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Gaseous Emissions and Energy Cost Minimization for Pig Production Through Effective Ground Channel Airflow System

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Abstract: Impact of ground channel airflow designed house was investigated on internal environment, gaseous emissions and energy cost of pig houses during Winter season. In the present experiment, impact of ground channel airflow (with ground level heating system) Designed house (GCA) was compared with conventional mechanical airflow (with halogen lamp heating) designed house (MA). Experimental houses consisted of MA with gestating sows (MA1), lactating sows (MA2) and finishing pigs (MA3) and GCA with gestating sows (GCA1), lactating sows (GCA2) and finishing pigs (GCA3). Result elucidated that, internal temperature in MA and GCA were in general requirements for gestating and finishing pig houses (GCA1 vs. MA1; GCA3 vs. MA3) except lower value was found in lactating sow house GCA2 in comparison to MA2. Although there was found significant differences in GCA2 and GCA3 relative to MA2 and MA3, respectively, relative humidity for both houses were in suitable range (50-90%). Emissions of CO_2 from slurry were significantly lower for GCA2 (20%) and GCA3 (9%) than MA2 and MA3, respectively. Ammonia concentration was around 30% repressed in GCA1-GCA3 in comparison to MA1-MA3, respectively. Energy consumption, energy cost and equivalent CO_2 emissions from energy use were significantly down trended (around 62%) in all GCA than MA. Overall, Ground channel airflow designed house was found effective (for Winter season) in reducing gaseous concentrations (CO_2 and NH_3) and minimizing energy cost without adverse impact on the internal animal environment.

Key words: Airflow designed house, gaseous emissions, energy cost, temperature, relative humidity

INTRODUCTION

Biodiversity loss and climate change are affected by air pollution which is considered the greatest threat to our planet (Holdren, 2008). The average global temperature is increasing above 2EC of the policy target temperature (to save the Globe) (Sanford *et al*., 2014). Global warming has led to a 25% reduction in agricultural production (Seguin, 2008); and decreased animal agriculture through affecting the internal animal environment and promoting the incidence and severity of certain infectious and noninfectious diseases over the long-term for human and animals (Eikmeier, 1965; Myer and Bucklin, 2007). Where, humans and their activities are the major factors that influence the ecosystems worldwide through biotic exchange and alterations in climatic conditions (Vitousek *et al*., 1996; Assessment, 2005). Agriculture and animal production (35 and 18%, respectively) are responsible among major activities for global anthropogenic emissions of Greenhouse Gases (GHGs) which affect atmospheric air and the environment (Steinfeld *et al*., 2006; Monteny *et al*., 2006). Animal industry as a subsector of Agriculture, generate different forms of elements to influence air pollution, including carbon dioxide, methane, nitrous oxide, ammonia and hydrogen sulfide (Crook *et al*., 1991; Blanes *et al*., 2008). Among the dominant livestock in the world (Cattle, Swine and Poultry), swine industry contribute a lot in

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this concern (contribute around 13% of total GHGs related to livestock) (Philippe and Nicks, 2015).

In addition, equivalent Carbon dioxide (CO_2) emissions are associated with the energy utilized (through fuel burning) for the production and management of animal agriculture (Sebarchievici and Sarbu, 2015). Among the animal agriculture, pork industry is the promising sector all over the world, since pork consumption is increasing day by day and it is expected that the pork consumption will increase almost 40% by 2050 (FAO, 2011) which would require a large amount of energy for maintenance; thus there has been the potential risk to influence global climate change through generation of equivalent CO_2. Previous reports indicated a 54% increase in GreenHouse Gases (GHG) between 1981 and 2001 (Verge *et al*., 2009) which is the most important issue. On the other hand, energy crisis is the important issue all over the world due to shortage of energy resources and over use in the modern society in all aspects. In this circumstances, reducing energy consumption associated with large pig industry can directly or indirectly reduce a large amount of greenhouse gas emissions (since it is the source of equivalent CO_2 emission) and the total cost of pig production as well. Specially, during Winter, swine producers have to pay extra money for heating because of higher energy consumption; consequently increase the total costs of production and gaseous emissions from the swine industry which is detrimental to the welfare and production of animals and health risk of human being. Therefore, minimization of production costs (specially the energy cost) and gaseous emissions through different systematic approaches is most important for the swine industry without negative impact on the welfare of pigs. To minimize the heating cost and reducing gaseous emissions, renewable energy sources (geothermal, solar and wind power utilization) are practiced for household and animal agriculture (Choi *et al*., 2010a, b; Islam *et al*., 2016). However, there is less attention on the design and structure of the animal house (ground channel ventilation and airflow design) which can have impact on energy consumption and gaseous emissions by maintaining internal thermal environment. It was reported that ventilation air flow can affect the internal animal environment and gaseous emissions of animal houses (Aarnink and Wagemans, 1997; Sevi *et al*., 2002; Topisirovic and Radivojevic, 2005). Some studies have shown that the benefits of ventilation airflow systems are associated with the uniform distribution of airflow in animal production systems (Gebremedhin and Wu, 2005) because, airflow helps to maintain temperature, relative humidity and manure gases as well as provides shelter from extreme internal environmental conditions (Vant and Heitlager, 1994; Carpenter, 2013).

Hence, minimization of gaseous emissions and energy along with suitable internal animal environment can ensure better welfare and production of pigs as well as protect health of pig producers. But, to date, there has been no specific research on ground channel ventilation and airflow design and structure of the animal house on the aspects of internal animal environment, gaseous emissions and energy saving for modern swine industry. Thus, present study was conducted to compare the ground channel airflow (with ground level heating system) designed house (GCA) and mechanical airflow (with halogen lamp) designed house (MA) (during Winter season) on maintaining internal thermal environment (temperature, relative humidity and ventilation flow), reducing gaseous emissions (CO_2, NH_3, H_2S and SO_2) and minimizing energy consumption, cost and equivalent CO_2 emission from the pig houses of different stages of production (gestating, lactating and finishing pigs).

MATERIALS AND METHODS

Experimental houses and animals: The location of the experimental farm was as follows: Latitude: 34E56'53" N, Longitude: 127E29'22" E, at 16 m above sea level. The name of the experimental farm: Sunchon National University experimental farm, Jeollanam-do, Republic of Korea. There are usually four seasons namely: Summer Autumn, Winter and Spring. During summer usually temperature ranges between 20-30°C while during Winter ranges below 0 (minus 20) to 5°C and relative humidity ranges from 30-100% for all seasons. In this study, two types of airflow designed pig houses were investigated for the management of pigs in the gestation to finishing phase. The houses were conventional mechanical airflow with halogen lamp heating system and ground channel airflow designed house with ground level heating system. Where gestating, lactating and finishing pigs were reared in both the MA and GCA houses. The observation for the present preliminary study of the pig houses were as follows: MA1 = mechanical airflow house with gestating sows; GCA1 = ground channel airflow house with gestating sows; MA2 = mechanical airflow house with lactating sows; GCA2 = ground channel airflow house with lactating sows; MA3 = mechanical airflow house with finishing pigs; GCA3 = ground channel airflow house with finishing pigs. All experimental houses were slatted floor type and of the similar size (4.0×9.0×3.0 m). Gestating houses were equipped with 10 separate individual pens having feeders and waterers while lactating sow houses were equipped with four separate individual pens for sows and piglets having feeders and waterers and finishing pig houses were equipped with four separate pens with a capacity of five individuals per pen having feeders and waterers.

In all experimental houses, Landrace×Yorkshire crossbred pigs were reared and observed for 7 week period during Winter season (December, 2014 to January,

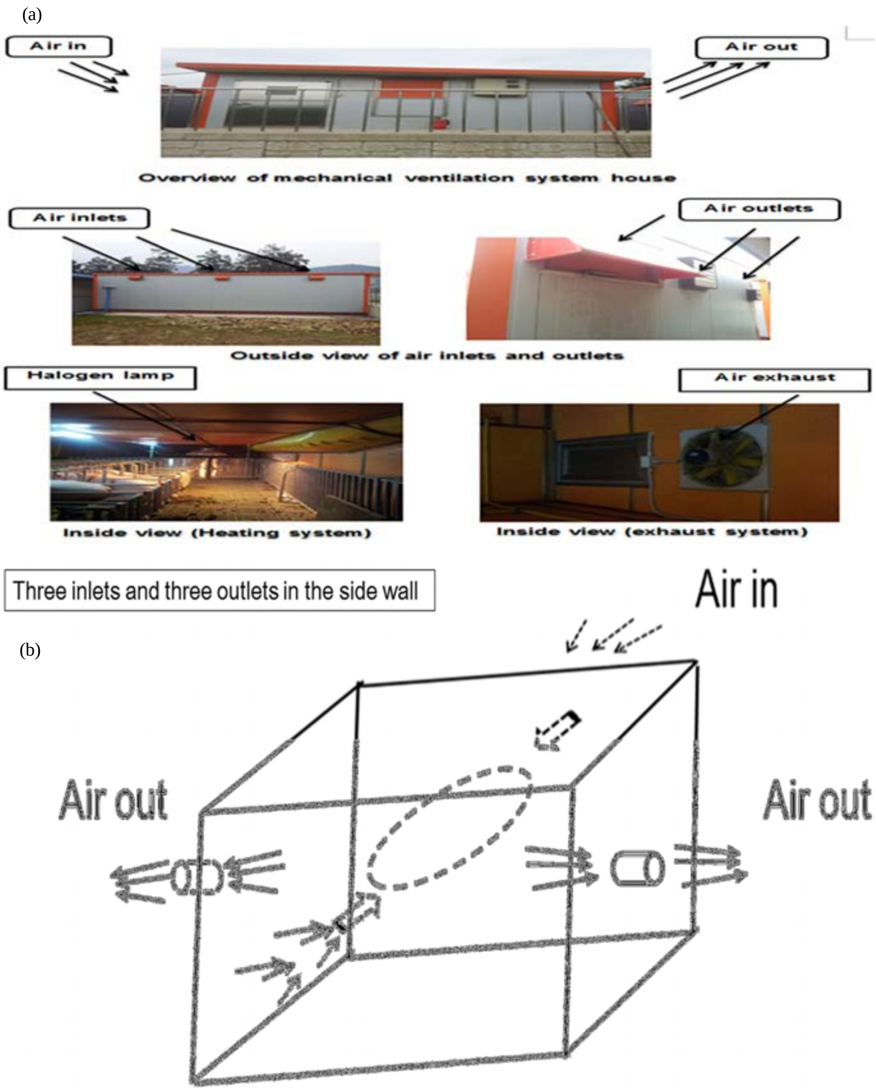


Fig. 1: a) Overview of Inside and outside and b) overall air flow pattern of mechanical ventilation airflow designed house (MA)

2015). All pigs were randomly allocated to different houses and pens according to body weight for proper observation. The floor space for gestating sows, lactating sows and finishing pigs was 1.6, 5.0 and 1.3 m^2/pig, respectively for the MA and GCA houses. The average (SE) body weight for gestating sows was: 201.36±2.91 and 201.40±2.70 kg pig^{-1} or MA1 and GCA1; lactating sows was: 189.15±1.12 and 186.37±1.13 kg pig^{-1} or MA2 and GCA2 and finishing pigs was: 96.21±5.07 and 96.00±4.70 kg/pig for MA3 and GCA3, respectively. In the present study, conventional airflow (with halogen lamp) designed houses and ground channel airflow (with ground level heating) designed houses were compared for similar stages of production (MA1 vs. GCA1; MA2 vs. GCA2 and MA3 vs. GCA3). Corn-soybean based basal diets were provided separately for each house to meet the nutrient requirements for different stages of production of pigs recommended by NRC. All Pigs of different stage of production were allowed *ad libitum* access to feed and water. Additionally, lighting and other factors were maintained according to the requirements and general practices of gestating, lactating and growing finishing stage pigs. Sufficient lighting was provided for both MA and GCA by mercury bulb throughout the observation period.

The overview inside and outside with halogen lamp heating of the MA house was shown in Fig. 1a and overall airflow pattern (horizontal airflow) of MA was shown in Fig. 1b. Mechanical airflow (with halogen lamp) designed house (MA) in general comprises of three air inlets and three outlets with exhaust fans in the side walls to control the internal house environment and equipped

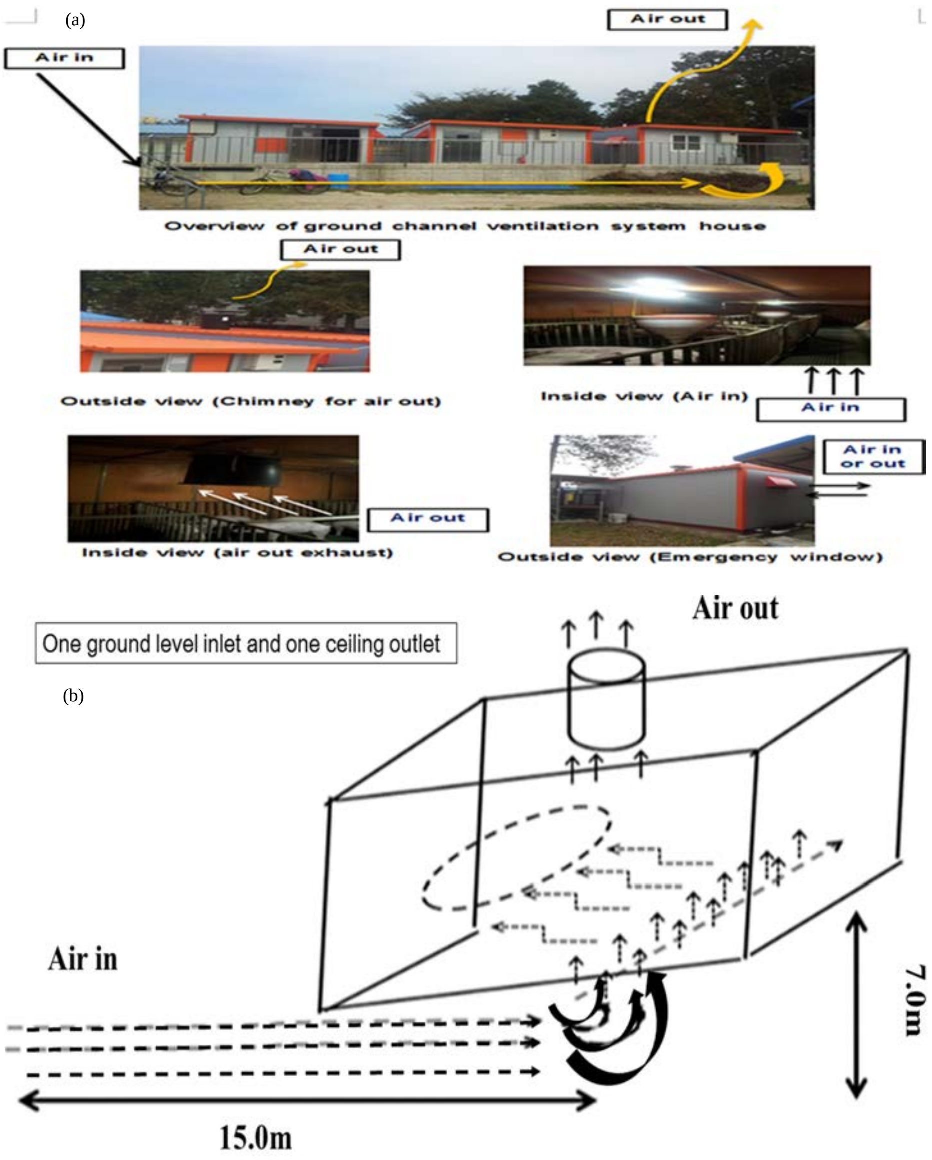
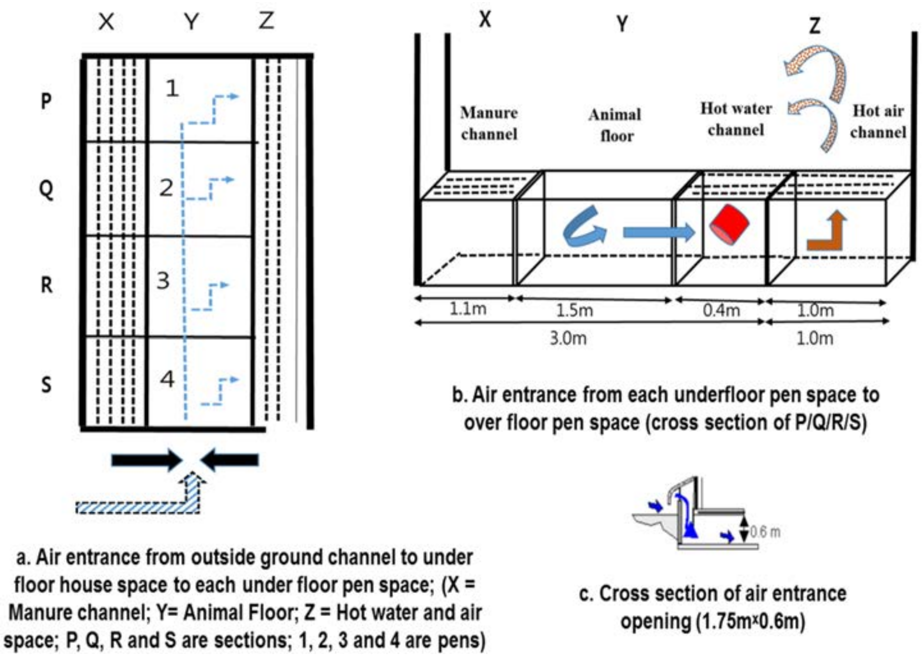


Fig. 2: a) overview of inside and outside and b) overall air flow pattern of ground channel ventilation and airflow designed house (GCA)

with a halogen lamp for heating system. The overview inside and outside with ground level heating of the GCA house was shown in Fig. 2a and overall airflow pattern (horizontal and vertical airflow) of GCA was shown in Fig. 2b. The ground channel airflow (with ground level heating) designed house (GCA) comprises of one ground level inlet and one ceiling outlet and one emergency window for controlling internal animal environment. Briefly, Ground Channel Airflow designed house (GCA) in general comprises of ground channel airflow structure (15.0 m long) for air inlet from outside to the ground channel space (Fig. 2b). The air passes through the insulated concrete space and enter inside the house through large opening in between the underfloor solid wall space (Fig. 3a, c). Then the air entered into the house passing through the space between each pen under the floor (Fig. 3b). Where there is underground insulated solid wall between each pen and air passes through 0.19 diameter hole throughout the house in the ground level (Fig. 3b). Finally, the air passes through the water channel space and enter into the house (over the floor) through the air channel space (Fig. 3b). The air entered into house become hot mainly due to the hot water channel; partially due to heat absorption from long concrete underfloor



a. Air entrance from outside ground channel to under floor house space to each under floor pen space; (X = Manure channel; Y= Animal Floor; Z = Hot water and air space; P, Q, R and S are sections; 1, 2, 3 and 4 are pens)

b. Air entrance from each underfloor pen space to over floor pen space (cross section of P/Q/R/S)

c. Cross section of air entrance opening (1.75m×0.6m)

Fig. 3: Detail structure and air flow pattern of ground channel ventilation and airflow design (GCA) of experimental pig house: a) air entrance from outside ground channel to under floor house space and under floor pen space; b) air entrance from each underfloor pen space to over floor pen space and c) cross section of air entrance opening

ground channel (15.0 m) and the under animal floor space in between the insulated solid floor. The hot air entered into the house through 0.2 m wide slot of the floor which is covered with slats and 50% opening. The air entered gently and ensured fresh air for the individuals of each pen. There is one chimney for air outlet on the midde of the ceiling (2.5 m above the floor) and one emergency air exchange window to control the internal house environment.

The current experiment was conducted according to the protocol approved by the Animal Care and Use Committee of Sunchon National University, South Korea.

Recording of temperature and relative humidity: The temperature of the outside and experimental pig houses was recorded by hanging thermo-couple temperature sensors (type T) from the ceiling at the entry (near the door), center and back of the house to measure the temperature at two points; 10 cm below the ceiling (upper point) and 10 cm above the floor (lower point). To record the data every hour, all measurement instruments were connected to a data acquisition system (CR10X data logger, Campbell Scientific Inc., Edmonton, AB, Canada). The humidity was recorded for all houses separately using a digital hygrometer (Electronic Digital Hygrometer HTC-1, Jinggoal International Ltd., Guangdong, China). Recorded data were compiled to generate the daily average and week average.

Measurement of ventilation airflow: Ventilation flow for animal houses is a fundamental variable during evaluation of the internal environment and gaseous emissions. Direct and indirect methods can be used to estimate ventilation flow in livestock buildings. However, direct calculation has several drawbacks. Specifically, calculation of ventilation flow based on a large number of ventilation fans in various positions in livestock buildings is difficult. Therefore, in this study, ventilation flow was calculated using the following formula (for steady state condition) adopted based on Pedersen *et al.* (1998) and Blanes and Pedersen (2005):

$$V = (S_b - AU\Delta t)/c\Delta t \qquad (1)$$

Where:

V = Ventilation flow (m^3/h)

S_b = Sensible heat production in the pig house, watts, (calculated based on body heat production in different houses)

A = Surface area of the livestock building (m^2) ($4.0\times 9.0 = 36.0\ m^2$)

U = Heat transmission coefficient for building surfaces, W/m^2K (considered, standard 0.5 for all houses)

Δt = Temperature difference between indoors and outdoors (oK)

c = Specific heat of air (J/m^3K) (standard 1.005 for all houses)

According to Pedersen and Sallvik, Q = S+L where, Q = Total body heat production, watts; S = Sensible heat, watts; L = Latent heat, watts. In addition, according to Pedersen *et al.* (1998) report and some modification for simplification, sensible heat production in the pig house:

$$S_b = K_s nS \tag{2}$$

Where:

K_s = The correction factor (considered standard 0.95 for all houses) then
S_b = 0.95nS

$$S_b = 0.95n\times(0.8\times Q) \text{ or } S_b = 0.76\times n\times Q$$

While sensible heat:

$$S = 1\times Q \tag{3}$$

Where:

1 = The proportion of total heat (considered, standard 0.8 for all houses) then
S = 0.8×Q

Combining Eq. 2 and 3, sensible heat production in the pig house:

$$S_b = 0.95n\times(0.8\times Q) \text{ or } S_b = 0.76\times n\times Q \tag{4}$$

Where:

n = The number of animals
Q = Total body heat production (watts)

Calculation of body heat production: Body heat production from different pig houses was calculated using the following formulas according to the stage of production (Pedersen *et al.*, 1998). The body weights of the pigs in each house were measured separately. Body heat production equation for dry sows and gilts:

$$Q_{tot} = 4.85m^{0.75} + 8\times10^{-5}p^3 + 76Y_2 \tag{5}$$

Where:

Q_{tot} = Total heat production (watts)
$m^{0.75}$ = Metabolic body weight (kg)
p = No. of days in pregnancy
Y_2 = Daily gain, standard daily gain for pregnant sows is 0.18 kg/day

Body heat production equation for nursing sows, including pigs:

$$Q_{tot} = 4.85m^{0.75} + 28Y_1 \tag{6}$$

Where:

Q_{tot} = Total heat production (watts)
$m^{0.75}$ = Metabolic body weight
Y_1 = Milk production (5-6 kg day^{-1})

Body heat production equation for piglets:

$$Q_{tot} = 7.4\,m^{0.66} + [1-(0.47+0.003)][n\times7.4-7.4\,m^{0.66}] \tag{7}$$

Where:

Q_{tot} = Total body heat production (watt)
$m^{0.66}$ = Metabolic body weight (kg)
m = Body weight of the animal (kg)
n = Daily feed energy

Body heat production equation for growing-finishing pigs:

$$Q_{tot} = 5.09\,m^{0.75} + [1-(0.47+0.003\,m)[n\times5.09-5.09m^{0.75}] \tag{8}$$

Where:

Q_{tot} = Total heat production (watts)
$m^{0.75}$ = Metabolic body weight
m = Body weight of the animal (kg)
n = Daily feed energy

After determination of body heat produced from each house, S_b was calculated according to Eq. 4). Major contributor of sensible heat production was considered the existed individuals into the different houses by ignoring other source of heat production to avoid complexity of calculation. Finally, ventilation flow was calculated based on Eq. 1. The mean data of body heat production, sensible heat production in the house and ventilation flow were presented in Table 1.

Measurement of CO_2 emissions: One of the most important greenhouse gases is Carbon dioxide (CO_2). Carbon dioxide emissions associated with electricity use and from slurry were measured for each experimental pig house separately using different formulas.

Measurement of equivalent CO_2 emissions from electricity use: The following equation was used to predict equivalent CO_2 emissions from energy according to Intellig Eenrgy Europe (IEE) (http://ec.europa.eu/energy/environment).

$$E-CO_2 = g_{el}E_{el} \tag{9}$$

Table 1: Internal temperature and relative humidity in the mechanical and ground channel ventilation and airflow designed houses

		Experimental pig houses							
Parameters	Outside	MA1	GCA1	MA2	GCA2	MA3	GCA3	SEM	p-values
Temperature (°C) (weeks)									
1-6	2.77^{d}	14.71^{c}	13.37^{c}	22.52^{a}	19.52^{b}	15.57^{c}	14.66^{c}	0.88	<0.0001
7-13	2.75^{d}	14.84^{bc}	13.40^{c}	23.79^{a}	18.51^{b}	16.78^{bc}	15.90^{bc}	1.14	<0.0001
1-13	2.76^{e}	14.78^{cd}	13.39^{d}	23.21^{a}	18.98^{b}	16.22^{c}	15.33^{cd}	0.75	<0.0001
Relative humidity (%) (weeks)									
1-6	51.21^{d}	62.06^{abc}	63.56^{ab}	56.69^{bcd}	60.57^{abc}	55.83^{cd}	67.92^{a}	2.14	0.0004
7-13	50.71^{d}	59.28^{bc}	62.70^{ab}	55.51^{c}	61.47^{ab}	61.33^{ab}	66.04^{a}	1.37	<0.0001
1-13	50.94^{e}	60.56^{bc}	63.10^{ab}	56.06^{d}	61.06^{bc}	58.79^{cd}	66.91^{a}	1.29	<0.0001

$^{a-d}$Means with different superscripts within the same row are significantly different ($p<0.05$). SEM: Standard Error of Mean; MA1: Mechanical ventilation airflow house with gestating sows; GCA1: Ground channel ventilation airflow house with gestating sows; MA2: Mechanical ventilation airflow house with lactating sows; GCA2: Ground channel ventilation airflow house with lactating sows; MA3: Mechanical ventilation airflow house with finishing pigs; GCA3: Ground channel ventilation airflow house with finishing pigs. The ambient temperature during the observation period was in the range of -5.50-7.86°C while the relative humidity was in the range of 24.53-84.36%

Where:

$E\text{-}CO_2$ = Equivalent Carbon dioxide (CO_2) emissions from electricity use (kg day^{-1})

g_{el} = 0.547 kg CO_2 kWh^{-1} which is the specific CO_2 emission factor for electricity

E_{el} = Amount of electricity consumed (kWh)

Measurement of CO_2 emissions from slurry of pigs: The slurry temperature is correlated with CO_2 release when compared to all other temperatures in different locations in the animal house (Ni *et al*., 1999). Therefore, the following equation was used based on Ni *et al.* (1999) following description of the single-factor relationship between CO_2 release and slurry temperature. Where, the slurry temperature was measured by inserting a thermometer 0.3 m depth into the slurry of slurry pit of each house. Temperature was recorded several times from different positions of the slurry pit to improve accuracy:

$$CO_2 = 1.968\exp(0.148\times T_s) \tag{10}$$

Where:

CO_2 = Estimated CO_2 emitted from slurry (kg day^{-1})

T_s = Temperature of slurry (°C)

Measurement of noxious gas (NH_3, H_2S and SO_2) emissions: Noxious gases emitted from the MA and GCA experimental pig houses were measured for three consecutive days every week. Gas was measured using a Gastec (model GV-100) gas sampling pump (Gastec Corp., Japan) and Gastec detector tubes. Specifically, gas detector tubes No. 3L (0.5-78 ppm), 3La (2.5-200 ppm) and 3M (10-1000 ppm) were used for NH_3 measurement where 4LT (0.1-4 ppm) and 4LK (1-400 ppm) was used for H_2S measurement and 5Lb (0.05-10ppm) was used for SO_2 measurement. All measurements were conducted 0.5 m above the slurry level and repeated 3 time in the different positions for more accuracy. The concentration of each gas was determined based on the average of the three measurements. Finally, the entire dataset was used to determine the average for MA and GCA houses separately and gas emissions was expressed in ppm for the MA and GCA houses.

Measurement of electricity consumption and cost: Electricity consumption for individual pig house management was recorded based on the electricity consumption recorded by individual meters (Model: LD 1210DRa-040, LSis, South Korea). To measure the electricity cost for each house, the total electricity consumption was multiplied by 21.61 Korean Won (KRW) (current electricity price for per unit of kWh of electricity in South Korea where 1 USD equivalent to 1,161 KRW). For comparison, electricity consumption and cost were measured separately for each experimental house per unit (m^3) of house space.

Statistical analyses:
Temperature, relative humidity, ventilation flow, air dust, gaseous emissions, energy consumption and energy cost data were analyzed using SAS Institute (2003). Means were compared based on Duncan's Multiple Range Test (DMRT) where $p<0.05$ was considered to indicate significance.

RESULTS

Impact of ventilation airflow design on internal temperature, relative humidity and ventilation air flow: The temperatures and relative humidity into different pig houses are presented in Table 1. The ambient temperature during the observation period was in the range of 5.50-7.86°C while the relative humidity was in the range of 24.53- 84.36%. Among the pig houses the highest average internal temperature was found in MA2 and the lowest in GCA1 during 1-6, 7-13 weeks and overall 1-13 weeks experimental period (Table 1). Although, there was no

Table 2: Body heat production, sensible heat production, ventilation airflow and air dust concentration in the mechanical and ground channel ventilation and airflow designed houses

	Experimental pig houses							
Parameters	MA1	GCA1	MA2	GCA2	MA3	GCA3	SEM	p-values
Body heat production (watt)	26.19^{c}	26.20^{c}	16.87^{d}	16.76^{d}	153.64^{a}	152.29^{b}	0.30	<0.0001
Sensible heat production (watt)	2162.73^{b}	2150.16^{b}	1733.22^{b}	1719.98^{b}	7920.54^{a}	7862.14^{a}	106.77	<0.0001
Ventilation flow (m^3/h)*	-197.42^{b}	-221.79^{b}	-103.28^{a}	-129.42^{a}	-611.66^{c}	-646.53^{c}	13.89	<0.0001

^{a,b}Means with different superscripts within the same row are significantly different ($p<0.05$). SEM: Standard Error of Mean; *Minus value of ventilation flow indicated negative air pressure. MA1: Mechanical ventilation airflow house with gestating sows; GCA1: Ground channe l ventilation airflow house with gestating sows; MA2: Mechanical ventilation airflow house with lactating sows; GCA2: Ground channel ventilation airflow house with lactating sows; MA3: Mechanical ventilation airflow house with finishing pigs; GCA3: Ground channel ventilation airflow house with finishing pigs

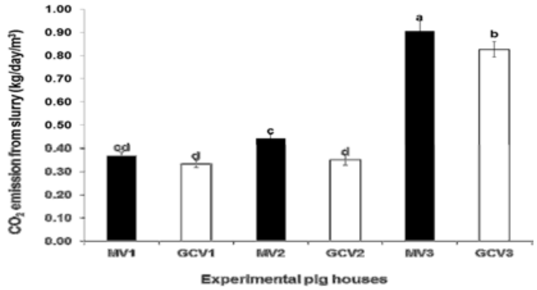


Fig. 4: CO_2 emissions from slurry in the mechanical and ground channel ventilation and airflow designed houses; $^{a-d}$Means with different superscripts letters in the same line are significantly different ($p<0.05$). Bars of different colors within same MA and GCA indicated 1-13 weeks average data and single line indicated the average of 13 weeks data where error bars indicate the standard error. MA1: Mechanical ventilation airflow house with gestating sows; GCA1: Ground channel ventilation airflow house with gestating sows; MA2: Mechanical ventilation airflow house with lactating sows; GCA2: Ground channel ventilation airflow house with lactating sows; MA3: Mechanical ventilation airflow house with finishing pigs; GCA3: Ground channel ventilation airflow house with finishing pigs

halogen lamp heating in any GCA houses, no significant differences were observed between GCA1 and MA1 ($p>0.05$) or between GCA3 and MA3 of average temperature ($p>0.05$). However, significantly lower temperature was observed in GCA2 than MA2 GCA1 during 1-6, 7-13 weeks and overall 1-13 weeks experimental period ($p<0.05$). Among the pig houses, the average Relative Humidity (RH) was highest in GCA3 and lowest in MA2 during 1-6, 7-13 weeks and overall 1-13 weeks experimental period (Table 1). No significant differences in RH were observed between MA1 and GCA1 ($p>0.05$), however, significant differences were observed between MA2 and GCA2 as well as between MA3 and GCA3, MA1 and GCA1 during 1-6, 7-13 weeks and overall 1-13 weeks experimental period ($p<0.05$). Overall, it was apparent that higher RH value was prevailed in all GCA relative to MA.

The body heat production from the existed individuals of the specific house, sensible heat production in the pig house, ventilation flow and air dust concentration into different pig houses are presented in Table 2. There was observed no significant differences in body heat production of GCA1 and GCA2 than MA1 and MA2; but it did differ between GCA3 and MA3 (<0.05). Sensible heat production in the pig houses did not differ significantly between GCA and MA (>0.05). In addition, it was elucidated that the ventilation flow did not differ within gestating sow house MA1 and GCA1; lactating sow house MA2 and GCA2 and within finishing pig house MA3 and GCA3 ($p>0.05$) (Table 2).

Impact of ventilation airflow design on gaseous concentrations (CO_2, NH_3, H_2S and SO_2): Carbon dioxide concentration from slurry (Fig. 4) were significantly lower in GCA2 (20%) and GCA3 (9%) than MA2 and MA3, respectively (<0.05). However, there were no significant differences in CO_2 concentration from slurry observed between GCA1 and MA1 ($p<0.05$), although in GCA1 it was around 10% lower CO_2 emission. In addition, as shown in Fig. 5, ammonia concentration was significantly lower (around 30%) in GCA1-GCA3 than MA1-MA3, respectively ($p>0.05$). However, no significant differences in H_2S and SO_2 concentrations were observed within the similar stage of production of GCA and MA houses ($p>0.05$).

Impact of ventilation airflow design on electricity consumption, cost and equivalent CO_2 emissions: Observation of the different pig houses revealed that the average electricity consumption was lower in GCA1-GCA3 compared to MA1-MA3, respectively (Table 3) ($p<0.05$). Consequently, the average electricity cost and equivalent CO_2 emissions from GCA1-GCA3 was significantly lower than that of MA1-MA3, respectively ($p<0.05$). These findings indicated that GCA required around 62% lower energy

Table 3: Energy consumption, energy cost and equivalent CO_2 emissions in the mechanical and ground channel ventilation and airflow designed houses

	Experimental pig houses							
Parameters	MA1	GCA1	MA2	GCA2	MA3	GCA3	SEM	p-values
Energy consumption (kWh/day/m^3)	0.803^b	0.308^c	0.897^a	0.324^c	0.797^b	0.312^c	0.025	<0.0001
Energy cost (KRW/day/m^3)	17.363^b	6.648^c	19.376^a	7.003^c	17.230^b	6.748^c	0.543	<0.0001
Equivalent CO_2 emission (kg/day/m^3)	0.440^b	0.168^c	0.490^a	0.177^c	0.436^b	0.171^c	0.014	<0.0001

$^{a\text{-}c}$Means with different superscripts within the same row are significantly different ($p<0.05$). SEM: Standard Error of Mean; MA1: Mechanical ventilation airflow house with gestating sows; GCA1: Ground channel ventilation airflow house with gestating sows; MA2: Mechanical ventilation airflow house with lactating sows; GCA2: Ground channel ventilation airflow house with lactating sows; MA3: Mechanical ventilation airflow house with finishing pigs; GCA3: Ground channel ventilation airflow house with finishing pigs. kWh: Kilowatt hour; KRW: Korean won (South Korea). To measure the electricity cost for each house, the total electricity consumption was multiplied by 21.61 Korean Won (KRW) (electricity price for per unit of kWh of electricity in South Korea; where 1 USD equivalent to 1,161 KRW)

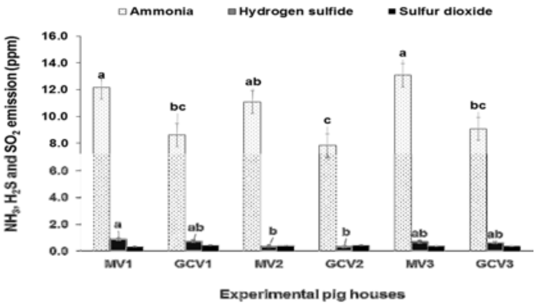


Fig. 5: NH3, H2S and SO_2 emissions in the mechanical and ground channel ventilation and airflow designed houses. $^{a\text{-}c}$Means with different superscripts letters are significantly different ($p<0.05$). Error bars indicate the standard error MA1: Mechanical ventilation airflow house with gestating sows; GCA1: Ground channel ventilation airflow house with gestating sows; MA2: Mechanical ventilation airflow house with lactating sows; GCA2: Ground channel ventilation airflow house with lactating sows; MA3: Mechanical ventilation airflow house with finishing pigs; GCA3: Ground channel ventilation airflow house with finishing pigs

consumption and cost and emitted around 3 lower equivalent CO_2 than MA in all stages of production of pig houses ($p<0.05$).

DISCUSSION

Temperature, relative humidity and ventilation flow in different pig houses: Temperature, relative humidity and ventilation flow are the most important factors for internal animal environment and for normal body physiology as well as the wellbeing of swine (Heitman and Hughes, 1949). The temperature for gestating and finishing pig houses should be between 10 and 2°C while lactating sows with piglets require higher temperatures (30-35°C for young piglets during first few days, then from 21- 27°C during weaning) (Bodman *et al*., 1989; England *et al*., 1981). In the current study, the temperature of the gestating (MA1 and GCA1) and finishing (MA3 and GCA3) pig house ranged from 12-18°C for MA1; 9-16°C for GCA1; 13-20°C for MA3 and 11-20°C for GCA3. The temperature of the GCA2 was lower than the MA2 as well as lower than the normal required temperature range for this stage of production (21-27°C) (England *et al*., 1981), indicating that supplementary heating with ground channel airflow heating system should be provided for the entire season to ensure the temperature requirement for young pigs as well protect from the cold stress. The result revealed that the ventilation airflow design can affect the internal temperature while the ground channel airflow design was efficient enough to maintain the internal temperature of GCA1 and GCA3. In the ground channel ventilation airflow structure, the under floor dynamic air flow through ground channel help to increase the temperature in the house by absorbing heat from the ground level, warm water passing through the side, concrete hollow structure, and under floor slurry of the house. The warmer temperature might also reflect the lower number of inlets and outlets in the GCA structure (one ground level inlet and one ceiling outlet) compared to the mechanical airflow structure (3 inlets and 3 outlets in the sidewall) because of the lower chance of heat loss. Consistent to that an earlier report suggested that maintenance of environmental conditions in intensive production systems is dependent on the design and performance of the ventilation system (Norton *et al*., 2007).

The relative humidity of the GCA and MA houses ranged from 54-67 and 55-68% for gestating (MA1 and GCA1), 51-62 and 55-66% for lactating (MA2 and GCA2), and 45-63 and 58-71% for finishing (MA3 and GCA3) pig houses. According to Hartung (1994) the range of relative humidity in the pig houses usually prevails in the range of 50-90% because <40% and >90% RH can cause cold or heat stress, dust generation and respiratory problems (Seedorf *et al*., 1998). In our study, we found a comparatively higher average RH in GCA2 (61.07%) than

MA2 (56.06%). The lower RH of MA2 relative to GCA2 might be attributed to the higher temperature supported by halogen lamp heating which was consistent with a report by Seedorf *et al.* (1998). Consistent to the higher value of RH in GCA, Xin *et al.* (1994) reported higher value of RH in the case of the tunnel ventilated house. However, internal temperature and relative humidity was in the general range for different stage of production of pig houses in the current study. Thus it was expected that GCA could ensure welfare and production for gestating to finishing pig production.

Insignificant differences in ventilation air flow indicated that, ventilation air flow design (MA and GCA) had no remarkable negative impact in the animal internal environment and risk of higher dust and microbial multiplication in the air, floor or bedding (Sevi *et al.*, 2001).

Gaseous concentrations from experimental pig houses: Greenhouse gases such as Carbon dioxide (CO_2), Nitrous Oxide (N_2O) and methane (CH_4) are involved in global warming as well as in climate change. Among these, carbon dioxide is the most important and can be emitted from animals and their managemental factors. Carbon dioxide in the slurry originated mainly through fermentation of organic matters (aerobic and anaerobic), enzymatic activity, pH content, degradability of carbon compound (Jeppsson, 2000; Wolter *et al.*, 2004). While in the animal house, physical, chemical and microbiological processes can be accelerated by temperature and moisture (Wolter *et al.*, 2004; Philippe and Nicks, 2015). Therefore, halogen lamp heating, temperature and moisture might be attributable in the lower CO_2 emissions from slurry in GCA2 (20%) and GCA3 (9%) when compared with MA2 and MA3, respectively (Fig. 4).

The reasons for the lower NH_3 emissions (30%) observed for GCA1-GCA3 compared with MA1-MA3 (Fig. 5) might be attributable to fermentation into the slurry pit, aeration and internal thermal environment (Osada *et al.*, 2000; Monteny *et al.*, 2006). Fresh air supply through the ground channel airflow system to the all pens through gently manner opined to be the reason of lower ammonia emission level in case of GCA relative to MA (Choi *et al.*, 2010a, b; Islam *et al.*, 2016). Supporting to our ground channel airflow heating system of 30% lower ammonia emission in GCA compared to MA (Fig. 5), Jacobson reported 20-30% lower ammonia emission due to geothermal heating system compared to conventional heating system from the furrowing pig house.

Electricity consumption, cost and equivalent CO_2 emission from different pig houses: Energy use is most important for animal agriculture as well as all aspects of modern society. The use and production of energy expected to remain top-priority item regarding economic and environmental aspects (Kanoglu and Cengel, 1999; Fridleifsson, 2001). Alternative source of heating for livestock house are gaining attention because of reducing the cost and environmental impact where heating represents 20% of the total energy consumption associated with pig houses, especially during Winter. The electricity consumption and cost of different pig houses differs because of the varying temperature requirements of different stages of pig production. In the MA type houses, the energy consumption and costs increased as heating was supported by halogen lamps, especially for young piglets in MA2. Thus, lower energy consumption was also found in GCA houses because of the ground channel ventilation airflow heating system. Lower number of air inlets and outlets in case of GCA (one ground level inlet and one outlet in GCA; 3 inlets and 3 outlets in MA), could reduce heat loss and therefore help to maintain internal temperature; consequently require lower energy for maintenance. In addition, the number of ventilation fans is an important factor to consider for electricity consumption and cost. Lower cost requirement supporting to the principle of air flow for maintaining temperature and relative humidity (Xin *et al.*, 1994; Modic, 2003). Therefore, the ground channel ventilation and airflow system and structure in the current study was assumed to be effective for maintaining internal environment thereby reduced the ultimate energy consumption and cost. It was expected that the ground channel ventilation airflow structure efficiently provided the desirable ventilation airflow and internal thermal environment because of the geometrical configuration of inlets and outlets (Klooster *et al.*, 1993) which consequently facilitate to the lower energy requirement for all GCA houses.

Since, all GCA houses were found to have lower electricity consumption (due to the absence of halogen lamp heating) (Table 2), thus it would obvious that it would reduce the equivalent CO_2 emissions associated with energy use (Zhang and Cheng, 2009). In addition, the type and power associated with ventilation systems can have significant effects on gas concentrations in pig houses (Topisirovic and Radivojevic, 2005). Therefore, it is obvious that energy utilization in livestock farms is a major concern, especially with higher populations and when considering long-term impacts on the animal industry (Verge *et al.*, 2009).

CONCLUSION

Internal animal environment was in the desirable range (temperature: 10 -21°C ; relative humidity: 50-90%) for the gestating and finishing pig houses of ground channel airflow (with ground level heating) designed house (GCA) and mechanical airflow (with halogen lamp heating) designed house (MA). There was found no significant differences of temperature in GCA1 and GCA3 in comparison to MA1 and MA3, respectively. Where, for lactating sow house (both in MA2 and GCA2) relative humidity was in the normal range (50-90%) but temperature was lower in GCA2 than that of MA2 which was also lower than the general temperature requirement (21-27°C) for the lactating stage. Hence, our result indicated that, extra heating should be provided to lactating houses during cold season to meet the general requirements and to protect the individuals from cold stress. Ventilation airflow did not differ between MA and GCA and did not indicate any large negative impact into the internal house conditions. In addition, CO_2 concentration from slurry were lower in GCA2 (20%) and GCA3 (9%) relative to MA2 and MA3, respectively and ammonia concentrations were lower (around 30%) in the GCA1-GCA3 relative to MA1-MA3, respectively. Furthermore, energy consumption, energy cost and equivalent CO_2 emission from energy use was lower (around 62%) for all GCA houses than MA houses. To sum up, during Winter season, ground channel airflow designed house (GCA) was effective in the reduction of gaseous concentrations (CO_2 and NH_3); minimization of energy consumption, energy cost and equivalent CO_2 emission from energy use, without negative impact on the internal animal environment compared to mechanical airflow (with halogen lamp heating) designed house (MA). Therefore, present result suggested that pig producers can take advantage by constructing such type of airflow design structure to cut the incurred money for energy and to reduce the gaseous concentrations from the swine house environment which would ensure the welfare and health of both animals and workers; ultimately helps to protect the environment and positively impacted on the agro-ecology. Further, detailed research is required to observe the impact of the ground channel airflow designed house on the productive and reproductive performances for different stage of pig production.

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