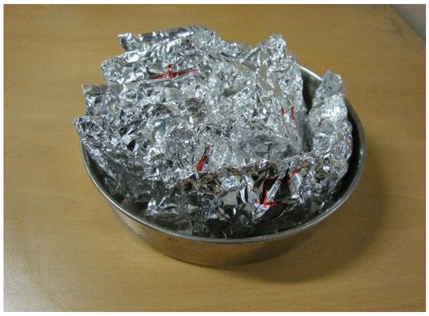
The bedding water content at the time of the experiment was measured in order to assess the characteristics of the bedding, one of the main sources of airborne dust within the broiler houses. Especially, lumps of bedding material include the skin, feather and excrement of broilers, feed, air and water and there is a large difference in the concentration of the dust produced according to the amount of water in them. Thus, the water content was quantitatively analyzed through the KS F2306 test methods, published by the Korean Standards Association, for an engineering judgement of dust production. Korean Standard defines water content as the percentage of the weight of water that is lost from a wet soil sample by oven-drying in a constant-temperature drying oven at 110±5℃ to the weight of the oven-dried soil. The equation for calculating the water content is shown as

Equation 2.

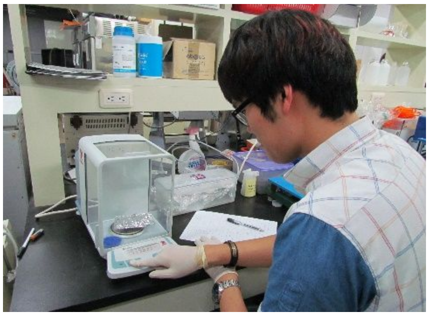
$$W = \frac{m_a - m_b}{m_b - m_c} \times 100 \qquad (2)$$

Here, W refers to the water content of bedding material (%), m_a is the mass of the sample and the container (g), m_b is the mass of the oven-dried sample and container (g) and m_c is the mass of the container (g). Container for bedding material was made out of aluminum foil into a size of approximately 12 cm × 12 cm in order to minimize the weight difference before and after the test. The weight of the container (m_c) was measured before the experiment. The total weight (m_a) was measured after putting the bedding of the broiler house in the container. The sample was then oven-dried for 24 hours in a constant-temperature drying oven kept at 110℃ for the consistent measurement of weights. The oven-dried sample was then withdrawn and cooled to room temperature before measuring the total weight (m_b). The following picture shows the sampling and monitoring processes of the bedding material (Figure 12).

(a) Sampling of bedding material



(b) Aluminum foil container for bedding material



(c) Weighing of bedding material

(d) oven-dried of bedding material

Figure 12 sampling and monitoring processes of the bedding material

3.6. Morphological and chemical analyses of collected dust

A FESEM-EDX analysis was conducted for the dust collected from the air as well as the materials that mainly cause production of dust in order to clarify the main sources of dust and qualitatively and quantitatively analyze its components. Because chemical analysis of the components can be readily done when the amount of the collected dust is over 20g, a bulk collection pump (MCS Flite2 Pump, SKC, UK) was used for collecting large amounts of dust. A bulk collection pump has the flux range of 2~26/min; for this experiment, the measuring flux was set at 10L/min.

The bulk collector was connected to a three-stage cassette (SKC. Inc., USA), whose upper parts were removed, with a 50cm-long Tygon tube. Dust was collected by OPEN-FACE method at a height of approximately 60cm from the floor (Figure 13).

(a) Bulk dust sampling using collection pump and three-stage cassette

(b) Bulk dust sampling by OPEN-FACE Method

Figure 13 Experimental view of bulk dust sapling by OPEN-FACE method in the broiler house

After the collection of dust, the morphology and components of each dust particle was measured and analyzed using a platinum coater (BAL-TEC/SCD 005, Bal-Tec AG, Liechtenstein), a scanning electron microscope (FESEM, SUPRA 55VP, Carl Zeiss Inc, Germany) and an element analyzer (EDS, Thermo / Bruker Inc, Germany), all of which are in the possession of National Instrumentation Center for Environmental Management. A FESEM can observe the surface structure of dust particles with high resolution and magnification. The electron beam emitted from the instrument collides with the sample to produce secondary and backscattered electrons, which produce a three-dimensional image. Also, FESEM is convenient in that with an energy-selective backscattered electron detector, a component analysis of the sample may be conducted. Thus, the bedding, feather and feed were sampled from a broiler house accommodating broilers 7 days old since they were thought to be less contaminated than broilers of other ages in order to compare the morphology and components of collected PM10 and the substances that mainly cause dust to be produced.

3.7. Statistical analysis

Correlation refers to the relationship between variables. For two or more variables, the correlation between them refers to the intensity and direction of the changes of the other variables according to the change in one of them. Thus, Pearson’s correlation analysis was conducted in order to assess the factors that have an effect on the concentration of dust (TSP, PM10, inhalable dust and respirable dust) in the air; a probability level of <0.05 and <0.01 were considered to be statistically significant. Data for internal and external environmental factors and dust concentration were analyzed using SPSS version 23 (IBM SPSS Inc.). The coefficient of correlation has a value between –1 and +1. A positive (+) coefficient of correlation represents a positive linear relationship between the two variables and a negative (-) coefficient a negative linear relationship, while a coefficient of correlation that is close to ‘0’ means that there is little to no linear relationship between the two variables and a coefficient whose absolute value is close to 1 means that there is a strong linear relationship (Won, 2009; Min, 2015). Also, a paired t-test was conducted for the average differences of concentration according to the activity in order to confirm whether the difference in the activity of broilers due to the entry and exit of workers had an effect on dust concentration. SPSS version 23 was used for the statistical analyses of data and the significance level was set as $p < 0.05$.

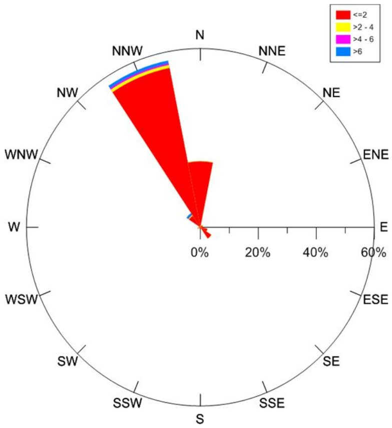
Chapter 4. RESULTS AND DISCUSSION

4.1. Monitoring results of internal and external thermal environments

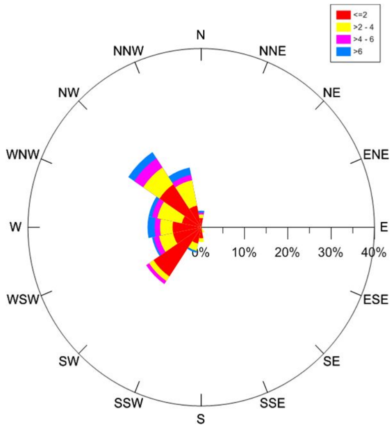
Through a portable weather station installed during the period of experiment (August 2013 ~ September 2014) on a rooftop in the farm where the experiment was conducted, the direction and speed of the wind were monitored for each season. Grapher (ver.11.4.770, Golden software, USA) was used to visualize the results with a windrose (Figure 14). The seasons during the monitoring period were classified into three, excluding the data in spring during which the experiment was stalled because a standstill order went into effect due to the outbreak of HPAI: summer (June 1 ~ September 15); autumn (September 16 ~ October 15); and winter (December 1 ~ December 30). The representative windrose value was calculated by averaging the frequency of the direction and speed of the wind during the period of experiment. The main wind direction in the summer was north-northwest (NNW) with an average speed of 0.75m/s. The main wind direction in the autumn was northwest (NW) with an average speed of 0.75m/s. The main wind direction in the winter was also northwest (NW) with an average speed of 1.5m/s. According to the analyses for average windrose, the wind during the period of experiment was significantly north-northwestern (NNW). Figure 15 shows the schematizations of the prevailing wind nearby the farm used for the experiment based on the monitoring results of seasonal directions and speeds of the wind.

When the prevailing wind occurs year-round around the farm in the north-

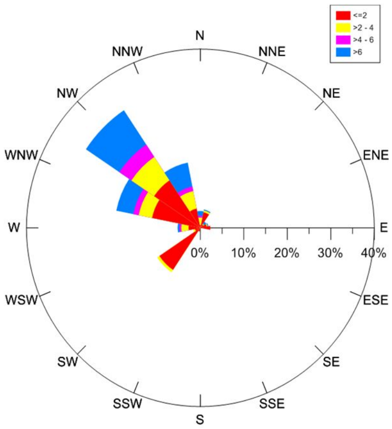
northwestern (NNW) direction, the two mechanically-ventilated broiler house becomes situated on the upwind side of the naturally-ventilated broiler house to disturb the main airflow. While this may have a positive effect on keeping the naturally-ventilated broiler house warm by blocking the effect of the wind in the winter, the mechanically-ventilated broiler house will interfere with the direct inflow of fresh external air when winch curtains are opened in the summer to ventilate the broiler house via natural convection currents. This will make it hard for the internal temperature of the broiler house to lower and the pollutant inside the house to be expelled when the winch curtains are opened. In particular, the interviews with the farm workers also support the conclusion of this meteorological analysis; they proclaimed that naturally ventilated broiler houses not only are inferior in terms of discharging gas such as carbon dioxide but also exhibit a relatively higher mortality rate of the broilers.



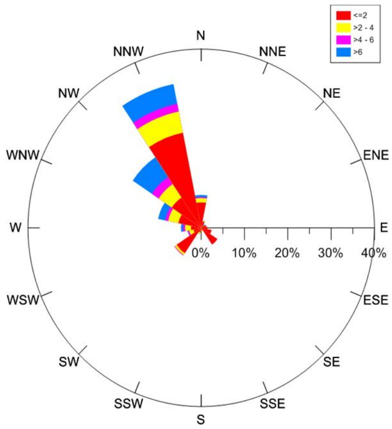
(a) Summer



(b) Autumn



(c) Winter



(d) Total Experiment period

Figure 14 Dispersion of wind speed and wind direction (2013. 09~2014. 09)

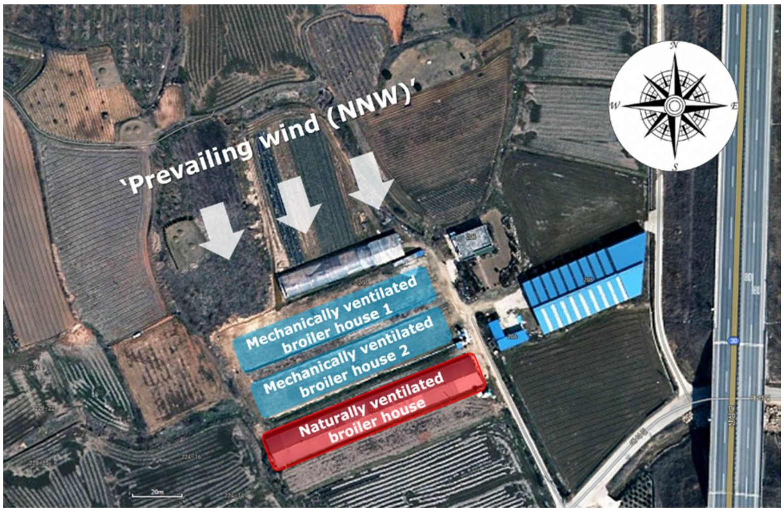


Figure 15 Prevailing wind at the experimental site (Jo et al., 2015)

The internal thermal environment was assessed using the information (Table 6) for the temperature and humidity suitable for the growth and development of livestock, as provided by the Rural Development Administration according to the age of bird (7, 14, and 28). The Table 7 shows a result of environmental monitoring data.

Table 6 Proper temperature and humidity considering age of bird in the broiler house

Age of bird (Week)	Temperature (℃)	Humidity (%)
1～2 days	34	70
3～4 days	32	70
5～7 days	30～32	70
2	28～29	65
3	26～27	60
4	24～25	60
5	22～23	60
6	21～22	60
7	18～21	60

Table 7 Result of external and internal environmental variable (humidity, temperature) monitoring data during experimental period

Season	Raising days	Outdoor A.T. (℃)	Outdoor R.H. (%)	Outdoor A.H. (kg/kg')	Indoor A.T. (℃)	Indoor R.H. (%)	Indoor A.H. (kg/kg')
Summer (2014.06～2014.07)	11	23.4	74.0	0.013	29.1	68.8	0.017
	18	25.9	59.7	0.012	30.2	57.6	0.015
	26	25.0	67.8	0.013	26.5	73.3	0.015
Summer (2014.08～2014.09)	7	27.6	63.9	0.014	31.8	65.3	0.018
	14	26.5	57.5	0.012	29.1	58.4	0.014
	28	24.4	49.1	0.009	29.0	59.1	0.014
Autumn (2013.09～2013.10)	7	23.3	82.3	0.014	28.8	75.5	0.018
	14	25.4	70.8	0.014	29.8	66.4	0.017
	28	23.4	45.6	0.008	24.7	75.5	0.014
Winter (2013.12)	5	8.8	52.3	0.003	29.8	46.9	0.012
	12	4.6	53.5	0.003	28.8	76.5	0.018
	22	-0.1	85.7	0.003	25.9	73.4	0.015

A.T.= Air temperature, R.H.=Relative humidity, A.H.=Absolute humidity

The Celsius temperature and relative humidity data inside and outside the broiler house were obtained using the thermal environment measurement device. The absolute humidity values under atmospheric pressure (P) was obtained using the ideal gas law and Dalton's law, as shown in Equation 3 (Nam et al., 2008).

$$\mathrm{W} = 0.62198\frac{P_w}{(P-P_{w})} \qquad (3)$$

Here, W represents the absolute humidity (kg/kg'), P is the atmospheric pressure (kPa) and PW is the partial pressure of water vapor (kPa). The humidity ratio may be determined if the dry-bulb temperature, atmospheric pressure and relative humidity are known. Thus, the partial pressure of water vapor (P_W) may be obtained from Equation 4, a formula that describes relative humidity.

$$\mathrm{RH} = \frac{P_w}{P_{ws}} \times 100 \qquad (4)$$

Here, RH represents the relative humidity (%), PW the partial pressure of water vapor (kPa) and PWS the saturated water vapor pressure (kPa), which is in turn obtained through Equation 5, shown in the following.

$$\ln(P_{ws}) = A_1/T + A_2 + A_3T + A_4T^2 + A_5T^3 + A_6\ln(T) \qquad (5)$$

Here, the saturated water vapor pressure is determined by the temperature; Equation 5 may be applied from 0 to 200℃, T represents the absolute temperature (K) and the variables take the following values.

$A_1 = 5.8002206 \times 10^3$, $A_2 = 1.3914993 \times 10^0$, $A_3 = -48.640239 \times 10^{-3}$,

$A_4 = 41.764768 \times 10^{-6}$, $A_5 = -14.452093 \times 10^{-3}$, $A_6 = 6.5459673 \times 10^0$

In the summer, while the temperature and humidity were generally in accordance with the standards set by the Rural Development Administration when the broilers were 7 days old, the temperature was 6% higher and the humidity 11.3% lower than the appropriate levels when the broilers were 14 days old. Also, the temperature was 8% higher and the humidity 22% higher than the standards when the broilers were 28 days old. For 28-day old broilers during the second summer, the internal humidity seems to have been measured as high because of precipitation; that is, the external humidity seems to have an effect on the internal humidity.

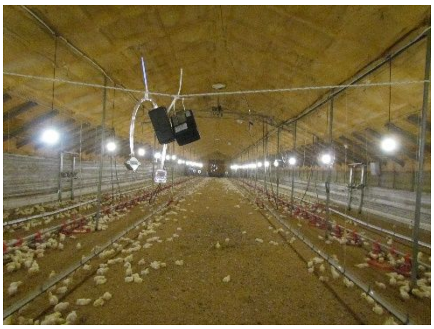
In the autumn, the temperature and humidity were both kept within appropriate ranges when the broilers were 14 days old. When the broilers were 7 days old, the internal temperature was 7% lower than the appropriate level while the humidity was 7% higher than appropriate. When the broilers were 28 days old, the temperature was being maintained within normal range but the humidity was 26% higher than optimal. This seems to be because it had almost consistently rained during the period of experiment in the autumn, which led to high humidity distributions in most of the cases since the external environmental factors have an effect in the interior when the winch curtains are opened. Especially, the experimentation for 28-day old broilers took place in the dawn because of shipping schedules and such – the low temperature and high humidity outside the broiler house seems to have heightened the internal humidity.

In the winter, the internal temperature was relatively kept within normal levels.

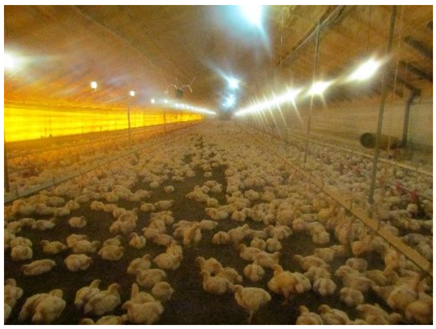
However, the internal humidity was 33% lower than appropriate when the broilers were 7 days old. Moreover, the humidity was higher than suitable when the broilers were either 14 or 28 days old. These results indicate that the internal humidity is not being controlled well.

4.2. Measurements of bedding water content within the naturally-ventilated broiler house

The bedding material was sampled from five points that were equally distanced from one another in the longitudinal direction within the experimental broiler house, as well as from the center points of the upwind and downwind sides. Table 8 shows the water content, measured in the laboratory according to the standard test methods. Since cross-ventilation is done in the summer by opening the winch curtains, the air is relatively actively exchanged with the airflow entering from the upwind side, thereby drying up the surface of the bedding material. Thus, its water content was relatively uniform at 30～40% at all ages and locations. The water content measured in the upwind and downwind side in the summer when the broilers were young (7 or 11 days old) was found to be somewhat high. This seems to be because the feedbox and feed-providing facilities were relatively clustered at the side walls, around which most of the broilers were gathered, leading to an increased number of broilers per unit area and the collection of large amounts of excrement on that location compared to the center zone, which in turn elevated the water content at that point (Figure 16-(a)). While cross-ventilation was employed for 7-day old broilers in the autumn, the effect of ventilation through the winch curtains is expected to more or less decrease, as approximately 70% of the winch curtains were closed. Also, the water content increased by 29% as the birds aged; the continuous accumulation of urine and excrement along with the aging of broilers seems to have contributed to this result. Thus, it may be deduced that the bedding water content in a closed facility is largely dependent on the broilers, such as their aging. There was a relatively high level of deviation among the collected specimens of bedding material in the winter. Cracks in the winch curtains due to the deterioration of the facilities in the case of naturally-ventilated broiler houses, the continuous inflow of external air through the inlet pipe and the formation of crowded and avoided areas by the inflow seem to have contributed to such results. Also, the water content tended to be higher in the downwind side than in the upwind side. This seems to be because the fan heater installed near the upwind side for the maintenance of internal temperature have had an effect on the internal humidity and the humidity of bedding material by drying up certain areas of the broiler house and so on (Figure 16-(b)).



(a) Dispersion of broiler near the Feed-providing facilities in summer (11 age of bird)



(b) Installation of fan heater near the windward in winter

Figure 16 Environmental condition according to season in the broiler house

Table 8 Bedding water contents according to season and age of bird

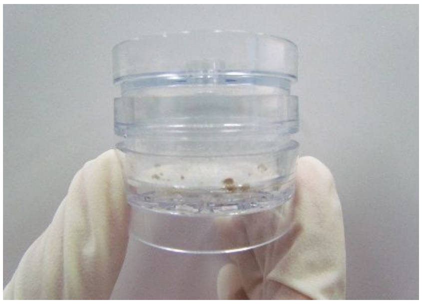
	Autumn			Winter			Summer					
Point \ Age of bird	7	14	28	5	12	22	11	18	26	7	14	27
1	37.2	66.8	63.5	-	38.4	78.8	21.1	24.9	31.6	28.6	8.8	36.8
2	29.8	19.3	84.4	11.3	28.5	41.4	32.0	27.3	41.5	24.9	4.4	36.7
3	20.4	42.8	62.8	10.5	36.7	36.0	35.2	33.8	35.9	45.6	5.1	40.1
4	25.5	38.2	47.1	20.2	34.1	44.9	22.7	26.5	32.9	27.8	7.8	43.1
5	28.5	66.3	42.1	-	54.0	35.3	20.6	29.5	58.2	38.2	5.8	33.2
Windward	-	41.2	-	13.2	25.8	41.4	44.5	32.9	49.7	42.6	7.2	43.4
Leeward	35.4	60.8	108.8	17.9	38.2	87.9	48.1	46.0	43.2	40.8	5.6	26.2
Average	27.9	47.9	68.1	14.6	36.5	52.2	32.0	31.6	41.9	35.5	6.4	37.1
STEDV	5.5	17.5	24.9	4.2	9.1	21.7	11.3	7.2	9.6	8.2	1.6	6.0

4.3. Monitoring results of dust concentration

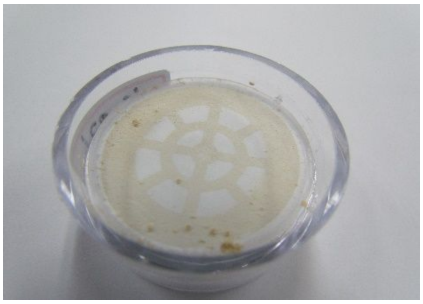
4.3.1. Measurements of concentrations of TSP and PM10

NV-2, NV-3 and NV-4, shown in Figure 7, were selected as areas of constant monitoring in order to assess the change in the average dust concentration in a single section according to the seasons. However, the PM10 concentrations were measured to be higher than that of TSP in some specimens. It is suspected that the difference in temperature in and out of the broiler house in the winter as well as between seasons caused condensation to occur on the walls of the collecting cassettes, which made the TSP to coagulate in lumps on the walls after entering the cassettes so that the concentrations of TSP were underestimated (Figure 17). Thus, these data were exempted from this study when calculating the average concentrations of TSP and PM10 collected at the average heights of respiratory systems of workers within broiler houses. Kwon *et al.* (2016) pointed out that the condensation phenomenon due to temperature differences as well as the dust-rich environment within the broiler house may either over- or underestimate the dust concentration when the processes used in the general industrial field are adapted for monitoring studies of dust within broiler houses. Kwon *et al.* then proceeded to propose a method for dust collection that takes into consideration the season within the broiler house, the age of birds and environmental parameters.

Table 9 shows the average concentrations of TSP and PM10 according to the age of birds and the season, which are obtained through the dust collection experiments.



(c) Condensation situation of dust on the walls of the collecting cassettes



(d) Condensation of dust mass after sampling of TSP on the Teflon filter

Figure 17 Condensation situation of TSP dust in the winter

Table 9 Measured concentration and PM10/TSP ratio according to season and raising days

Season	Raising days	TSP (mg/m^3)	PM10 (mg/m^3)	PM10/TSP (%)
Summer	11	1.14	0.65	0.57
	18	0.71	0.56	0.79
	26	0.76	0.60	0.79
Summer	7	0.94	0.53	0.56
	14	0.42	0.35	0.83
	28	0.62	0.55	0.89
Autumn	7	0.65	0.51	0.78
	14	0.54	0.43	0.80
	28	2.92	2.67	0.91
Winter	5	-	-	-
	12	1.37	0.85	0.62
	22	2.19	1.94	0.89

The TSP within the broiler house in the summer showed a high concentration at 0.94 mg/m^3 when the broilers were 7 days old. The concentration dropped to 0.42

mg/m^3 when the broilers were 14 days old; it showed a moderate increase again to 0.62 mg/m^3 when the broilers were 28 days old. The TSP concentration in the autumn exhibited a similar pattern: it was 0.65 mg/m^3 when the broilers were 7 days old, 0.54 mg/m^3 when they were 14 days old and 2.92 mg/m^3 when they were 28 days old. It is notable that the concentration was very high when the broilers were 28 days old. Two possible causes seem to have contributed to this result: the winch curtain within the broiler house was closed and the broilers were very active because the feed was being continuously supplied, as they were just awaiting shipment. These must have led to the dispersal of a large amount of dust. In the winter, a large amount of dust coalesced on the wall of the collecting cassette when the broilers were 7 days old and thus the data for that timeframe was excluded. The dust concentration showed an increase with the age of birds: it was 1.37 mg/m^3 when the broilers were 14 days old and 2.19 mg/m^3 when they were 28 days old.

The average TSP concentration in the summer was 0.77 mg/m^3. In the in-between seasons, it was 1.37 mg/m^3 and in the winter it was 1.78 mg/m^3; they showed a 77.9% and 131.2% increase, respectively, when compared to the average TSP concentration in the summer, thereby displaying a considerable difference in dust concentration according to the season. The employment of different methods of ventilation, such as the opening and closing of the winch curtains and the periods and duration of operation of the ventilation fans, according to the temperature and humidity inside and outside of the broiler house seems to have contributed to this result. The opening of winch curtain in the summer seems to have introduced a large amount of airflow from the exterior into the broiler house, leading to increased ventilation through which a substantial amount of dust was discharged, thereby decreasing the internal dust concentration. In the in-between seasons, the dust concentration within the broiler house seems to increase according to the ratio of opening of the winch curtain. In the winter, on the other hand, while the winch curtains are entirely closed and external airflow is accepted through the inlet pipes installed along with the slope of the roof, the ventilation fans installed on the front and the back of the broiler house has a short period and duration of operation and thus the amount of ventilation is less than that in the summer. Therefore, a less amount of dust would be expelled and a rather dust-rich environment would be created.

7-day old broilers in the summer showed a high average concentration of PM10 at 0.53 mg/m^3. The concentration fell to 0.35 mg/m^3 when the broilers aged to 14 days old, and then rose back to 0.55 mg/m^3 when they were 8 days old. In the autumn, 7-day old broilers showed an average PM10 concentration of 0.51 mg/m^3; for 14-day old ones, it decreased to 0.43 mg/m^3; and when they were 28 days old the concentration sharply increased to 2.67 mg/m^3. 12-day old broilers in the winter produced an average PM10 concentration of 0.85 mg/m^3, while for those aged 28 days old it was 1.94 mg/m^3; it showed a similar trend as TSP as the broilers aged. The total average concentrations of PM10 in the summer, in-between season and winter were 0.54 mg/m^3, 1.20 mg/m^3 and 1.40 mg/m^3, respectively, showing a similar pattern to those of TSP. Also, the differences in the concentrations of TSP and PM10 were generally small. Thus, it can be inferred that most of the dust at the height of the respiratory system of a worker within the broiler house is less than 10 μm in size.

From these results, the ratios of PM10 to TSP were estimated in order to obtain a rough understanding of the particle size distribution of the dust collected at the height of the broiler house worker’s respiratory system. In the summer, the concentration ratio was 57～89%; in the in-between seasons, it was 78～91%; and in the winter it was 62～89%. Overall, the ratios of PM10 increased along with the age of birds. This seems to be because the circulation fan was operated as the broilers grew older in order to circulate the internal air and expel heat, thereby leading to a higher probability of PM10 produced from bedding and feather being dispersed, especially by the circulation fan installed near the floor. Thus, it can be thought that physical factors, such as the circulation fan, must have had the largest effect on the increase of the ratio of PM10 and smaller dust. Since PM10 that is, dust with a particle size less than 10 ㎛ that can easily infiltrate the human bronchi and lungs—has a substantial effect at the height of the respiratory system of the workers, it can be said that there is a high risk of respiratory diseases when the worker is exposed to the interior of the broiler house for a long time.

4.3.2. Measurement of concentrations of inhalable and respirable dust

Figure 18, 19, 21 and 22 shows the average concentrations of inhalable and respirable dust measured at the heights of the respiratory systems of broilers and workers according to the season. The concentrations of inhalable and respirable dust in the in-between season when the broilers were 7 days old were considered as missing values due to the malfunction of the aerosol spectrometer and thus were excluded from the results. Overall, the results show a similar pattern as the TSP and PM10 concentrations as presented above. There was a significant difference for each type of dust according to the season: the average dust concentrations were found to be higher in the winter and in-between season compared to those in the summer. The average concentration of inhalable dust in the summer was 2.61±0.73

mg/m^3 at the height of the broilers' respiratory systems, while those in the in-between season and the winter were found to be 5.36±1.12 mg/m^3 and 5.26±0.69 mg/m^3, respectively; the concentrations of inhalable dust in the two seasons were found to be 105.4% and 101.5% higher, respectively, than that in the summer. The dust concentration at the average height of the workers' respiratory system showed a similar tendency. The average concentrations of inhalable dust at that height in the summer, winter and in-between season were 1.66±0.187 mg/m^3, 4.23±0.28 mg/m^3, 4.65±0.63 mg/m^3, respectively. A number of causes seem to have contributed to this result. Winch curtains are closed in the winter, leading to a relatively smaller amount of ventilation; because of the low level of schematic ventilation the pollutants inside the broiler house is unable to be expelled. Moreover, the operation of fan heaters for the maintenance of internal thermal environment makes the air inside the broiler house arid, making it easy for large amounts of dust to disperse into the air. Also, the 28-day old broilers in the in-between season were situated in a special circumstance: they were facing shipment and thus were continuously provided feed. Furthermore, the feed-providing motor continued to be in action even after the feed supply was finished, making noise and thus resulting in a relatively high activity of the broilers. Additionally, as shown in Figure 20-(a), the winch curtain at the upwind side was approximately 40% open while the one at the downwind side was 10% open, creating together an environment where the dust inside the broiler house could not be easily discharged. This seems to have contributed to a somewhat higher average dust concentration in the in-between season compared to other periods of time.

When the dust concentrations of broilers with different ages of birds were compared, the measured concentration was lower with 14-day old broilers than with 7-day old ones. Also, the concentration was relatively high right before shipping (28 days old). The differences in the guidelines for temperature, humidity and ventilation within the broiler house according to the age of the broilers seem to have contributed to this result. That is, when the birds are younger, due to the inefficient insulation of the broilers the ventilation is kept at a minimum in order to maintain a high internal temperature with a rather low internal humidity. Additionally, some of the bedding were replaced when new flocks of broilers moved into the broiler house and thus the bedding was relatively dry when the broilers were 7 days old, giving rise to a somewhat high level of dust concentration. Broiler houses with 28-day old broilers nearing shipment exhibited high concentrations of dust despite extensive ventilation. Possible reasons include the larger size of broilers, which produces an increased amount of feather and dust from the broilers, and particularly the increase in feed supply near shipment, which causes an upsurge in the broilers' activity that in turn causes dispersal of bedding, feed and great amounts of feather fragments enough to be seen with naked eye.

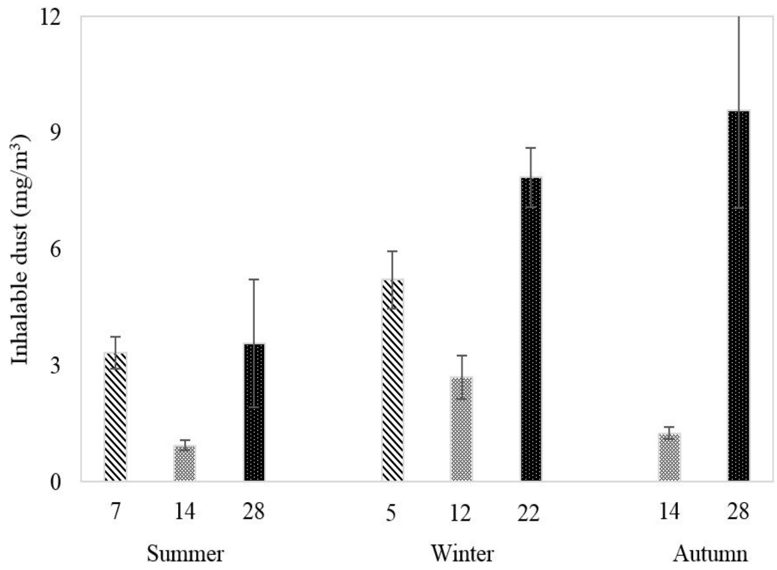


Figure 18 Concentration of inhalable dust according to season and age of bird at the broiler's respiratory height

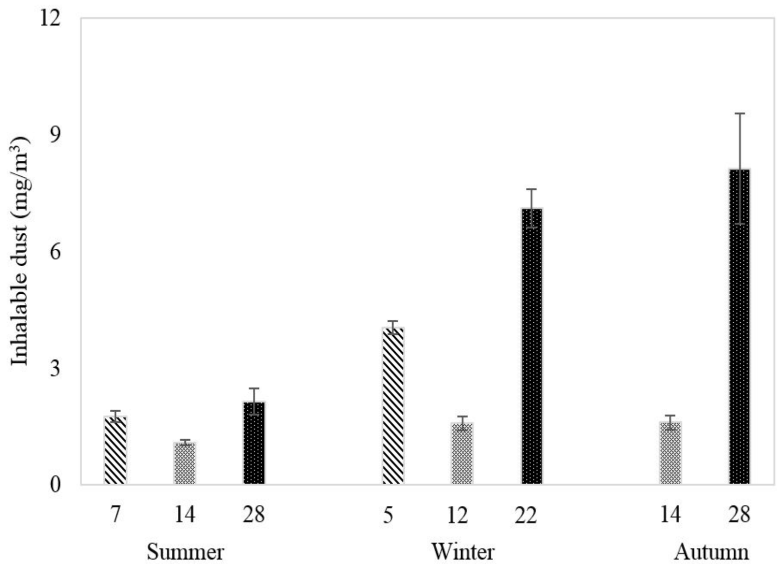


Figure 19 Concentration of inhalable dust according to season and age of bird at the worker's respiratory height

(a) Internal environment at awaiting shipment

(b) Shipment work 28 days of birds in Autumn

Figure 20 Internal environment when the shipment (28 age of birds)

Winkel *et al.* (2015) proposed the following regression for determining the amount of PM10 emission according to the age of birds.

$$Y = 0.0013x^{2.3855} \quad (R^2 = 0.89) \qquad (6)$$

Here, Y represents the PM10 emission (mg/h·animal) and x represents the age. Also, Lingjuan *et al.* (2012) have mentioned the following equation for obtaining the rate of dust production according to the dust concentration and the ventilation rate.

$$\text{Emission rate} = \text{Concentration} \times \text{Ventilation rate} \qquad (7)$$

The amount of ventilation in the experimental broiler house was estimated according to the minimal ventilation settings guidelines for the winter (Appendix Ⅰ) to be 0.29 m^3/s, 1.96 m^3/s and 4.21 m^3/s for the respective ages of broilers. The rate of dust production according to the age of birds, as proposed by Equation 6, along with the ventilation rate within the experimental broiler house were put into Equation 7 to determine the dust concentration, which were found to be 0.46 mg/m^3·animal, 0.36 mg/m^3·animal and 0.88 mg/m^3·animal for the respective ages. Thus, the dust concentration is expected to be the lowest when the broilers are 14 days old, which is in accordance with the results from this study. Especially, the studies by Choi *et al.* (2005) and Vučemilo *et al.* (2007) have confirmed similar dust concentration patterns by the age of broilers. Therefore, the amount of dust emission, which is related to the amount of ventilation and age of birds, also seems to have an effect on the different dust concentrations.

The average concentration of respirable dust at the height of the broilers was 0.26±0.03 mg/m^3 in the summer, 0.53±0.80 mg/m^3 in the in-between season and 0.60±0.05 mg/m^3 in the winter while its concentration at the height of the workers was 0.21±0.01 mg/m^3 in the summer, 0.54±0.03 mg/m^3 in the in-between seasons and 0.58±0.02 mg/m^3 in the winter, showing a similar trend to that of inspirable dust. However, there was little difference in the concentration of respirable dust measured at different heights, implying that the height of measurement has little effect on the dust concentration. At most of the time both inhalable and respirable dust exceeded the threshold limits that Donham *et al*. (2000) proposed with the lung function in consideration, necessitating additional measures of dust reduction through physical means such as the opening of winch curtains and the utilization of ventilation fans.

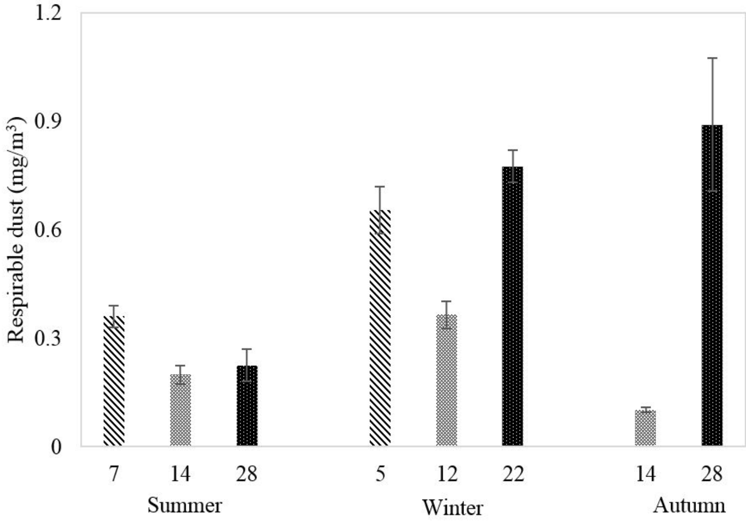


Figure 21 Concentration of respirable dust according to season and age of bird at the broiler's respiratory height

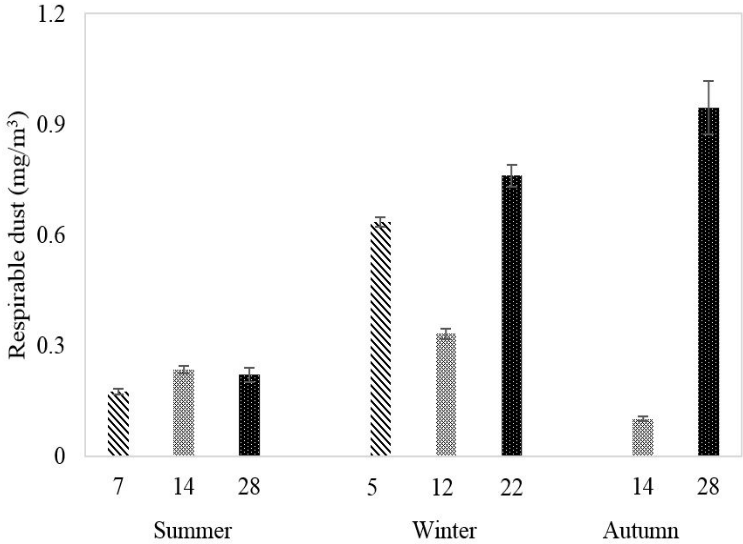


Figure 22 Concentration of respirable dust according to season and age of bird at the worker's respiratory height

4.4. Measurements of dust concentrations according to entry and exit of workers

Inhalable and respirable dust were measured at the heights of respiratory systems of broilers and workers (1.5 m) when the broilers were either actively moving or relatively stable, according to the entry and exit of the workers. Figures 21 and 22 show the dust concentrations according to the location of collection. The concentration of inhalable dust increased with the activity of the broilers. This trend was especially evident when the birds were 28 days old and awaiting shipment, as well as during most of the summer season. At the height of the broilers, the concentration of inhalable dust increased by 769.6% when the broilers were active, compared to when they were stable; the older the broilers were, the larger the difference was.

The average concentrations of inhalable dust at the height of workers' respiratory systems showed a similar pattern to those at the height of the broilers' respiratory systems, but with less differences. Especially, there was almost no difference in the average concentrations for 14-day old broilers in the summer and for 5-day old broilers in the winter, at 0.2 mg/m^3 and 0.18 mg/m^3, respectively. In the summer the circulation fan is operated near the floor in the center of the broilers, dispersing not only the bedding material but also the excrement and feathers of the broilers stacked on it. Thus, a high level of dust concentration was measured at the broilers' height. At the workers' height, on the other hand, the opening of winch curtains led to increased ventilation, discharging significant amounts of dust at the height of the winch curtains, minimizing the difference in concentration according to the level of activity. The in-between season also sees large amounts of dust dispersal due to the group movements of the broilers by the entry and exit of workers as well as the intermittently operated circulation fan. However, the ratio of opening of the winch curtains is smaller compared to that in the summer, leading to a large difference in the concentration according to the level of activity with increasing age of birds. In the winter the difference in concentration according to the level of activity was small because the initial dust concentration was already high due to minimal ventilation. However, the difference was found to moderately increase with the age of birds.

For respirable dust, distinct results were found for different heights (Figure 25, 26). At the height of the broilers, the concentration of respirable dust increased according to the levels of activity in the summer; especially, the margin of increase for 28-day old broilers amounted to 882.3% compared to when the broilers showed a low level of activity. On the other hand, there was little difference according to the levels of activity in the winter and in-between season except for 28-day old broilers. Dust concentrations measured at the height of the workers exhibited little dependence on the level of activity at all seasons except for 28-day old broilers.

A t-test was performed in order to confirm whether the activity of broilers of different ages had an effect on the dust concentration at the workers' height. The p value for 1-week old and 2-week old broilers for inhalable dust was found to be 0.13 and 0.11 respectively, not warranting a significant difference in the average concentration according to the level of activity at a significance level of 5%. For 4-week old broilers, however, the t value was -2.50, which is beyond $\pm$ 1.96, and the p value was 0.047, which is smaller than 0.05. Thus, the average dust concentration for 4-week old broilers showed a statistically significant difference according to the level of activity of the broilers (Table 10). For respirable dust no significant difference was found between the average dust concentrations of different levels of activity when the broilers were either 1 or 2 weeks old, showing p values of 0.11 and 0.43, respectively. However, when the broilers were 4 weeks old the t value was −2.67, which is beyond ± 1.96, and the p value was smaller than 0.05, implying a significant difference (Table 11). Thus, it may be said that for all types of dust the level of activity of the broilers has an effect on increasing the average dust concentration when the broilers are older. Therefore, protective devices such as masks are thought to be necessary for workers approaching broiler houses with broilers nearing shipment.

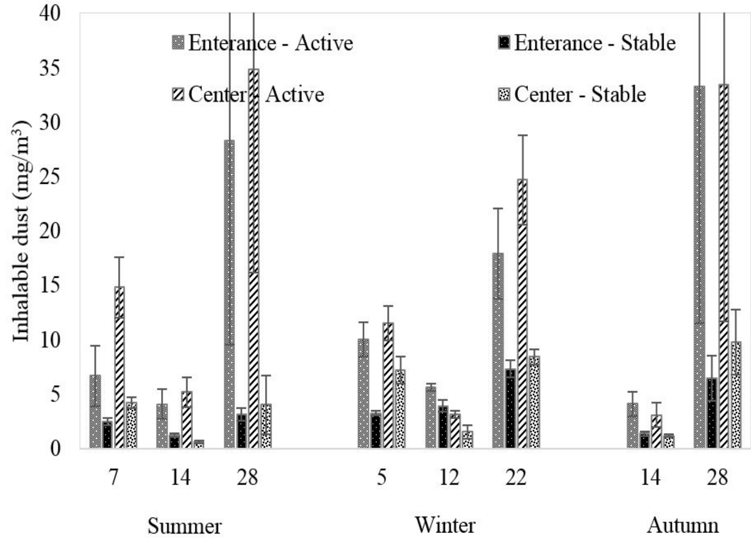


Figure 23 Concentration of inhalable dust according to broiler's activity at the broiler's respiratory height

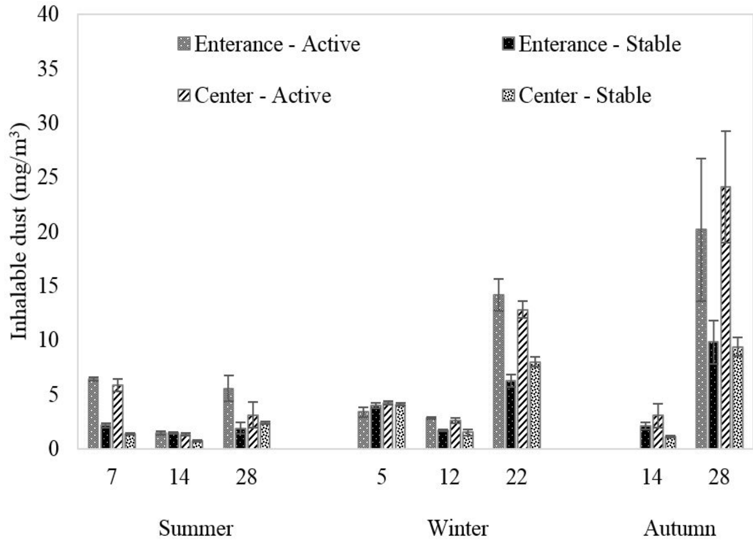


Figure 24 Concentration of inhalable dust according to broiler's activity at the worker's respiratory height

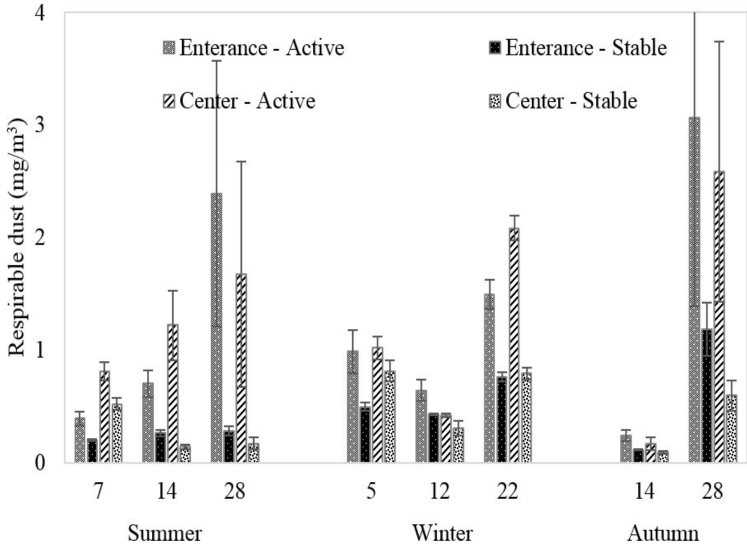


Figure 25 Concentration of respirable dust according to broiler's activity at the broiler's respiratory height

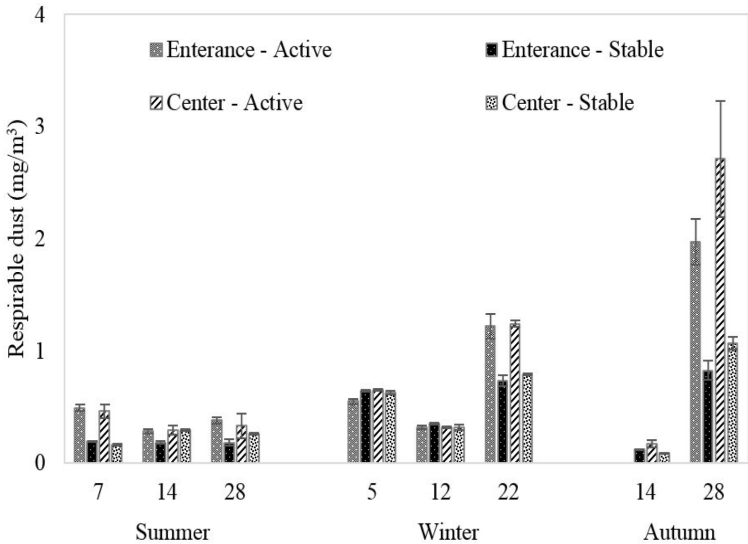


Figure 26 Concentration of respirable dust according to broiler's activity at the worker's respiratory height

The concentrations of inhalable dust were, for most cases, above the threshold limit for the workers' lung function as proposed by Donham *et al.* (2000) when the broilers were active. Especially, the dust environment increased up to 500.2% in the in-between season and the winter. Moreover, the threshold limit for the broilers' lung function as proposed by CIGR (1994) was mostly violated as well when the broilers showed a high level of activity. However, even when the broilers exhibited a relatively low level of activity, the dust concentrations for some periods of time in the winter and in-between season exceeded the threshold limit set by Donham *et al.* (2000) by up to 196% and 238%, respectively, and the one set by CIGR (1994) by up to 114% and 159%.

Table 10 t-test results of inhalable dust according to broiler’s activity at the worker’s respiratory height

Variable		N	Dust concentration	t	p-value
Age of birds (wk)	Broiler's activity-Dust type		Mean±SD (mg/m^3)		
1	Stable-Inhalable dust	6	1.31±0.54	-1.81	0.13
	Active-Inhalable dust	6	1.72±0.70		
2	Stable-Inhalable dust	5	2.05±1.09	-2.049	0.11
	Active-Inhalable dust	5	3.09±0.47		
4	Stable-Inhalable dust	7	5.49±3.76	-2.499	0.047*
	Active-Inhalable dust	7	11.56±8.69		

*P<0.05

Table 11 t-test results of respirable dust according to broiler’s activity at the worker’s respiratory height

Variable		N	Dust concentration	t	p-value
Age of birds (wk)	Broiler's activity-Dust type		Mean±SD (mg/m^3)		
1	Stable-Respirable dust	6	0.32±0.25	-1.95	0.11
	Active-Respirable dust	6	0.47±0.15		
2	Stable-Respirable dust	5	0.23±0.12	-0.88	0.43
	Active-Respirable dust	5	0.27±0.06		
4	Stable-Respirable dust	7	0.58±0.36	-2.67	0.04*
	Active-Respirable dust	7	1.17±0.92		

*P<0.05

4.5. Morphological and chemical analyses of the collected dust

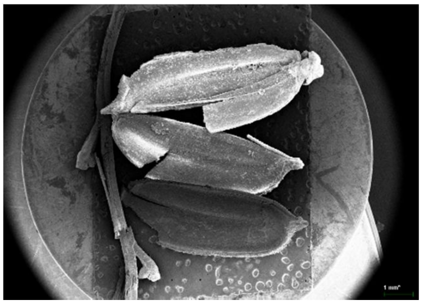
Preliminary studies have found that the main sources of dust within a broiler house include the feather and excrement of broilers and bedding material (Cambra-López *et al.,* 2010).

Thus, in order to elucidate the main sources of dust within the broiler house in this experiment and conduct a qualitative and quantitative analysis of its components, airborne dust was collected and a FESEM-EDX analysis of the collected dust as well as the main candidates for dust production was carried out: the results are as the following.

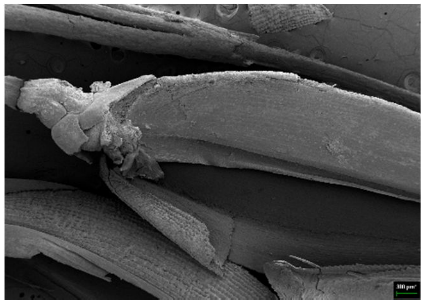
4.5.1. Morphological analysis

4.5.1.1. Bedding

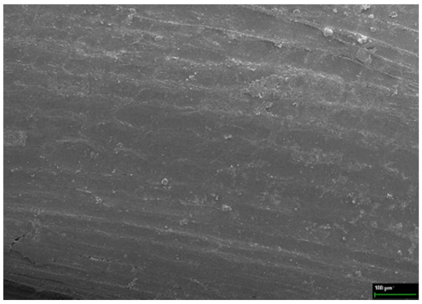
The bedding material is completely desiccated and mostly made up of rice hull, some of which were observed to be connected to a thin stem. Rice hull grains were observed at x20, x50, x100, x300 and x1,000 magnifications with FESEM; most were oval in shape with a smooth surface. The edges of the hull were partially fragmented due to the drying process and were thus found to be rather coarse (Figure 27).



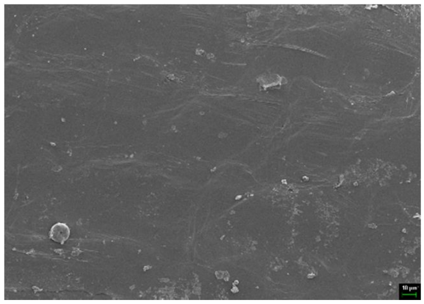
(a) x50 (1mm*)



(b) x100 (300㎛*)



(c) x300 (100㎛*)



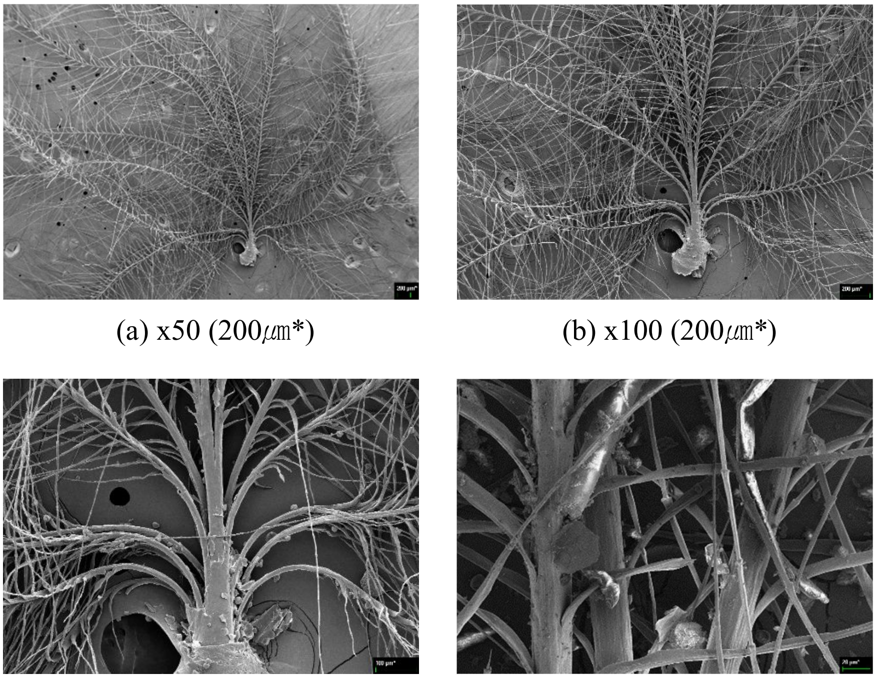
(d) x1,000 (10㎛m*)

Figure 27 Three-dimensional images of bedding material

('*' mark means scale)

4.5.1.2 Feather

Most of the feathers were fan-shaped, thin and long; barbs were stemming from the both sides of a solid shaft and small crooked barbules were sprouting around the barbs. During FESEM analysis, an air-brush was used to remove particles that are dispersed within the instrument. When this happened the barbules readily broke off from the shaft and were airborne for a long time. The sampled feathers were observed at x50, x100, x300 and x1,000 magnifications. Especially, when the observation was done at x1,000, grain-shaped circular material were found between the barbs in some samples (Figure 28). It should be noted that the stem parts of the bedding material share a similar morphology with the shafts of feathers and their origin should be further confirmed by chemical analyses.



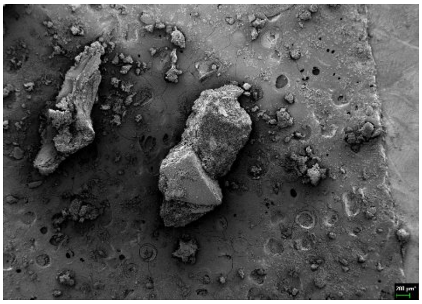
(a) x50 (200㎛*) (b) x100 (200㎛*)

(c) x300 (100㎛*) (d) x1,000 (20㎛*)

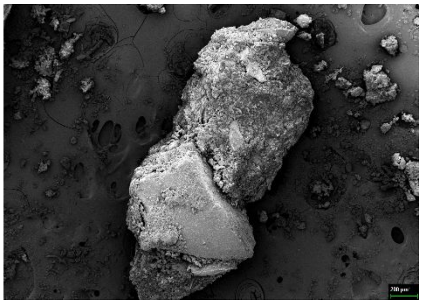
Figure 28 Three-dimensional images of feather ***('*' mark means scale)***

4.5.1.3 Feed

The feed, transported from the feed tank installed at the front of the broiler house through a pipe, dispersed dust when it was being poured into the feedbox, which was so much that it could be observed with the naked eye. The feed grain and particle sampled from the feedbox and feed tank were observed to reveal a structure of entangled spherical lumps. The edges were mainly coarse (x50), and when they were magnified to approximately x1,000, an aggregate of small spherical particles of various sizes was observed (Figure 29). The feed sampled directly from the feedbox had a diameter of approximately 1mm. The feed was ground before observation through FESEM to facilitate the fixation of the sample on the stub by increasing its surface area. Compared to the feed particle before grinding, a magnification of x50 showed aggregates of many small spherical particles, while a magnification of x1,000 revealed shapes that were fairly small and angulated, rather than the distinctly spherical ones that were observed before grinding.

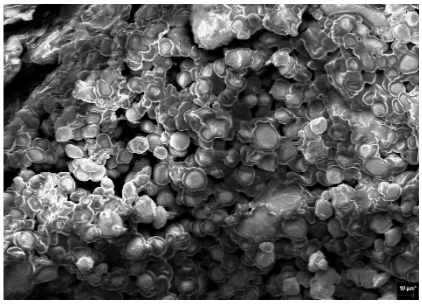


(a) x50 (200㎛*)



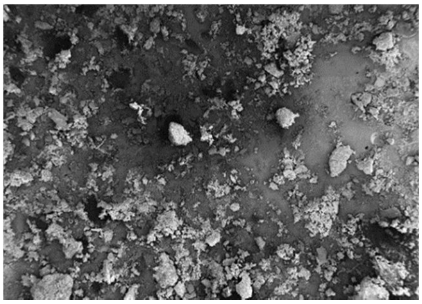
(b) x100 (200㎛*)

(c) x300 (100㎛*)

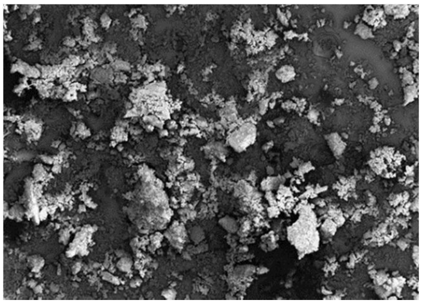


(d) x1,000 (10㎛*)

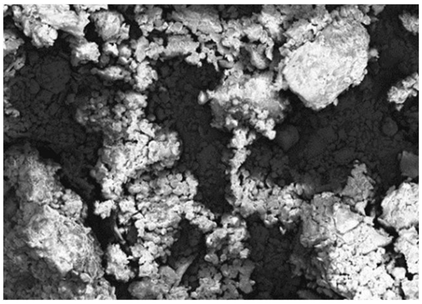
Figure 29 Three-dimensional images of feed *('*' mark means scale)*



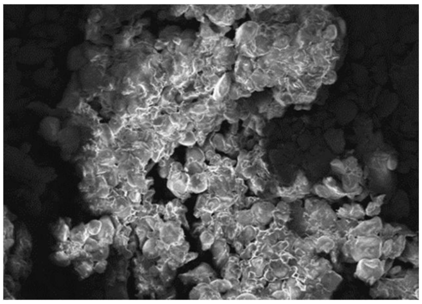
(a) x50 (200μm*)



(b) x100 (200μm*)



(c) x300 (100μm*)

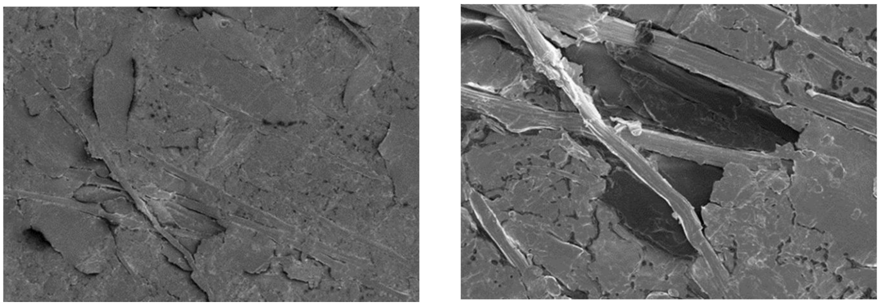


(d) x1,000 (20μm*)

Figure 30 Three-dimensional images of crushed feed *('*' mark means scale)*

4.5.1.4 Collected dust from the broiler house (after pelletization)

When platinum was sprayed on the sample stationed in the platinum coater as a preparation process for FESEM analysis of the PM10 collected in the cassettes, the dust was scattered into the air within the instrument, contaminating it. Thus, the collected dust was pelletized so to minimize dust scattering. The results observed through FESEM are as the following (Figure 31). The pelletized dust was firmly compressed; shapes such as shafts of feathers or stems of the bedding material could be distinctly discerned, but the aggregates of spheres that were observed in magnifications of feed particles were mostly unobservable. The reduction in the pore space between the particles and the increase in density that happen during the compression of the collected dust for pelletization seem to have contributed to such a result. Thus, pelletized dust is thought to be unsuitable for morphological analyses for determining the sources of dust.

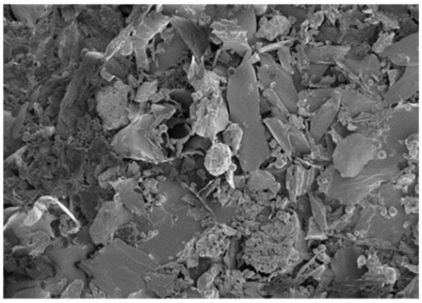


(a) x 1,000 (10㎛*) (b) x 3,000 (10㎛*)

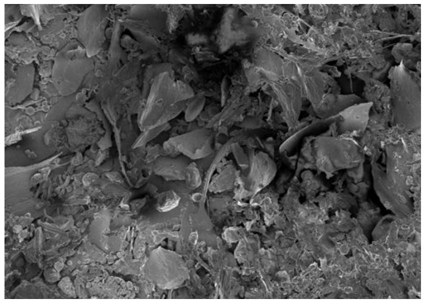
Figure 31 Three-dimensional images of collected dust (after pelletization)
('*' mark means scale)

4.5.1.5 Collected dust from the broiler house

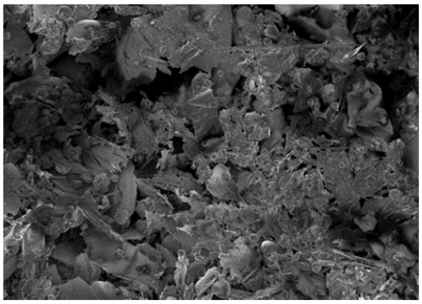
The three-dimensional images of the dust collected from within the naturally-ventilated broiler house showed many fragments of small diameters and sizes. Their edges were round and angulated, while the central surface was smooth. Especially, the pattern on the flat fragment as shown in (g) and (j) of Figure 32 is thought to be highly similar to the morphology of the fragmented bedding material as observed in (c) and (d) of Figure 27. Thus, most of the dust collected from the naturally-ventilated broiler house is thought to originate from the bedding material. While thin, sharp stem-like shapes with joints were found as well, they were thinner than the stems that constitute the bedding material; their diameter resembles that of the barbs of feathers. Thus, these stems seem to have originated mainly from the feathers of broilers. Also, spherical aggregates were mostly absent, suggesting that the feed contributed less to the production of dust.



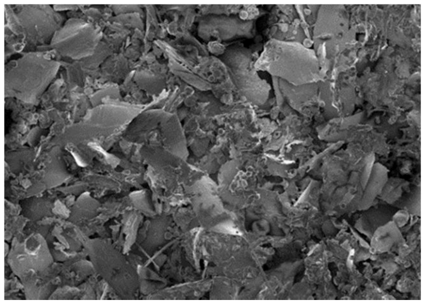
(a) x1,000 (20㎛*)



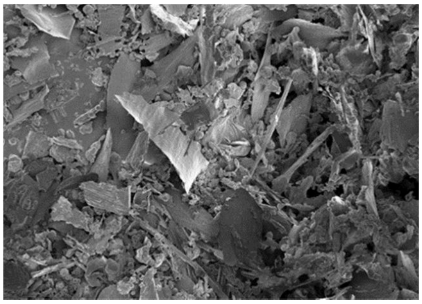
(b) x1,000 (20㎛*)



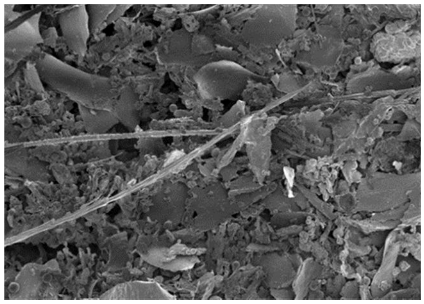
(c)x1,000 (20㎛*)



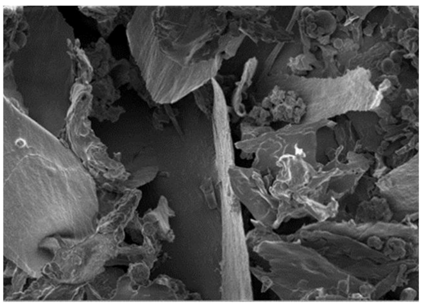
(d) x1,000 (10㎛*)



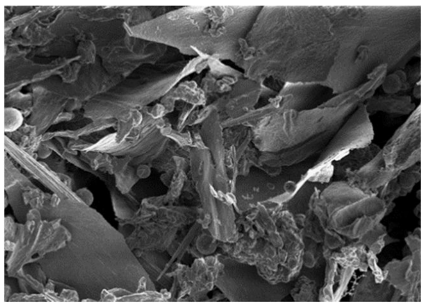
(e) x1,000 (10㎛*)



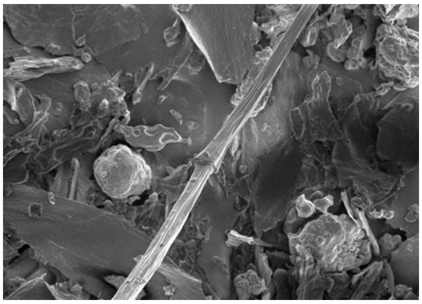
(f) x1,000 (10㎛*)



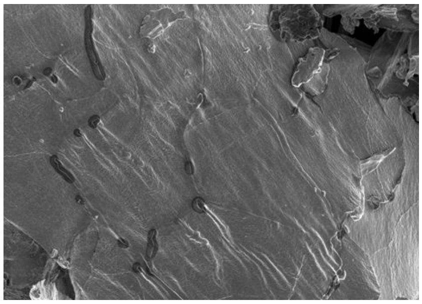
(g) x3,000 (10㎛*)



(h) x3,000 (10㎛*)



(i) x3,000 (10㎛*)



(j) x3,000 (10㎛*)

Figure 32 Three-dimensional images of collected dust
***('*' mark means scale)* (a) ~ (f): x1000/ (g) ~ (j): x3,000**

4.5.2. Chemical analysis

4.5.2.1. Chemical analyses for the main sources of dust

The raw data were classified according to the results of the morphological analyses for the main sources of dust. Then, a chemical components analysis was conducted with EDS for each specimen. For all specimens carbon (C), oxygen (O), nitrogen (N) and platinum (Pt) were commonly found. Carbon must have been produced from the carbon tape that is used to fix the specimen and prevent its charging, while platinum is thought to be derived from the platinum coat that is used to improve the quality of the image by enhancing the conductivity of the specimen and oxygen from the water content of each specimen.

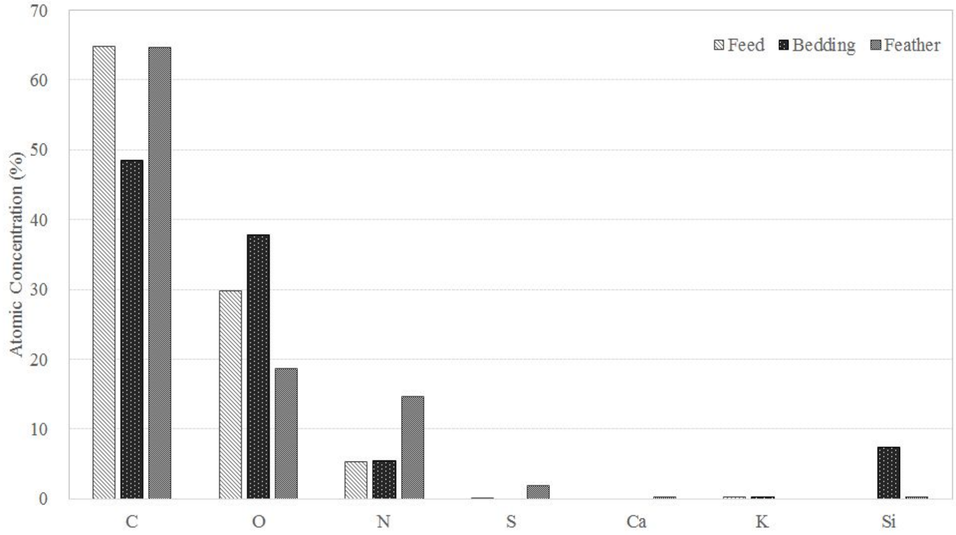


Figure 33 Atomic concentration profile of each main sources of dust

Feed contained carbon (C), platinum (Pt), oxygen (O), nitrogen (N), sulfur (S) and potassium (K) as its components; it had an especially high content of nitrogen and potassium, while calcium and silicon were absent. Silicon is a main constituent of soil and rock, and is contained in plants including rice, bamboo and equisetum as well as in diatoms and the feathers and talons of animals (Yoon, 2011). This seems to be why silicon was not detected in the feed. Calcium, one of the chemical components of the feed, was not found; the difference in the mixing process of the feed seem to have contributed to this and an accurate database should be constructed through the accumulation of additional raw data in the future.

The bedding material contained carbon, oxygen, nitrogen, potassium and silicon as its elements. Silicon was found to be more abundant than in other sources of dust, while sulfur and calcium were absent. The high level of silicon seems to be derived from rice hull, the main component of the bedding material.

Component analysis of feathers revealed carbon (C), oxygen (O), nitrogen (N), sulfur (S), calcium (Ca) and silicon (Si). Especially, the ratios of nitrogen and sulfur was somewhat higher than those found in the feed and the bedding. Since a high level of sulfur-containing amino acid is accumulated in the feather of domestic fowls due to the sulfides supplied through the feed, it must have led to a higher amount of sulfur than compared to other sources of dust (Go, 2014). Moreover, sulfur is a biologically essential element that strengthens the feathers when bound to proteins (Park, 2011). Meanwhile, in contrast to the other sources of dust, calcium was not found in the feathers. Biologically, calcium plays an essential role for the normal cellular functions. While it exists in the intracellular fluid of an animal cell, its concentration is higher in plant cells and is thus supplied through the fertilizer, which may have led to calcium being found in the other sources of dust.

Overall, there was a considerable difference for sulfur (S), potassium (K) and silicon (Si) among the different sources of dust. Such chemical characteristics are expected to be useful for the determination of the sources of each dust specimen.

4.5.2.2 Chemical analyses of the collected dust from naturally-ventilated broiler house

The data for dust collected from the naturally-ventilated broiler house was classified by a number of characteristics based on the morphology and chemical composition of each main source of dust as analyzed with FESEM-EDX. From the pelletized specimen carbon, oxygen, nitrogen, calcium, potassium, sulfur, magnesium and silicon was observed. When the effects of physical alterations of the specimen were excluded, three elements were found to be the most abundant in the specimen: nitrogen, calcium and potassium, in the decreasing order. Calcium is mainly found from feed and feathers, while potassium is mainly observed in feed and bedding. Since silicon, another main element found in bedding, is detected as well, it may be thought that pelletized specimen originates primarily from bedding and feed.

In the first experiment for naturally-ventilated broiler house, carbon, oxygen, nitrogen, potassium, sulfur, magnesium, chlorine and sodium was found. When the elements by-produced from physical alterations are exempted, nitrogen (17.18%), potassium (0.78%), sulfur (0.66%) and chlorine (0.3%) were found in high levels (Figure 34). The second experiment additionally revealed fluorine, while sodium was absent this time; chlorine was found in abundance in both rounds of experiment. While chlorine (Cl) was not found in the primary chemical analysis of the sources of dust, it has been reported that the feathers of broilers characteristically contain large amounts of sulfur (S) and chlorine (Cl), which were also found to have a high composition in the specimen examined in this study compared to other elements (Cambra *et al.,* 2010). Thus, it may be concluded that the specimen collected from within the naturally-ventilated broiler house contains large amounts of dust produced from feathers. Moreover, fluorine is an element that has not been observed in the chemical analyses of the main sources of dust.

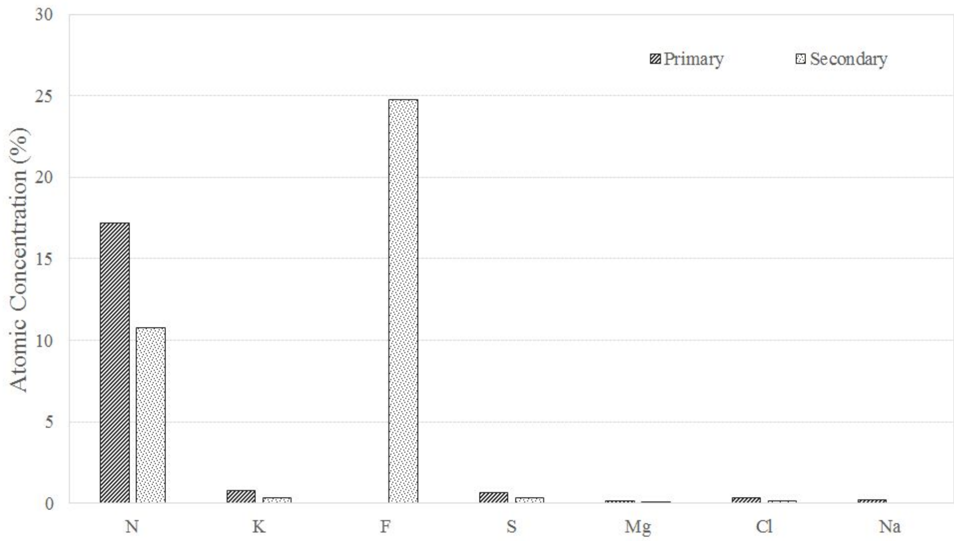


Figure 34 Atomic concentration profile of collected dust

Fluorine only exist in compound forms in the nature; a wide array of fluorine compounds are synthesized to be used as pesticides, industrial materials and such. Thus, the detection of pesticide on the bedding material could be a possible reason for the discovery of the element (Park, 2011). While magnesium was also not found in the main sources of dust, it is an inorganic element often found in feed while existing in only trace amounts in animals. Thus, the detected magnesium seems to have originated from feed, rather than the feathers of broilers. A more detailed analysis of the components with bolstered raw data is required in the future.

4.6. Statistical analysis of the environmental factors

A variety of parameters have an effect on the concentration of airborne dust within a broiler house. In this study, temperature, humidity and bedding water content are selected as measured environmental parameters. The confidence level for the correlational analyses between the environmental parameters and the dust concentrations at the height of the human respiratory system was set at 95% (α=0.05) and 99% (α=0.01). Tables 12 to 18 show the results of the analyses, and its main conclusions are as the following.

4.6.1. Correlation between inhalable and respirable dust and environmental parameters according to the age of birds

The coefficients of correlation between environmental parameters and inhalable dust produced by 1-week old broilers were mostly very high (Tables 12, 13). Especially, the coefficient of correlation with internal relative humidity showed the largest negative value at –0.982; strong negative correlations were also present with external absolute humidity, external relative humidity and external temperature as well, with the coefficients being –0.949, -0.924 and –0.922, respectively. These environmental parameters were significant at a level of 0.01. Meanwhile, internal absolute humidity and bedding water content showed strong negative correlations with coefficients of –0.869 and –0.814, which were significant at a level of 0.05. Thus, the lower the internal relative humidity, the external absolute humidity, the external relative humidity, the external temperature and the internal absolute humidity, the higher the concentration of inhalable dust was, while more water in the bedding material meant a lower concentration of inhalable dust.

Table 12 Coefficients of correlation between environmental parameter and inhalable dust (1week old of birds)

	Mean	SD	Inter-construct Correlations							
			1	2	3	4	5	6	7	8
1. Inhalable dust	2.387	1.313	1							
2. Water content	24.743	13.733	-0.814*	1						
3. Indoor R.H.	60.329	10.515	-0.982**	0.740	1					
4. Indoor A.H.	0.016	0.002	-0.869*	0.815*	0.879*	1				
5. Indoor A.T.	30.227	1.262	-0.143	0.441	0.133	0.589	1			
6. Outdoor R.H.	63.402	9.702	-0.924**	0.588	0.946**	0.677	-0.196	1		
7. Outdoor A.H.	0.010	0.005	-0.949**	0.806	0.963**	0.975**	0.395	0.823*	1	
8. Outdoor A.T.	19.933	8.846	-0.922**	0.814*	0.935**	0.991**	0.476	0.769	0.996**	1

A.T.= Air temperature, R.H.=Relative humidity, A.H.=Absolute humidity

*. p<0.05, **. P<0.01

Table 13 Coefficients of correlation between environmental parameter and respirable dust (1week old of birds)

	Mean	SD	Inter-construct Correlations							
			1	2	3	4	5	6	7	8
1. Respirable dust	0.318	0.245	1							
2. Water content	24.743	13.733	-0.784	1						
3. Indoor R.H.	60.329	10.515	-0.995**	0.740	1					
4. Indoor A.H.	0.016	0.002	-0.919**	0.815*	0.879*	1				
5. Indoor A.T.	30.227	1.262	-0.225	0.441	0.133	0.589	1			
6. Outdoor R.H.	63.402	9.702	-0.911*	0.588	0.946**	0.677	-0.196	1		
7. Outdoor A.H.	0.010	0.005	-0.983**	0.806	0.963**	0.975**	0.395	0.823*	1	
8. Outdoor A.T.	19.933	8.846	-0.963**	0.814*	0.935**	0.991**	0.476	0.769	0.996**	1

A.T.= Air temperature, R.H.=Relative humidity, A.H.=Absolute humidity

*. $p<0.05$, **. $P<0.01$

No significant correlation was found between inhalable dust produced by 2-week old broilers and the environmental parameters (Tables 14, 15). The lack of a clear correlation seems to indicate that parameters other than the environmental ones measured in this study had an effect on the results. The results of assessment of the dust environment within the broiler house, as presented above, have shown that the difference in ventilation led to variances in the internal dust environment. Thus, it may be concluded that there was an overwhelming effect of ventilation for inhalable dust produced by 2-week old broilers. Respirable dust produced for the same period showed strong negative correlations with internal absolute humidity, external relative humidity and external absolute humidity with coefficients of −0.922, -0.908 and −0.837; all three were significant at a level of 0.01. There was also a relatively strong negative correlation with the external temperature with the coefficient being −0.728, which was significant at a level of 0.05. In short, respirable dust produced by 2-week old broilers exhibit a strong correlation with the humidity; it seems that the smaller the particle diameter is, the less the concentration is dependent on additional parameters such as ventilation.

Table 14 Coefficients of correlation between environmental parameter and inhalable dust (2week old of birds)

	Mean	SD	Inter-construct Correlations							
			1	2	3	4	5	6	7	8
1. Inhalable dust	1.861	0.866	1							
2. Water content	31.899	20.357	-0.416	1						
3. Indoor R.H.	64.727	8.160	-0.285	0.493	1					
4. Indoor A.H.	0.015	0.002	-0.133	0.536	-0.267	1				
5. Indoor A.T.	29.472	0.586	-0.253	0.310	-0.606	0.663	1			
6. Outdoor R.H.	60.382	6.869	-0.151	0.574	-0.206	0.998**	0.630	1		
7. Outdoor A.H.	0.009	0.004	0.151	-0.024	-0.799*	0.785*	0.732*	0.745*	1	
8. Outdoor A.T.	20.614	9.867	0.225	-0.208	-0.906**	0.636	0.697	0.587	0.977**	1

A.T.= Air temperature, R.H.=Relative humidity, A.H.=Absolute humidity

*. p<0.05, **. P<0.01

Table 15 Coefficients of correlation between environmental parameter and respirable dust (2week old of birds)

	Mean	SD	Inter-construct Correlations							
			1	2	3	4	5	6	7	8
1. Respirable dust	0.218	0.094	1							
2. Water content	31.899	20.357	-0.346	1						
3. Indoor R.H.	64.727	8.160	0.426	0.493	1					
4. Indoor A.H.	0.015	0.002	-0.922**	0.536	-0.267	1				
5. Indoor A.T.	29.472	0.585	-0.698	0.310	-0.606	0.663	1			
6. Outdoor R.H.	60.382	6.868	-0.908**	0.574	-0.206	0.998**	0.630	1		
7. Outdoor A.H.	0.009	0.005	-0.837**	-0.024	-0.799*	0.785*	0.732*	0.745*	1	
8. Outdoor A.T.	20.614	9.867	-0.728*	-0.208	-0.906**	0.636	0.697	0.587	0.977**	1

A.T.= Air temperature, R.H.=Relative humidity, A.H.=Absolute humidity

*. $p<0.05$, **. $P<0.01$

Both inhalable and respirable dust produced by 4-week old broilers were found to have a significant correlation with the internal temperature (Figure 16, 17). This is in contrast to the dust produced by 1- and 2-week old broilers, whose concentration did not display any correlation with the internal temperature. There was a strong negative correlation between the concentrations of inhalable and respirable dust and the internal temperature with the coefficients being −0.816 and −0.849, respectively. Both were significant at a level of 0.05.

From the results of correlational analyses for broilers aged 1, 2 and 4 weeks old, it could be concluded that the older the broilers were, the more significant the correlation with the internal temperature was. Such a result implies that the concentration may increase since the internal temperature appropriate for rearing decreases according to the age of birds. It is expected that the amount of dust produced by the broilers according to their age, including their feathers and skin fragments, to also have an effect on determining the dust concentration. Moreover, the younger the broilers were, the stronger the correlations with the bedding water content as well as internal and external temperature and humidity were, while older broilers did not show any significant correlation with external environmental factors. Thus, further correlational analyses for a variety of environmental factors other than temperature and humidity are needed for older broilers.

Table 16 coefficients of correlation between environmental parameter and inhalable dust (4week old of birds)

	Mean	SD	Inter-construct Correlations							
			1	2	3	4	5	6	7	8
1. Inhalable dust	5.491	3.763	1							
2. Water content	54.427	20.833	0.630	1						
3. Indoor R.H.	69.918	7.439	0.678	0.583	1					
4. Indoor A.H.	0.013	0.004	-0.497	-0.471	-0.237	1				
5. Indoor A.T.	26.526	1.796	-0.816*	-0.681	-0.968**	0.433	1			
6. Outdoor R.H.	60.044	18.127	0.100	-0.024	0.311	0.797*	-0.156	1		
7. Outdoor A.H.	0.007	0.003	-0.577	-0.291	-0.303	-0.370	0.313	-0.766*	1	
8. Outdoor A.T.	17.333	11.927	-0.351	-0.137	-0.333	-0.630	0.252	-0.946**	0.933**	1

A.T.= Air temperature, R.H.=Relative humidity, A.H.=Absolute humidity

*. p<0.05, **. P<0.01

Table 17 coefficients of correlation between environmental parameter and respirable dust (4week old of birds)

	Mean	SD	Inter-construct Correlations							
			1	2	3	4	5	6	7	8
1. Respirable dust	0.577	0.360	1							
2. Water content	54.427	20.833	0.740	1						
3. Indoor R.H.	69.918	7.439	0.736	0.583	1					
4. Indoor A.H.	0.013	0.004	-0.434	-0.471	-0.237	1				
5. Indoor A.T.	26.526	1.796	-0.849*	-0.681	-0.968**	0.433	1			
6. Outdoor R.H.	60.044	18.127	0.174	-0.024	0.311	0.797*	-0.156	1		
7. Outdoor A.H.	0.007	0.003	-0.592	-0.291	-0.303	-0.370	0.313	-0.766*	1	
8. Outdoor A.T.	17.333	11.927	-0.400	-0.137	-0.333	-0.630	0.252	-0.946**	0.933**	1

* A.T.= Air temperature, R.H.=Relative humidity, A.H.=Absolute humidity

*. $p<0.05$, **. $P<0.01$

Chapter 5. CONCLUSION

This study has set a naturally-ventilated broiler house as the object of study for the periodic monitoring of the concentrations of TSP, PM10 and inhalable and respirable dust with the experimental parameters including the age of birds, the season, the activity of broilers according to the entry and exit of workers, temperature and humidity. Moreover, the monitoring results for dust concentrations was evaluated with the threshold limits proposed by Donham *et al.* (2000) and CIGR (1994) for the assessment of the air quality within the broiler house. Physicochemical and statistical analyses were conducted on the measured dust in order to investigate the main sources of the dust and assess the primary factors that affect the concentration of airborne dust.

The concentrations of TSP and PM10 at the height of the workers' respiratory system was measured for the different seasons. The average concentration of TSP in the summer, autumn and winter were found to be 0.8 mg/m^3, 1.4 mg/m^3 and 1.8 mg/m^3, respectively, while those of PM10 were 0.5 mg/m^3, 1.2 mg/m^3 and 1.4 mg/m^3 according to the seasons; there was an evident trend in the dust concentrations with the changes in season. The PM10 concentration was at a relatively high ratio compared to that of TSP, indicating that dust at workers' height consists mainly of PM10. The ratio of PM10 increased with the age of birds, in accordance with the results of many past studies which reported that the older the broilers are, the more PM10 is produced. While the seasonal trend of dust concentrations was found to be similar to the ones found in past Korean studies, a rather low concentration was measured in the winter. A possible reason for this result is the underestimation of dust concentration due to the difference in temperature in and out of the broiler house when collecting TSP and PM10, which led to condensation within the collection filter, which in turn caused the coagulation of the dust particles. That is, the application of NIOSH Manual of Analytical Methods may be less than optimal for collecting dust within a broiler house. Thus, a modified method that better reflects the circumstances of a broiler house ought to be designed in the future.

There was a considerable difference in the concentration of inhalable dust across the seasons according to the changes in the schematic amounts of ventilation. Especially, in the summer the concentration measured at the workers' height was up to 89% higher than the concentration at the broilers' heights. Also, the concentration decreased for 14-day old broilers compared to that of 7-day old broilers, only to increase again for 28-day old ones nearing shipment. The concentrations of respirable dust across the season showed a pattern similar to those of inhalable dust. However, there was little difference of the concentration according to the heights of the measurement. Thus, it may be concluded that the smaller the particle size is, the less effect the height of measurement has on the dust concentration and the longer the dust is present within the broiler house. There was a significant change in the dust concentration when the broilers became more active with the entry and exit of the workers, with a higher level of concentration at the height of the broilers compared to that at the height of the workers. Especially, the average concentrations of both inhalable and respirable dust were found to show a significant difference ($p < 0.05$) according to the level of activity of the broilers when they were older. However, the difference became smaller at the workers' height when the broilers were younger; it may be concluded that the smaller the particle size of the dust is, the less it is affected by the activity of the broilers.

The concentrations of inhalable dust samples were mostly found to be higher than the threshold limit proposed by Donham *et al.* (2000) when the broilers were active. The concentrations also rose over the permissible standards proposed by CIGR (1995) as the activity of the broilers increased. This trend persisted even when the broilers were relatively stable during the winter and certain periods of the in-between season. The concentrations of respirable dust also exceeded the threshold limit of Donham *et al.* (2000), both when the broilers were active and when they were stable. Thus, it may be concluded that a noxious dust environment has already been created within the broiler house. The fact that respirable dust was more prone to breach the threshold limits than inspirable dust indicates that a definite analysis should be additionally conducted for the range of particle size that is discharged according to the method of ventilation.

A physicochemical analysis of the collected dust revealed that most of the morphologies found in the dust resembled those found in the bedding material and feathers, while those in the feed were mostly not found. Thus, feed seems to have only a small effect on the production of airborne dust. N, K, F, S, Mg, Cl and Na were found from the collected dust; especially, the composition of nitrogen, sulfur, chlorine and fluorine was higher than those of the other elements. Since these are components that are characteristically found in the feathers of broilers and bedding material, it may be concluded that the collected dust is largely produced from feathers and bedding.

Also, a correlational analysis of the environmental parameters, such as temperature, humidity and the bedding water content, found that there was a strong negative correlation between the internal and external environmental parameters and the dust concentration when the broilers were younger ($p < 0.01$). When the broilers grew older, however, the correlation with the external environmental parameters disappeared while a significant negative correlation was present with the internal temperature ($p < 0.05$). This implies that the internal temperature appropriate for rearing decreases with the age of birds and the amount of dust produced by the broilers with the increase in age, including feathers and skin fragments, may have an effect on the dust concentration. Also, there was a significant correlation with the bedding water content when the broilers were younger, but not for dust of smaller size. Thus, it can be inferred that the dust dispersed from the bedding in correlation to its water content is mainly inhalable dust.

This study provides preliminary data for the assessment of air quality within a ventilated broiler house based on its dust concentration and investigate the sources of the dust. The results of this study is hoped to help with further studies for dust reduction within broiler houses by aiding in the estimation of the main sources of dust and the control of dust production from the sources.

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APPENDIX Ⅰ

최소환기 셋팅 지침
*동절기 야간온도 -1℃ 이하시 3분(180초) 싸이클로 변경 사용 (육계 30,000 수)

일령	휀	야간온도			세팅온도
		-1℃이하/CFM	-1℃～15.5℃사이	15.5℃ 이상	
1~5	36“ 3대 ON OFF	20초 380초/0.05	30초 270초	40초 260초	32～33℃
6~7	36“ 3대 ON OFF	25초 375초/0.07	30초 270초	50초 250초	29.5℃
8~9	36“ 3대 ON OFF	28초 268초/0.1	40초 260초	60초 240초	29℃
10~11	36“ 3대 ON OFF	38초 262초/0.13	50초 250초	70초 230초	28.5℃
12~13	36“ 3대 ON OFF	47초 253초/0.17	60초 240초	80초 220초	28℃
14~15	36“ 3대 ON OFF	57초 243초/0.20	70초 230초	90초 210초	27.5℃
16~17	36“ 3대 ON OFF	66초(40) 234초(140)	80초 220초	100초 200초	27℃
18~19	36“ 3대 ON OFF	76초(46) 224초(134)	95초 205초	120초 180초	26℃
20~21	36“ 3대 ON OFF	86초(52) 214초(128)	110초 190초	140초 160초	25℃
22~23	36“ 3대 ON OFF	95초(57) 205초(123)	120초 180초	140초 160초	24℃
24~25	36“ 4대 ON OFF	85초(50) 215초(130)	95초 205초	110초 190초	23℃
26~27	36“ 4대 ON OFF	90초(55) 210초(125)	105초 195초	135초 165초	22℃
28~29	36“ 4대 ON OFF	95초(60) 205초(120)	115초 185초	145초 155초	22℃
30~31	36“ 4대 ON OFF	105초(60) 195초(120)	125초 175초	150초 150초	21℃
32~33	36“ 4대 ON OFF	115초(65) 185초(115)	135초 165초	160초 140초	21℃
34~35	36“ 4대 ON OFF	120초(70) 180초(110)	135초 165초	160초 140초	20℃
36~37	36“ 4대 ON OFF	125초(70) 175초(110)	140초 160초	170초 130초	20℃
38~39	36“ 4대 ON OFF	130초(75) 170초(105)	145초 155초	180초 120초	19.5℃
40~41	36“ 4대 ON OFF	140초(80) 160초(100)	150초 150초	185초 115초	19.5℃
42~43	36“ 4대 ON OFF	145초(80) 155초(100)	155초 145초	190초 110초	19℃
44~45	36“ 4대 ON OFF	150초(85) 150초(95)	160초 140초	195초 105초	19℃
46~47	36“ 4대 ON OFF	160초(85) 140초(95)	170초 130초	200초 100초	19℃

국문초록

윈치커튼식 육계사 내 공기 중 분진 농도 분석

조 예 슬

생태조경 지역시스템공학부 지역시스템공학 전공

서울대학교 대학원

국내 양계생산성의 향상은 가금 산업의 수출경쟁력에 긍정적인 영향을 미치고 있으나 공급량 확보를 위한 대형화 및 과잉생산은 사육밀도를 증가시켜 계사 내 열악한 환경을 조성한다. 특히 밀집형 사육환경은 계사 내 취약한 분진환경을 조성하며 이는 계군 및 작업자의 기관지염, 직업형 천식 등 호흡기성 질병을 유발하는 요소로 작용하고 있다. 그러나 이러한 피해에도 불구하고 양계장 내 분진환경에 대한 정기적인 모니터링 및 연구가 미비할 뿐만 아니라 양계장 내 허용기준치와 같은 법적 기준이 마련되어 않은 실정이다. 따라서 본 연구에서는 윈치커튼식 계사를 대상으로 TSP, PM10, 흡입성분진, 호흡성 분진의 농도를 계절, 일령, 계군의 활동성에 따라 정기적으로 모니터링을 하였으며, Donham *et al.* (2000) 및 CIGR (1994)가 제시한 허용기준치에 의거하여 계사 내 공기질 평가를 수행하였다.

시기에 따른 TSP 및 PM10 측정 결과 계절에 따라 상이한 분진 농도 차이가 발생하였으며 평균 분진 농도는 동절기, 가을철, 하절기 순으로 높게 나타났다. TSP 대비 PM10 농도비는 큰 차이가 나타나지 않았으며, 일령에 따라 비율이 증가하는 것으로 나타나 일령의 증가에 따라 PM10 발생률 또한 증가하고 있는 것으로 사료되며, 작업자 호흡기 위

치에 존재하는 분진은 대부분 PM10 이하로 구성되어 있을 것으로 판단된다.

계절에 따른 흡입성 및 호흡성 분진 농도 측정 결과 설계환기량에 차이에 의하여 계절에 따른 분진농도가 확연하게 나타났으며, 작업자의 출입에 따라 계군의 활동성이 활발해 지는 경우 계군의 활동성이 안정한 시기 대비 흡입성 분진의 경우 최대 769.6% 증가 (하절기, 28일령), 호흡성 분진의 경우 최대 882.4% 증가한 수치를 나타냈으며 (하절기, 28일령), 이러한 활동성에 따른 차이는 계군의 일령이 높을 수록 유의하게 증가하였다 (p < .05). 또한 작업자의 출입에 따라 계군의 활동성이 활발해 지는 경우 대부분 Donham *et al.* (2000)이 제시한 인간의 폐기능을 고려한 상시감시 기준치 및 CIGR (1994)에서 제시한 닭의 폐기능을 고려한 상시감시 기준치를 초과하였으며, 특히 호흡성 분진의 경우 계군의 움직임이 안정한 시기 또한 대부분 상시 감시 기준치를 초과하고 있기 때문에 계사 내부에 이미 작업자 및 닭에게 유해한 분진환경이 조성되어 있는 것으로 나타나 계사 내 작업 시 마스크 등의 보호장비가 권고되는 바이다. 또한 공기 중에서 포집한 분진을 토대로 물리·화학적 분석을 한 결과 N, K, F, S, Mg, Cl, Na 의 성분을 확인하였으며 특히 계사 내 공기 중 분진은 계군의 깃털이나 바닥재에서 기인한 성분이 다수 확인되었다.

분진 농도와 계사 내·외부 환경변수의 상관관계 분석으로부터 계군의 일령이 어릴수록 분진 농도 및 환경 변수 간 강한 음의 상관관계가 나타났으나, 계군의 일령이 증가함에 따라 외부와의 상관관계가 거의 나타나지 않았으며, 내부 온도와 강한 음의 상관관계를 보임에 따라, 일령의 증가에 따라 적정 사육온도가 감소하고 이는 계군의 깃털이나 피부조각 등 계군으로부터 발생하는 분진의 양의 차이가 분진 농도 차이에 영향을 주고 있음을 시사한다. 또한 흡입성 분진은 일부 시기에 통계적으로 유의미한 상관관계 수치를 파악할 수 없음에 따라 환기와 같은 물리적인 원인에 의하여 분진농도가 통제 되는 것으로 예상되나, 호흡성 분진의 경우, 분진농도와의 상관관계가 도출됨에 따라 환기 등과 같은 물

리적인 요인과의 관련성이 다소 미비할 것으로 추측된다. 본 연구는 윈치커튼식 계사 내 분진 농도로부터 공기질을 평가하고 분진 발생원을 규명하기 위한 기초자료로써, 추후 주 분진 발생원을 추정하고, 주 발생원으로부터 발생하는 분진을 조절함으로써 계사 내 분진 저감 연구에 도움이 될 것이라 판단된다.

Keywords: PM10, TSP, **분진모니터링, 윈치커튼식 계사, 호흡성분진, 흡입성분진**
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