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Optimization of energy consumption per kg of pure meat by electrical and thermal systems in broiler chicken farms

[*Otimização do consumo de energia por kg de carne pura por meio de sistemas térmicos em granjas de frangos de corte*]

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ABSTRACT

The present study was conducted to investigate the effect of electrical and thermal systems optimization on energy consumption in broiler farms. Experiments were conducted in 4 different climates (cold, hot, dry, and temperate) with four treatments (4 broiler farms in each region) and 5 iterations (5 rearing periods per farm) on the Ross 308 strain of broiler chicken in a completely randomized basic design. The results showed that the solutions applied in cold and dry climates had a significant effect on reducing energy consumption (P<0.05). In the hot climate, although the reduction in energy consumption was observed after the application of the solutions, the difference was not statistically significant (P>0.05). Also, the application of solutions in temperate climates created a significant difference in the specific amount of thermal energy consumption per kilo of meat and total energy (P<0.05). Overall, the results of the present experiment showed that optimizing the electrical and thermal systems of broiler houses could reduce energy consumption in all climates.

Keywords: electrical System, optimization, energy, climate, broiler chicken, thermal system

RESUMO

O presente estudo foi realizado para investigar o efeito da otimização de sistemas elétricos e térmicos no consumo de energia em fazendas de frangos de corte. Foram realizadas experiências em 4 climas diferentes (frio, quente, seco e temperado) com quatro tratamentos (4 granjas de frangos de corte em cada região) e 5 iterações (5 períodos de criação por granja) na cepa Ross 308 de frangos de corte em um projeto básico completamente aleatório. Os resultados mostraram que as soluções aplicadas em climas frios e secos tiveram um efeito significativo na redução do consumo de energia (P<0,05). No clima quente, embora a redução no consumo de energia tenha sido observada após a aplicação das soluções, a diferença não foi estatisticamente significativa (P>0,05). Além disso, a aplicação de soluções em climas temperados criou uma diferença significativa na quantidade específica de consumo de energia térmica por quilo de carne e energia total (P<0,05). Em geral, os resultados do presente experimento mostraram que a otimização dos sistemas elétricos e térmicos das casas de frangos de corte poderia reduzir o consumo de energia em todos os climas.

Palavras-chave: sistema elétrico, otimização, energia, clima, frangos de corte, sistema térmico

INTRODUCTION

Today, the agricultural sector is heavily dependent on energy to meet the food needs of the world's growing population and to provide adequate food. Attention to limited natural resources and the adverse effects of improper use of various energy resources on human health and the environment has made it necessary to revise energy consumption models in the agricultural sector (Mohammadshirazi *et al*., 2012; Soltanali *et al*., 2016). Due to population growth and resource limitations, development of the agricultural sector must take into account not only optimal use and productivity improvement of production factors, but also the growing needs of food products and overall economic development as well (Nabavi-Pelesaraei *et al*., 2014).

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The agricultural sector has a smaller share in terms of energy consumption compared to the industry sector, but it has been found that the amount of input energy is much higher. Unfortunately, little attention is paid today to the exploitation and optimal use of energy in industry and agriculture; so, many countries aim to optimize energy consumption in these two sectors (Kizilaslan, 2009). Poultry farming is one of the largest branches of agriculture and the most developed industry in the world. In a world with increasing population growth, welfare, and income, and thus increasing demand for white meat, the expansion and development of the broiler industry appear to be necessary to meet protein needs. However, the poultry industry consumes a large amount of energy in various forms.

Poultry farmers play a key role in the energy efficiency of production units by using a variety of production methods (Jekayinfa, 2007; Silva *et al*., 2016). Precisely describing the points of energy consumption for broiler production can be difficult because poultry are living organisms and the growing of poultry requires a dynamic system inwhich energy loss may occur during many processes (Payandeh *et al*., 2017; Poor ghasemi *et al*., 2013). Due to limited energy resources and the needs in many countries to optimize energy consumption in the broiler industry, reforms should be made in these energy consumption conditions (Liang *et al*., 2009; Das *et al*., 2016; Poorghasemi *et al*., 20115). A lot of research has been done in broiler industries to analyze energy consumption, and the results of energy audit and implementation of energy-saving solutions in broiler farms and suggestions for cost-free, low-cost, and costly solutions have been presented. According to the literature, the main energy losses in this industry are due to low combustion efficiency in existing heating systems, inadequate air conditioning, and lack of insulation of houses (Heidari *et al*., 2011; Nabavi-Pelesaraei *et al*., 2013a).

For example, Amid *et al*. (2015) measured energy consumption directly and indirectly in two broiler houses. One of the houses was insulatedand the other one was not. Their reports showed that the non-insulated house consumed more thermal and electrical energy. They eventually concluded that the energy efficiency of the insulated house was higher. However, research on energy consumption in broiler chicken rearing have yielded different results in different regions raising the question of whether energy-saving solutions may differ between various regions.

The results of these studies have also shown that with better management, broiler farmers can reduce the cost of energy and avoid spending capital in this area as much as possible. Therefore, to provide a consistent and direct comparison of energy efficiency in different environments, the present study examined energy consumption in broiler farms in four different climates (cold, hot, dry, and temperate) before and after using comparable energy consumption and reduction solutions.

MATERIALS AND METHODS

Different regions with different climatic conditions in Iran were selected to conduct this study. The study regions were cold climate, hot climate, dry climate, and temperate climate. This experiment was conducted with a completely randomized basic design in 4 different climates (cold (38.2537° N, 48.3000° E), hot (31.4360° N, 49.0413° E), dry (32.6539° N, 51.6660° E), and temperate (37.2809° N, 49.5924° E) with four treatments (4 broiler farms in each region) and 5 replications (5 rearing periods per farm). The climatic characteristics of the experimental climates are presented in Tables 1, 2, 3 and 4. All studies were conducted with the Ross 308 strain of broiler chicken. This study was conducted in all the climates over 2 years (the first year without and the second year with energy consumption reduction solutions) and taking into account the length of the rearing period of 50 days in 5 periods of each year.

Prior to beginning the experiments, data on weather conditions in each region, average changes in temperature and humidity were collected, and after selecting broiler houses in each climate, the following items were examined. In order to perform the energy audit, the structural and architectural information of each house was first examined and then the heat transfer coefficient of each of the walls, the roof, and the floor of the farm was measured. To estimate the amount of ventilation in the houses, the characteristics of the vents (the number and diameter of the vents) were determined.

Table 1. Temperature changes in cold climate (Adapted from: http://www.irimo.ir)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Average of maximum temperature (℃)	3	4	11	18	20	23	24	26	22	18	10	5
Average of minimum temperature (℃)	-9	-10	-4	3	5	8	12	13	10	5	0	-2
Average humidity (%)	70	63	50	35	25	20	20	25	25	30	35	65
Number of days with clear skies	13	14	14	13	22	26	24	23	27	21	17	13
Number of semi-cloudy days	9	8	9	10	3	1	4	5	1	6	9	10
The number of completely cloudy days	8	8	7	7	5	3	2	2	2	3	4	7

Table 2. Temperature changes in warm climate (Adapted from: http://www.irimo.ir)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Average of maximum temperature (℃)	17.5	20	24.5	33	40	44.5	46.5	46	42	35	27	20
Average of minimum temperature (℃)	9.5	10	13	20	25	28	31	31	26	21	14.5	11
Average humidity (%)	70	63	50	35	25	20	20	25	25	30	35	65
Number of days with clear skies	14	15	18	17	27	29	30	29	29	24	18	15
Number of semi-cloudy days	9	8	9	10	3	1	1	2	1	6	9	10
The number of completely cloudy days	8	5	4	3	1	0	0	0	0	1	3	6

Table 3. Temperature changes in dry climate (Adapted from: http://www.irimo.ir)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Average of maximum temperature (°C)	9	12	17	24	29	35	38	36	32	25	15	11
Average of minimum temperature (°C)	-3	-1	3	10	13	18	21	19	16	9	5	-1
Average humidity (%)	45	40	35	35	25	20	20	25	25	30	35	45
Number of days with clear skies	13	14	14	13	26	28	24	23	27	21	19	15
Number of semi-cloudy days	9	8	9	10	3	1	4	5	1	6	7	8
The number of completely cloudy days	8	8	7	7	5	3	2	2	2	3	4	7

Table 4. Temperature changes in temperate climate (Adapted from: http://www.irimo.ir)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Average of maximum temperature (℃)	14	12	15	18	27	31	30	30	25	23	16	14
Average of minimum temperature (℃)	5	6	7	10	18	22	22	21	18	16	11	9
Average humidity (%)	82	88	85	82	78	70	80	84	86	88	89	86
Number of days with clear skies	132	88	114	149	207	332	247	205	92	116	58	72
Number of semi-cloudy days	4	5	5	5	4	2	3	4			6	6
The number of completely cloudy days	7	15	18	13	11	6	10	10	18	15	18	19

The inlets and pad coolings installed at the beginning of the houses were also examined. Energy losses included electrical and thermal energy losses during operation. All factors of energy consumption in the electrical and thermal sections of the houses were calculated based on the behavior of the operator. Electrical energy losses were measured by analyzing electricity consumption in the desired period by the lighting system, electro-fans, feeders, blower fans, and water pumps. After calculating electrical energy loss, heat loss was estimated by considering the structure and architecture of the houses through the entry of fresh air from the roof, walls, floors, doors, and walls adjacent to the uncontrolled space of the houses. The intelligent control system operation regulating the indoor air temperature was assessed by calculating the generated metabolic heat of chickens in each rearing period based on the pattern of 5 rearing periods per year. This amount of heat varies depending on the species, weight, and age. The mean rate of chicken metabolic heat in a month was calculated from the sum of the numbers in Table 5 and based on the desired week. Table 5 shows the amount of heat generated by every 1000 chickens. The numbers in Table 5 were multiplied by 13 to estimate the recoverable amount of chicken metabolic heat in the farm. At this stage, interior conditions were measured, including temperature, humidity, lighting, ammonia, and carbon monoxide inside the houses at various locations.

Table 5. Measurement of metabolic heat production by chickens

Chickens' age (weeks)	Metabolic heat obtained from 1000 chickens (kilowatts)
1	0.4
2	1.1
3	2.3
4	3.9
5	5.5
6	7.7
7	9.9

Based on combustion analysis performed on direct hot air blowers, combustion conditions and combustion parameters (output oxygen (O_2), carbon monoxide (CO), excess air (E Air), exhaust gas temperature (FT), carbon dioxide (CO_2), engine room ambient temperature (AT) and nitric oxide (NO) were measured in this regard. In the second year, the experiment was performed by applying solutions to reduce the consumption of electrical and thermal energy in broiler houses. In order to reduce electricity consumption, the position of lighting systems was changed to enable broilers to be raised with similar light levels but lower electricity use. The height of the lamps installed in the houses was lowered by about one meter, increasing the amount of light on the poultry by more than three-fold. To maintain approximately the same light intensity on the broilers, the power of each lamp was reduced, so that 23 W lamps were used instead of 40 W lamps. Finally, the amount of electricity saving was calculated using the following formula: Power saving = (available lamp power – recommended lamp power) × number × number of operating hours.

At this stage, to reduce the amount of thermal energy consumption and also increase thermal quality in the houses, insulation was added to improve the insulation condition of the roofs and excess insulation was added to the exterior walls of the houses. Insulation materials were made of polyurethane (20 kg/m^3) or mineral wool (40 kg/m^3). Hot water (hydraulic) heating system was used for underfloor heating. In this heating system, hot water with a temperature of 30-60°C flows in underfloor pipes. At the end of each period, the specific thermal energy consumption, the specific electric energy consumption, the total energy consumption by considering the metabolic heat, the specific usable metabolic energy, and the total energy in each year were calculated using the following formulas. Specific thermal energy consumption (SEC_{th}) = Thermal energy consumption (MJ) / Live chicken weight (kg) Specific electric energy consumption (SEC_{th})= Electric energy consumption (MJ) / Live chicken weight (kg).

Specific chicken metabolic heat = Mean heat made by chicken body in the period (kW/period) × 24 (hours) × Number of days of the period ×3.6 (MJ). Total specific energy consumption (including usable chicken metabolic heat) (SEC_{tot}) = SEC_{th} + (SEC_e ×3.6 ÷ 0.315) 3.6: Kilowatt-hour to megajoules conversion coefficient 0.315: Power plant conversion coefficient based on the mean efficiency of the country's power plants and losses in transmission and distribution lines. Total energy = SEC_{th} + SEC_e This experiment was performed in a completely randomized design and the data were analyzed using SAS statistical software (SAS, 2004) and general linear model method, and the mean of treatments was compared using Duncan's test at 5% probability level (P<0.05). The statistical model of the project was Yij = µ + Ai + eij. In this model Yij was the value of each observation for the studied attribute, µ was mean observations, Ai was the effect of experimental treatments, and eij was the effect of trial error.

RESULTS

Table 6 shows the results of energy consumption in the cold climate. The results showed that in all types of energy consumption, project implementation significantly reduced energy consumption (P<0.05). Table 7 shows the heat energy consumption in the hot climate. Although reductions in average energy consumption were observed, considerable variation occurred so that the observed average reduction was not statistically significant (P>0.05). The average energy consumption was much smaller in the hot climate to start with (year 1 of hot climate compared to year 1 of the cold climate, P<0.05), so that there was less "room for improvement" in these measures.

Table 6. Amount and comparison of energy consumption in different modes before and after implementation of energy consumption reduction solutions in the cold climate

Energy type (MJ)	A	B	A-B	SEM	P
Specific consumption of thermal energy per kilogram of pure meat	49.28	25.69	23.59	4.085	0.010
Specific consumption of electrical energy per kilogram of pure meat	1.96	1.78	0.18	0.041	0.024
Total specific energy consumption including usable chicken metabolic heat	37.24	15.53	21.71	4.312	0.015
Specific usable metabolic energy	14.00	11.95	2.05	0.230	0.003
Total energy	51.24	27.48	23.77	4.114	0.010

A: Before applying energy reduction solutions, B: After applying energy reduction solutions, and A-B: The difference between before and after applying energy reduction solutions.

Table 7. Amount and comparison of energy consumption in different modes before and after implementation of energy consumption reduction solutions in the hot climate

Energy type (MJ)	A	B	A-B	SEM	P
Specific consumption of thermal energy per kilogram of pure meat	8.47	3.39	5.09	3.541	0.246
Specific consumption of electrical energy per kilogram of pure meat	0.90	0.81	0.09	0.034	0.074
Total specific energy consumption including usable chicken metabolic heat	5.05	3.18	1.87	1.808	0.153
Specific usable metabolic energy	5.75	1.99	3.76	1.802	0.186
Total energy	9.37	4.20	5.18	3.574	0.243

A: Before applying energy reduction solutions, B: After applying energy reduction solutions, and A-B: The difference between before and after applying energy reduction solutions.

Table 8 shows the results of energy consumption before and after applying optimization solutions in the dry climate. The results showed that the solutions applied had a significant effect on reducing energy consumption (P<0.05). Table 9 shows the results of energy consumption in the temperate climate. According to the results, the specific thermal energy consumption per kilo of pure meat was significantly reduced (P<0.05). While several of the underlying individual measurements of energy consumption were not significantly reduced (P>0.05), the overall total energy consumption was significantly reduced. Table 10 shows the results of energy consumption reduction in the four experimental climates, combined. The results showed that energy consumption reduction solutions significantly (P<0.05) reduced the energy consumption for all measures being considered.

Table 8. Amount and comparison of energy consumption in different modes before and after implementation of energy consumption reduction solutions in the dry climate

Energy type (MJ)	A	B	A-B	SEM	P
Specific consumption of thermal energy per kilogram of pure meat	27.84	11.63	16.21	2.653	0.009
Specific consumption of electrical energy per kilogram of pure meat	3.53	3.40	0.13	0.030	0.022
Total specific energy consumption including usable chicken metabolic heat	20.82	8.38	12.44	2.540	0.016
Specific usable metabolic energy	10.55	6.66	3.89	0.308	0.001
Total energy	31.37	15.03	16.34	2.673	0.009

A: Before applying energy reduction solutions, B: After applying energy reduction solutions, and A-B: The difference between before and after applying energy reduction solutions.

Table 9. Amount and comparison of energy consumption in different modes before and after implementation of energy consumption reduction solutions in the temperate climate

Energy type (MJ)	A	B	A-B	SEM	P
Specific consumption of thermal energy per kilogram of pure meat	11.01	5.94	5.07	1.263	0.028
Specific consumption of electrical energy per kilogram of pure meat	0.84	0.60	0.24	0.128	0.410
Total specific energy consumption including usable chicken metabolic heat	5.75	3.88	1.87	1.808	0.153
Specific usable metabolic energy	6.16	2.40	3.75	1.882	0.184
Total energy	11.85	6.54	5.31	1.0179	0.020

A: Before applying energy reduction solutions, B: After applying energy reduction solutions, and A-B: The difference between before and after applying energy reduction solutions.

Table 10. Amount and comparison of energy consumption in different modes before and after application of energy consumption reduction solutions in the 4 climates

Energy type (MJ)	A	B	A-B	SEM	P
Specific consumption of thermal energy per kilogram of pure meat	24.15	11.66	12.49	2.451	<0.001
Specific consumption of electrical energy per kilogram of pure meat	1.81	1.64	0.16	0.035	<0.001
Total specific energy consumption including usable chicken metabolic heat	22.68	9.75	12.93	3.009	0.002
Specific usable metabolic energy	10.60	7.42	3.18	0.532	<0.001
Total energy	25.96	13.31	12.65	2.455	<0.001

A: Before applying energy reduction solutions, B: After applying energy reduction solutions, and A-B: The difference between before and after applying energy reduction solutions.

DISCUSSION

According to the results, the consumption of energy in broiler farms in all but the hottest climates was significantly reduced by energy consumption reduction solutions; a significant reduction in energy consumption was observed in cold, dry and temperate climates. The trend towards reduction in average energy consumptions in the hot climate is also suggestive of a possible benefit of consumption reduction solutions in hot climates as well. Attia *et al*. (2016) identified that energy costs are the most important and major part of the capital required for broiler farms. They said the electricity and fuel needed to warm up the houses in a broiler farm could account for up to 60 percent of the cost. According to their results, improving the insulation of broiler houses enables them to be heated more efficiently in cold areas and to be cooled more efficiently in the warm seasons, which would also save energy, in agreement with the present study. According to the results, management practices using reduction solutions reduced the thermal and electrical energy consumption significantly, which is consistent with Amini *et al*. (2015).

Amini *et al*. (2015) reported that modern heat generation systems and correct insulation are important management tools to control the environmental parameters of the houses. In addition to controlling temperature and humidity, these systems also provide fresh air and removing harmful gases from the houses. This can lead to economic efficiency by saving energy and improving the health of the broilers. Constantino *et al*. (2018) examined energy efficiency as well as its consumption in different parts of the warm climate and concluded that by carefully choosing an insulation system to prevent heat loss, fuel consumption is reduced and energy efficiency can be improved, which is consistent with the present study.

In the present experiment, the use of energy-saving lamps and proper management in the lighting of houses reduced electrical energy consumption, which is consistent with Nabavi-Pelesaraei *et al*. (2013b) and Zhang (2015). Nabavi-Pelesaraei *et al*. (2013b), examined broiler farms and concluded that using solutions such as consumption management by using energy-saving lamps for lighting can greatly reduce electrical energy consumption. Zhang (2015) reported that one of the factors in reducing electricity consumption is adjusting lighting in the houses according to the age of the chickens and hens, which can be achieved after the first week of rearing chickens using energy-saving lamps and planning correct lighting in the broiler houses.

Baughman & Parkhurst (1977) examined energy consumption in two broiler houses in North Carolina (one with insulation and a modern heating system and the other without insulation and with a traditional heating system) and stated that house under control (with insulation and a modern heating system) consumed less energy to produce the same weight of meat produced in traditional houses (without insulation and with curtain walls). In the present experiment, one of the ways to reduce thermal energy consumption was to use underfloor heating systems in broiler houses. Some researchers say that the use of new heating equipment under the floor of poultry houses (hydraulic heating system), in addition to lower fuel consumption, improves the air in the houses and thus reduces the incidence of respiratory diseases compared to conventional and old heating systems (Baxevanou *et al*., 2017; Atilgan and Hayati, 2006).

Tabler (2007) and Jahedi and Zarei (2020) reported that underfloor heating systems, in which radiant heat transfer contributes greatly to the warming process, compared to other thermal systems, have many strengths not only in saving and optimizing energy consumption but also in terms of thermal wellbeing and comfort because it distributes heat evenly throughout the rearing surface and space and prevents the emission of carbon monoxide and carbon dioxide into the house. The results showed that energy efficiency optimization solutions can reduce the specific consumption of thermal and electrical energy per kilo of pure meat. Oderkirk (2009) also concluded that any factor that can reduce energy consumption per kilo of meat production will definitely lead to better economic performance in production.

Oderkirk (2009) and Gholami *et al*. (2020) reported that environmental factors in different climates can affect the economic performance of broiler farms because the poultry industry is one of the most sensitive and energy-consuming industries so that decreasing or increasing any factors such as temperature and climate conditions have a great impact on the production and losses of poultry. Hence, the accurate control of energy consumption has a very high priority. They also stated that by optimizing thermal and electrical energy consumption, the increase in per capita cost of production in the poultry sector could be prevented because fossil fuels and electricity consumption are the important and costly factors in the poultry industry, which directly affect the cost of production.

The results showed that the highest amount of energy consumption was in thermal energy, which was higher in cold and dry climates than in hot and temperate climates. The application of reduction solutions reduced thermal energy consumption by more than 50% in cold and dry climates. Some researchers have found that the cold weather and very cold nights in the desert and dry conditions of cold climates increase the consumption of thermal energy to create optimal temperature conditions inside the rearing houses (Qotbi *et al*., 2001; Simmins *et al*., 1997). Also, the results of some research show that if energy consumption optimization solutions are applied in cold and dry areas during the rearing period, a significant reduction in the energy consumption trend will occur, which is consistent with the present study (Hemmati *et al*., 2013).

CONCLUSION

The amount of energy measured before and after the application of energy consumption optimization solutions in the poultry farms studied in the present study shows that energy efficiency requires knowledge of equipment and awareness of the architectural structure of rearing houses as well as of their energy consumption pattern. Significant reductions of energy consumption in rearing houses observed as a result of reducing the loss of electrical and thermal energy due to lighting management of houses, improvements in building insulation, and installation of a modern heating system. Therefore, according to this study, better management can reduce energy costs and the consumption of capital in this area, resulting in more product for less cost.

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