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Design of Stocking Density of Broilers for Closed House in Wet Tropical Climates

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ABSTRACT

The objectives of this research were to: 1) design the stocking density of broiler reared at a closed house system in wet tropical climates based on the heat released by broiler, 2) design broiler harvesting system based on the housing heat load, and 3) design required housing area based on the broiler age. The housing design used to determine the broiler stocking density was based on Computational Fluid Dynamics (CFD) with Solid Works Flow Simulation software. The method had good validation shown by small number of average percentage of deviation (6.07%). Simulation was carried out by changing the number of broilers i.e. 16, 18, 20, 21 and 22 birds/m^2. According to the CFD simulation result, total heat load inside the house was 233.33 kW at 21 birds/m^2 at weight 1.65 kg/bird. At that stocking density the housing can be occupied by 27,224 birds until 22 days of age. The highest total weight was produced by daily harvesting started from 22 to 32 d. It can be concluded that the stocking density of closed house for broiler is 34.65 kg/m^2, total production is 45,717 kg per period and the required area for 27,224 broilers is 248.63 m^2 (1 to 7 days of age broiler), 562.52 m^2 (8 to 14 days of age broiler) and 1,000 m^2 (15 to 22 days of age broiler).

Key words: broiler, computational fluid dynamics, stocking density, total heat

ABSTRAK

Penelitian ini bertujuan mendesain kepadatan ayam broiler pada kandang sistem tertutup di daerah beriklim tropika basah berdasarkan panas yang dikeluarkan ayam broiler, mendesain pemanenan ayam broiler berdasarkan beban panas kandang dan mendesain kebutuhan luas kandang menurut umur ayam. Desain kandang yang digunakan untuk menentukan kepadatan ayam broiler pada *Computational Fluid Dyanamics* (CFD) dengan software *Solidworks Flow Simulation* memiliki tingkat validasi cukup baik dengan nilai rataan persentase deviasi cukup rendah (6,07%). Simulasi dilakukan pada saat ayam broiler mendekati panen (umur 30 hari, bobot 1,65 kg) dengan cara mengubah jumlah ayam broiler yaitu 16, 18, 20, 21, dan 22 ekor/m^2. Berdasarkan hasil simulasi menggunakan CFD (luas kandang 1.000 m^2) diperoleh total panas ayam broiler sebesar 233,33 KW dengan kepadatan 21 ekor/m^2 pada bobot badan 1,65 kg/ekor. Pada tingkat kepadatan tersebut, sampai umur 22 hari dapat diisi 27.224 ekor ayam broiler dan menghasilkan total bobot panen tertinggi apabila dipanen setiap hari dari umur 22 sampai 32 hari. Dengan demikian diperoleh tingkat kepadatan ayam broiler 34,65 kg/m^2, total bobot panen 45.717 kg dan luas kandang yang dibutuhkan adalah 248,63 m^2 (umur ayam 1 sampai 7 hari), 562,52 m^2 (umur ayam 8 sampai 14 hari) dan 1.000 m^2 (umur ayam 15 sampai 22 hari).

Kata kunci: broiler, computational fluid dynamics, kepadatan, panas total

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INTRODUCTION

Some efforts could be implemented to increase the productivity of broiler chicken reared in a closed house system. Some of those are feed management, disease prevention and treatment, in-house micro environmental control including temperature, air velocity and relative humidity, and also stocking density designed based on the broiler's age and body weight (North & Bell, 1990). Stocking density design of a closed house system may affect the placement position of feeding and drinkers' line, number of feeding and drinkers set, control panel of temperature and relative humidity which in certain condition could make some difficulties to broiler-breeder.

Stocking density rate in a closed house system applied by broilers holders may vary across countries as they design based on the regular practice, recommendation from business partners and literature references (Buijs *et al*., 2009). A closed house system could occupy 12 to 16 birds/m^2. In a particular condition such as too high stocking density rate, broiler holders will do early harvesting at 22 to 24 days of age. However, the stocking density of broiler depends on the age or body weight. In addition, a closed house system with favorable housing micro environment could occupy 16 to 20 birds/m^2 or 30 to 36 kg/m^2 (North & Bell, 1990; Yardimci & Kenar, 2008; Abudabos *et al*., 2012; Abudabos *et al*., 2013).

It was reported that the increasing of broiler's stocking density in a closed house system could give some effects. Some of those were reducing feed intake, reducing feed efficiency, reducing broiler growth performance, increasing mortality and cannibalism, and increasing ventilation equipment (North & Bell, 1990), and increasing number of microbes found in litter (Yardimci & Kenar, 2008), reducing weight of lymphoid and increasing concentration of corticosterone in the serum (Quinteiro-Filho *et al*., 2010), reducing broiler performance and welfare (Abudabos et al., 2012; Abudabos *et al*., 2013). The important condition should be noticed that the increasing stocking density rate could increase the thermal heat load due to the accumulation of broiler's heat released into housing environment. This condition causes stress on broiler thus reduce growth rate (Sugito *et al*., 2007; Kusnadi & Rahim, 2009).

Total heat released per unit weight of broilers decreases in conjunction with the increases of age and weight, but it increases at each of broiler due to an increase on the body weight which then contributes to the increasing of total heat inside the house (Cordeau & Barrington, 2010). Thus, calculation on the maximum total heat inside the house should be conducted to provide comfort environment for flocks. This calculation results the maximum stocking density rate in which the in-house environment condition is still comfort, number of broilers which can be harvested on schedule, and total of space area required by different age and weight.

Computational Fluid Dynamics (CFD) based on two or three dimensional numeric analysis through integration equation of mass, momentum and energy was applied in this research to calculate the maximum heat load occurred at broiler's closed house system in wet tropical climates (Versteeg & Malalasekera, 1995). In this research, CFD was used to model the geometry, the thermo physical properties and the total heat of heat sources occurred at experimental closed house which include plafond, rice husk, curtain, cooling pad, fan and broiler chicken itself. The objectives of this research were to: 1) design the stocking density of broiler at closed house system in wet tropical climates based on the heat released by broiler and micro environmental condition, 2) design harvesting system of broiler chicken based on the total heat load occurred at the house, 3) design housing area based on the broiler age or rearing period.

MATERIALS AND METHODS

The research was carried out in a closed house system for broiler at the Faculty of Animal Science, Bogor Agricultural University from May to July 2013. The dimension of the experimental house was 100 m length x 10 m width x 2.4 m height occupied with 9.656 broilers chicken. The floor was made from concrete cement with rice husk placed on, the stud was made of iron material, the wall was made of expose mercy brick to support the curtain, the plafond was made of galvaniz, the ventilation system consisted of 6 fans with 1.27 m in diameter, in-house lighting consisted of 60 units of 8 watt bulb lamp, and cooling pad was set up to reduce the in-house temperature.

The tools used in the experiment were portable paperless recorder (Yokogawa, MV Advance 1000), anemometer, lux meter to measure micro environmental condition inside the house, personal computer, caliper, weighing scale and infrared thermography with 2% precision level and spectral ranges from 7.5 to 13 µm to measure the body surface temperature of broiler chicken (head, leg and body). The capture distance between broiler and camera was 2 m, emissivity was set at 0.95 and temperature ranged from 30 ^{o}C to 45 ^{o}C. The temperature of body surface was measured when the housing temperature was fairly high, i.e. 32.5 ^{o}C with relative humidity was 71%. This environment condition was designed for broiler to release maximum heat. Micro environment data, such as air temperature and relative humidity (inside and outside), wind speed, air velocity, temperature of husk, plafond, curtain, litter, were measured and recorded with interval 30 min started from 06:00 to 18:00 during one breeding period (35 d).

In this experiment ThermaCAM Researcher Professional and CFD with Solid Works Flow Simulation software were used to analyze data. Data measurement from infrared thermography was used to analyze the body surface temperature of broiler using ThermaCAM Researcher Professional software. CFD with Solid Works Flow Simulation software used to determine the stocking density of broiler in the experimental house showed good validation with small number of average percentage of deviation (2.18%). Thus, determination of material and boundary condition of CFD was appropriate and could present real house condition. Environment data from measurement on June 29th 2013 at 13:00 (1 pm) were selected as representing sunny day which heat load of closed house reached maximum. In accordance with the measurement, the micro environment condition outside the house was 808 Watt/m^2, 34.3 ^{o}C, 57% and 1,027.5 Bar for radiation intensity, temperature, relative humidity and air pressure, respectively. While the micro environment condition inside the house was 54.09, 32.54, 27.41, 30.88, 34.93, and 34.95 ^{o}C for roof temperature, soil temperature at 0.2 m depth, water temperature of cooling pad, rice husk temperature, plafond temperature and curtain temperature, respectively. The environment conditions both inside and outside closed house showed the maximum heat load in region of wet tropical climate. The maximum heat load is critical condition to design of stocking density broilers for closed house.

Convection Coefficient of Broiler Chicken

Birds release heat through head, leg, and body thus it analogue as radiator in designing the stocking density of broiler house (Yani *et al*., 2007). Heat is released through radiation, convection, and conduction where the highest amount occurs by convection and radiation. Total heat released from the whole body of bird has to be taken into consideration in designing closed house system in wet tropical climates. Heat transfer coefficient of convection (h) of birds was calculated from equation developed by Yahav *et al*. (2004) and Van Brecht *et al*. (2005) as follow:

$$Q_T = Q_R + Q_C \quad \text{......(1)}$$

$$Q_R = e\,\sigma\,A\,(T_s^4 - T_\infty^4) \quad \text{......(2)}$$

$$Q_C = h\,A\,(T_s - T_\infty) \quad \text{......(3)}$$

$$h = \frac{Q_T - Q_R}{A(T_s - T_\infty)} \quad \text{......(4)}$$

where Q_T= total heat released by birds (Watt), Q_R= heat loss by radiation (Watt), Q_C= heat loss by convection (Watt), e= bird emissivity (0.95), σ= Stefan-Boltzman constant (5.67 x 10-8 Watt/m^2/^{o}K^4), h= heat transfer coefficient of convection (Watt/m^2/^{o}C), A= bird surface area (m^2), Ts = bird surface temperature (^{o}C), T∞= housing temperature (^{o}C). The total broiler surface area was calculated using this following equation (Yanagi *et. al*., 2001):

$$A = 0.1067 \times m^{0,705} \quad \text{......(5)}$$

where A= bird surface area (m^2) and m= bird weight (kg).

Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD) could be used to design the stocking density rate of a closed house designed for broiler in wet tropical climates as CFD operated on the basis on numeric analysis of volume control which deals with the equation integration that represented three balance process of mass, momentum and energy. Thus, the equation of two or three dimensional could be derived faster and simultaneously (Versteeg & Malalasekera 1995). The principal work of CFD is designed by modeling the condition of a closed house comprising the geometry, material of the building, thermo physical properties of the building, heat source and the amount of heat source, environment condition affecting the heat and energy balance, and heat amount released by the material of the building.

Computational Fluid Dynamics (CFD) consisted of three main elements, i.e. pre-processor, solver and post-processor. The activities at pre-processor were: 1) defining the geometry of the region; 2) mesh generation at each domain; 3) selection of required physical and chemical phenomena; 4) definition of conductivity, viscosity, specific heat, and density; 5) specification of appropriate boundary condition (Versteeg & Malalasekera, 1995). The activities at solver were: 1) approximation of the unknown fluid flow using simple equation; 2) discretization; 3) solution of the algebraic equation. In solver computation, there are three streams of fluid i.e. conservation law of mass fluid, Newton's second law and the First Law of Thermodynamic. The result of pre-processor and solver was then displayed in post-processor in the form of domain geometry and grid display, vector plot, two or three dimensional surface plots, air temperature and flow rate, particle movement and color output.

Stocking Density Simulation of Broiler's Closed House

CFD simulation to determine the stocking density inside the house was performed by alternating the number of broilers of 16, 18, 20, 21, and 22 birds/m^2 (North & Bell, 1990; Yardimci & Kenar, 2008; Abudabos *et al*., 2012; Abudabos *et al*., 2013). Simulation was designed using broiler which closed to the harvesting age at 30 days with average weight of 1.65 kg. This experimental condition was designed to obtain sufficient heat inside the house as the bird at this age releases the highest amount of heat. The maximum housing air velocity was generated from 6 units of fan with 69.948 m3s-1 and cross-sectional area of 24 m2. This number of air velocity was considered to be in the range of comfort zone (Donald, 2010).

Housing temperature obtained from simulation was the average temperature occurred inside the house. Taken together with air flow rate of 2.92 ms^{-1}, effective temperature was obtained in order to determine the comfort zone at simulated stocking density. The temperature of cooling pad was set at the lowest daily comfortable temperature occurred inside the house, i.e. 22.5 ^{o}C (Pereira & Naas, 2008).

In this research, underlying assumptions used to determine the stocking density of broiler reared in a closed house system were: 1) air inside the house was incompressible; 2) fan speed was assumed constant during simulation; 3) specific heat, conductivity, and viscosity of air were constant (Prandtl number of air was constant); 4) temperature of rice husk was uniform in accordance to the boundary condition; 5) temperature of plafond was uniform in accordance to the boundary condition; 6) temperature of curtain was uniform in accordance to the boundary condition; 7) temperature of light bulb was uniform in accordance to the boundary condition; and 8) temperature of roof did not affect the boundary condition of plafond's temperature.

RESULTS AND DISCUSSION

Broiler stocking density in a closed house system was determined by the micro environmental condition such as air temperature, relative humidity and solar radiation (micro environment outside the house), water temperature of cooling pad, air flow rate inside the house, relative humidity inside the house, plafond temperature, curtain temperature, wall temperature, rice husk temperature (micro environment inside the house), and broiler surface temperature as heat source (radiator). As a heat source, broiler releases sensible and insensible heat (North & Bell, 1990). The amount of heat released at each part of broiler was closely related to surface temperature presented in Figure 1. Temperature of leg was higher than body and head. Surface temperature at body featherless area was higher than those which covered by feather (Naas *et al*., 2010). According to the result of measurement and calculation using Solid Works Flow Simulation software, surface area which covered by feather was 68.42% and others which were not covered was 31.58%. The surface area of body, leg and head was basically computed by the weight of body (1.477 kg), head (0.119 kg) and leg (0.054 kg).

The surface temperature of broiler which used as input data in CFD simulation was the temperature at the highest heat loss by broiler. In other words, if broiler released lower temperature then the stocking density design was more favorable for broiler providing more comfortable environment. In this simulation, broiler was considered as a modeled like radiator which releases heat continuously throughout the head, body and leg. Thus, broiler was a new material in the SolidWorks Flow Simulation software. According to the measurement, calculation and analysis, the properties and input of CFD program are shown in Table 1.

Standing position of the bird was used to simulate CFD using Solid Works Flow Simulation. The distance of leg, body and head from rice husk (litter) was 0 to 0.07 m, 0.07 to 0.15 m, and 0.15 to 0.21 m, respectively. Broiler body parts such as leg, body and head were horizontally overlaid in a closed house system where the occupied area was associated with the housing stocking density with 1,000 m^2. The position of each body parts of broiler at closed house simulated using CFD is shown in Figure 2.

According to the simulation resulted from CFD, increasing of stocking density increased the effective

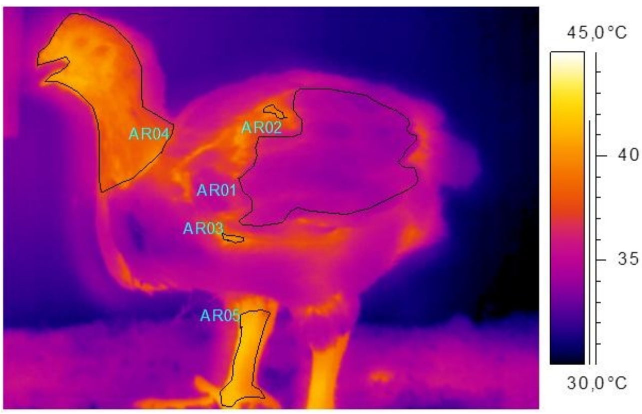

Figure 1. Surface temperature profile of broiler resulted from measurement using infrared thermography

Table 1. Body weight, surface area and temperature, sensible heat and heat transfer coefficient of each bird

Component	Body featherless area	Body covered by feather	Head	Leg
Area (m^2)	0.0491	0.1063	0.0081	0.0014
Temperature (°C)	39.5000	34.7000	38.8000	40.6000
Sensible heat (Watt)	3.1400	6.8051	0.8014	0.3636
Heat transfer coefficient of convection (W/m^2 °C)	9.1368	29.0959	15.6936	32.7582

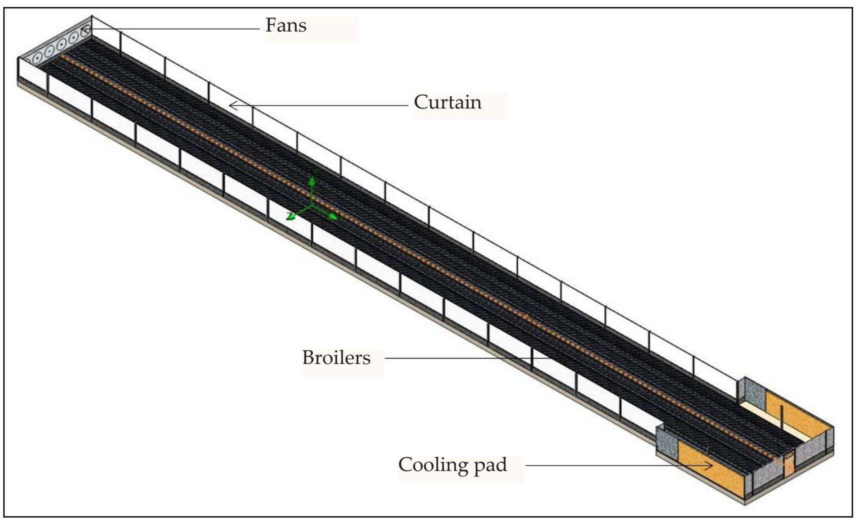

Figure 2. The geometry of experimental house and position of each parts used for Computational Fluid Dynamics (CFD) simulation

temperature inside the house (Table 2) due to the accumulation of total heat released by broiler. The highest amount of heat accumulated at the house was obtained when the effective temperature closed to or not higher than 24.5 °C which was still comfortable for broiler (Donald, 2010). The optimum condition for relative growth rate of live weight for broilers was 20-24 °C at finisher phase (Herawati & Adiwinarto, 2012). The effective temperature was obtained at stocking density of 21 birds/m² (34.65 kg/m²) with total heat inside the house was 233.33 KW (Table 3). This finding was higher than those suggested by North & Bell (1990) of 30.4 kg/m², by Abudabos *et al*. (2012) of 31.8 kg/m² and by Yardimci & Kenar (2008) of 33 kg/m².

Maximum total heat inside the house resulted from CFD simulation i.e. 233.33 KW was used to determine number of broiler based on the age, harvesting schedule, number of broiler that could be harvested on schedule, optimum bird weight at harvest, and housing area based on the bird age. According to the age and weight, maximum number of broiler inside the house was 27,224 calculated from maximum heat during the first early harvesting of 22 d (Table 4). Total number of broiler at

Table 2. Stocking density resulted from Computational Fluid Dynamics (CFD) simulation

Simulation (birds/m²)	Body weight (kg/m²)	Total heat inside the house (Watt/m²)	Effective temperature inside the house (°C)
16	26.40	117.78	22.876
18	29.70	200.00	23.931
20	33.00	222.22	24.240
21	34.65	233.33	24.397
22	36.30	244.44	24.505

Table 3. Number of broiler occupied at a closed house system based on heat load in accordance with broiler age

Broiler age (day)	Weight per bird (kg)[1]	Total heat loss of broiler (Watt/kg)	Total heat loss per bird (Watt)	Maximum total heat loss (KW)	Number of broiler (birds)	Dead off grade broiler	Total broiler
1	0.057	10.940	0.624	233.333	27,566	17	27,584
2	0.075	10.892	0.817	233.333	27,549	17	27,566
3	0.096	10.837	1.040	233.333	27,532	17	27,549
4	0.118	10.778	1.272	233.333	27,515	17	27,532
5	0.143	10.712	1.532	233.333	27,498	17	27,515
6	0.170	10.641	1.809	233.333	27,480	17	27,498
7	0.200	10.562	2.112	233.333	27,463	17	27,480
8	0.232	10.478	2.431	233.333	27,446	17	27,463
9	0.267	10.385	2.773	233.333	27,429	17	27,446
10	0.306	10.282	3.146	233.333	27,412	17	27,429
11	0.348	10.171	3.540	233.333	27,395	17	27,412
12	0.391	10.058	3.933	233.333	27,378	17	27,395
13	0.438	9.934	4.351	233.333	27,360	17	27,378
14	0.490	9.796	4.800	233.333	27,343	17	27,360
15	0.547	9.646	5.276	233.333	27,326	17	27,343
16	0.609	9.482	5.775	233.333	27,309	17	27,326
17	0.674	9.311	6.275	233.333	27,292	17	27,309
18	0.741	9.134	6.768	233.333	27,275	17	27,292
19	0.810	8.952	7.251	233.333	27,258	17	27,275
20	0.880	8.767	7.715	233.333	27,241	17	27,258
21	0.950	8.582	8.153	233.333	27,224	17	27,241
22	1.021	8.395	8.571	233.333	27,224	17	27,241
23	1.093	8.204	8.967	233.333	26,003	16	26,019
24	1.167	8.009	9.347	233.333	24,948	16	24,964
25	1.242	7.811	9.701	233.333	24,036	15	24,051
26	1.320	7.605	10.039	233.333	23,228	15	23,242
27	1.399	7.397	10.348	233.333	22,534	14	22,548
28	1.480	7.183	10.631	233.333	21,935	14	21,949
29	1.563	6.964	10.884	233.333	21,424	13	21,437
30	1.646	6.745	11.102	233.333	21,005	13	21,018
31	1.731	6.520	11.286	233.333	20,661	13	20,674
32	1.817	6.293	11.435	233.333	20,393	13	20,406

Note: [1] Production target

Table 4. Harvesting schedule, number of harvested broiler, and weight harvested broiler

Broiler age (day)	Number of broiler (birds)	Number of harvested broiler (birds)						Weight of harvested broiler (kg)					
		1 d harvesting	2 d harvesting	3 d harvesting	4 d harvesting	5 d harvesting	10 d harvesting	1 d harvesting	2 d harvesting	3 d harvesting	4 d harvesting	5 d harvesting	10 d harvesting
22	27,224	1,221	2,276	3,188	3,996	4,690	6,831	1,247	2,324	3,255	4,080	4,788	6,975
23	26,003	1,055						1,153					
24	24,948	912	1,720					1,065	2,007				
25	24,036	808		2,101				1,003		2,609			
26	23,228	694	1,293		2,223			916	1,706		2,935		
27	22,534	599				2,141		838				2,996	
28	21,935	511	931	1,275				757	1,377	1,886			
29	21,424	419						655					
30	21,005	344	612		21,005			566	1,007		34,574		
31	20,661	268		20,661				463		35,764			
32	20,393	20,393	20,393			20,393	20,393	37,054	37,054			37,054	37,054
Total		27,224	27,224	27,224	27,224	27,224	27,224	45,717	45,476	43,514	41,588	44,838	44,028

1 to 22 days of age was relatively similar as the absence of early harvesting and added with 2% of mortality risk (North & Bell, 1990) during rearing period which meant that there were always dead or off-grade birds every day. Number of broiler at 22 to 32 days of age tends to decrease due to the increasing of body weight (total heat released by broiler also increased).

Determination of the number of harvested broilers was calculated from excess heat released by broiler thus harvesting could be carried out daily, every two days, three days, four days, five days or only twice, i.e. at 22 d (early harvesting) and 32 d (peak harvesting). Number of total harvested broiler per house was similar (27,224 birds) for every harvesting schedule (daily, every two days and so on). However, it produced different total weight at each different harvesting schedule (Table 4). The highest weight was 45,717 kg which produced by daily harvesting started from 22 to 32 d. Meanwhile, the lowest was 41,588 kg which produced by harvesting schedule per four days. Thus, the difference was 4,129 kg. Breeders usually harvested twice: early harvesting at 22 days of age and peak harvesting at 32 days of age. This scenario produced 44,028 kg which was fewer than daily harvesting scenario (45,717 kg).

Breeders have different perspectives in determining the housing area required for one breeding period where harvesting is carried out based on the total heat load. Prior to the first harvesting age (22 d), a broiler chick requires small area which were 248.63 m^2 (24.86%) for 27,224 broilers with 1 to 7 days of age, 562.52 m2 (56.25%) for 8 to 14 days of age, and 1,000 m2 (100%) for broiler with 22 to 32 days of age. For the shake of efficiency, two or three houses recommended to be built in one breeding period. Under this scenario, broilers could be replaced from one house to the other thus empty house could be used on the next period of rearing. This condition could increase the number of broiler breeding period from 6 to 7 times to 12 to 14 times in a year for two houses scenario and 18 to 21 times in a year for three houses scenario.

CONCLUSION

Number of broiler that can be placed in the experimental house of 100 m length x 10 m width x 2.4 m height is 27,224 birds with the highest weight of 45,717 kg harvested daily started from 22 to 32 d. It is suggested that the housing area for 27,224 birds is 248.63 m^2 for broiler at 1 to 7 days of age, 562.52 m^2 for 8 to 14 days of age, and 1,000 m^2 for broiler with 15 to 22 days of age.

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