Field study on effects of a heat exchanger on broiler performance, energy use, and calculated carbon dioxide emission at commercial broiler farms, and the experiences of farmers using a heat exchanger

E. A. M. Bokkers,*[1] H. H. E. van Zanten,*† and H. van den Brand†

*Animal Production Systems Group, and †Adaptation Physiology Group, Wageningen Institute of Animal Sciences, Wageningen University, PO Box 338, 6700 AH, Wageningen, the Netherlands

ABSTRACT In broiler houses, ventilation removes moisture and maintains ambient temperature and air quality. During cold weather conditions, ventilation can result in undesirable heat loss from the house. Extra input of energy for heating the building is needed then, resulting in extra CO_2 emissions when fossil fuels are used for this purpose. In such a situation, an air-to-air heat exchanger (HE) might be valuable because it recovers heat by prewarming fresh supply air with warm inside air. The aim of this study was to analyze effects of on-farm use of an HE on broiler performance, energy use, and CO_2 emission by comparing production cycles with and without an HE, and to inventory the experiences of farmers using an HE. Data were collected of production cycles finished with (102) or without (149) an HE on 25 farms. Data on mortality, feed intake, water intake, and BW gain were obtained to analyze broiler performance. When available, gas and electricity use were obtained to analyze energy use and to calculate CO_2 emission. Farmers were interviewed about their experiences regarding the HE. The use of an HE tended to increase daily weight gain (56 vs. 55, SEM 0.3 g/d; $P = 0.07$), but did not affect other performance variables. Based on 13 farms, gas use was reduced by 38% ($P < 0.01$) after installing an HE. Based on 3 farms only, an HE did not affect electricity use, total energy use, or calculated CO_2 emission. It appeared that farmers were satisfied with the HE because they experienced an increase in job satisfaction, an improvement of climate conditions and litter quality in the broiler house, and a more uniform temperature and broiler distribution in the house. We concluded that the use of an HE reduced gas use and has the ability to improve broiler weight gain but had no effect on other broiler performance variables. Effects on CO_2 emission were unclear. Farmers appeared to be positive about using an HE, because it improved broiler house climate and job satisfaction.

Key words: broiler performance, CO_2 emission, energy use, farmer experience, heat exchanger

2010 Poultry Science 89:2743–2750
doi:10.3382/ps.2010-00902

INTRODUCTION

Broiler performance is directly influenced by environmental conditions (May et al., 2000; Feddes et al., 2003; Simmons et al., 2003; Jones et al., 2005; Blahová et al., 2007). Although the exact thermoneutral zone of broilers at different ages is not well known (Chepete and Xin, 2002), too-high and too-low ambient temperatures (**T_a**) in combination with insufficient air velocity in broiler houses can have a negative effect on, for example, BW gain (**BWG**), feed efficiency, health, and mortality rate (May et al., 2000; Heier et al., 2002; Baarendse et al., 2006; Blahová et al., 2007; Akşit et al., 2008). Because heat production increases with age, T_a needs to be lowered over time (Chepete and Xin, 2002); T_a and humidity in broiler houses tend to be too low in wk 1 and too high in the latter half of the production cycle (Jones et al., 2005). The main function of ventilation is to remove moisture and keep the litter in good condition. By ventilating, however, T_a, air velocity, and air quality can be affected. Ventilation is therefore a key factor in controlling climate conditions in a broiler house (Jones et al., 2005). The temperature of the incoming air depends on the outside temperature; when the outside temperature is low, cold air enters the house. This results in a lower T_a, which may lead to cold stress unless heat loss is compensated for with extra heating. Extra heating, however, results in higher energy use because of the combustion of fossil fuels, which in turn increases emissions of the greenhouse gas CO_2 and thus contributes to global warming (Bokkers and de Boer, 2009).

Instead of extra heating, ventilation may be lowered when the outside temperature is low. However, this may

Received May 19, 2010.
Accepted September 6, 2010.
[1]Corresponding author: eddie.bokkers@wur.nl

result in poor climate conditions for broilers (high T_a, and increased levels of dust, CO_2, and humidity; Savory, 1995). It also can cause an unequal movement of temperature and air throughout the house, resulting in unequal distribution of broilers and poor litter conditions (Weaver and Meijerhof, 1991; Wheeler et al., 2003). Poor litter conditions are associated with an increased occurrence of contact dermatitis and reduced carcass quality (Weaver and Meijerhof, 1991; Haslam et al., 2006).

To overcome the discrepancy between optimized broiler house conditions by ventilation and reduced energy use to heat the house during periods of low outside temperatures, a heat exchanger (**HE**) might be valuable equipment. An HE recovers heat that is normally lost in exhausted ventilation air by prewarming the fresh supply air (Selders et al., 1989; Kennedy et al., 1991). In this way, it is possible to increase the ventilation rate without causing a decrease in T_a in a broiler house. Hence, air speed can be higher, T_a and air distribution might be more uniform in the broiler house, and air quality at the broiler level might be improved. Previous experimental studies on the effect of an HE showed that an HE improved broiler performance and reduced gas use (Selders et al., 1989; Kennedy et al., 1991). Effects of an HE under field conditions, however, have not been thoroughly investigated. Furthermore, experiences of farmers with an HE and the consequences for total energy use and CO_2 emissions are not described to our knowledge. The present study investigated all these aspects using field data obtained from commercial broiler farms.

MATERIALS AND METHODS

Data for this study were obtained from 21 farms in the Netherlands, 3 farms in Belgium, and 1 farm in Germany. All farms were equipped with the Agro Clima Unit HE (Agro Supply B.V., Eersel, the Netherlands), which was installed in 2007 or 2008. The Agro Clima Unit is an air-to-air HE with counterflow generated by 2 built-in fans. Two additional circulation fans were installed in the ridge of each broiler house to create uniform distribution of air throughout the house. The maximum airflow capacity of the HE was 0.35 m^3/h per broiler. Agro Supply B.V. advises farmers to ventilate via the HE only during the first 12 d of life using about 20% of the capacity of the HE for 1-d-old broiler chicks and increasing to 100% at about 12 d. Thereafter, additional conventional ventilation is needed, and the capacity of the HE is lowered gradually to about 75% in a few days and continues at that level until the birds are removed from the house. Farmers in the study indicated that they followed these recommendations. The number of houses with an HE varied from 1 to 5 per farm; in total, 37 HE were installed. The same researcher visited all farmers once in February or March 2009. Farmers were interviewed to collect data on their experiences related to the HE. Furthermore, data on broiler performance and energy use were collected, aiming for 7 production cycles before and 7 production cycles after an HE was installed. Data of production cycles of house(s) without an HE, but with a similar design and dimensions as the house(s) with an HE were also collected at these farms over the same period. For this study, a production cycle was defined as a group of broilers delivered from the same hatchery and housed in the same broiler house until they were brought to the slaughterhouse.

Broiler Performance

To analyze effects of an HE on broiler performance, the following data were collected per production cycle: starting date, slaughter age, number of broilers at start, breed, mortality per d, feed intake per day, water intake per day, number of broilers slaughtered, kilograms of meat delivered at the slaughterhouse, feed supplier, and hatchery. Furthermore, broiler house characteristics—construction year, ventilation type, floor type, and floor surface of the broiler house (m^2)—were recorded.

Energy Use

To analyze effects of an HE on total energy use (MJ), data on gas and electricity use per broiler house per production cycle were collected. Gas use per production cycle (MJ) was calculated from heating hours per day, gas use of the heater (m^3/h), and type of combusted gas. The type of combusted gas was Dutch natural gas with a heating value of 31.65 MJ per m^3 (Heslinga and van Harmelen, 2006) or propane with a heating value of 25.3 MJ/L (see http://www.propanegas.ca/FileArea/PGAC/Propane%20properties.pdf; accessed October 2010). Electricity use (1 kWh = 3.6 MJ) per house included not only electricity for ventilation but also that used for lights and computers. Because the weather has a direct effect on gas use, the outside temperature was obtained from the Royal Dutch Meteorological Institute (http://www.knmi.nl). Nine weather stations in the Netherlands provided information on daily temperatures for the last 3 yr. The nearest weather station was used to obtain daily temperatures for each farm. Average outside temperature during a production cycle was used to analyze the effect of outside temperature on energy use.

CO_2 Emission

Both the combustion of natural gas or propane for heating and the generation of electricity (e.g., for ventilation) contribute to the greenhouse effect because CO_2 is emitted. To be able to analyze effects of an HE on CO_2 emission, the contributions of combusting gas or propane and use of electricity to CO_2 emissions were computed. When Dutch natural gas is combusted, 0.056 kg of CO_2 per MJ is generated (Heslinga and van Harmelen, 2006). When propane is combusted, 0.060 kg of CO_2 per MJ is generated (see http://www.propanegas.ca/FileArea/PGAC/Propane%20properties.pdf). For generating electricity, 0.17 kg of CO_2/MJ is emitted on average in the Netherlands (SimaPro, LCA software, Amersfoort, the Netherlands). With these values and data on natural gas, propane, and electricity used, total CO_2 emissions per production cycle were computed per 100 broilers.

Experiences of Farmers

Farmers were interviewed to analyze their experiences with the use of an HE at their farms. The questionnaire consisted of 35 multiple-choice questions (Likert scale) and 1 open question. Questions were divided in 8 subsections: general statements, climate control in broiler houses, litter quality, animal health, animal activity, broiler performance, energy use, and reasons for buying an HE.

Statistical Analyses

All statistical analysis were performed with the statistical software program SAS (version 9.4, 2004; SAS Institute Inc., Cary, NC). Model assumptions were checked by examining the distributions of means and residual. Unless indicated, variables met assumptions of normality. Production cycles before and after installing an HE in a house, and production cycles of comparable houses at 1 farm with or without an HE were pooled. Broiler performance, energy use, and CO_2 s were analyzed using generalized linear regression with the fixed factors farm and HE. Body weight gain per day (g); feed conversion ratio (**FCR**); cumulative mortality at d 3, 7, 14, and total mortality (%); cumulative feed intake (kg) per broiler at d 3, 7, and 14; and cumulative water intake per broiler at d 3, 7, 14 and total water intake (L) were analyzed to evaluate broiler performance. Body weight gain per day was obtained by dividing average BW of broilers at delivery at the slaughterhouse (kg) by the slaughter age of broilers (d) × 1,000. Feed conversion ratio was obtained by dividing the amount of provided feed (kg) during the production cycle by the total BW of all broilers at delivery at the slaughterhouse (kg). Data on cumulative mortality were not normally distributed and were analyzed after an angular transformation.

Gas use per meter squared of the surface of a broiler house per week, total gas use per meter squared, total electricity use per meter squared, and total energy use per meter squared were analyzed to evaluate energy use per production cycle. Total gas use (heating hours × gas use of heater per hour × MJ per gas type) plus total electricity use (used kWh × MJ per kWh of electricity) resulted in total energy use. Total energy use was based on data from farms that supplied both gas use and electricity use per production cycle. The average outside temperature during a production cycle per farm was used as a covariate when energy use was analyzed. Besides on-farm energy use, on-farm CO_2 emissions based on gas use (natural gas or propane) and electricity use were analyzed per production cycle.

Values are expressed as least squares means (±SEM). In case of mortality data, least squares means values from original data are presented, whereas P-values are given for the analysis with transformed data. Use of an HE and farm effect were analyzed for significance at $P < 0.05$.

The experiences of farmers were analyzed using a χ^2 test for uniformity. When a significant effect appeared, pairwise comparisons were analyzed with a binomial test. As a response to the open question, farmers could give arguments for buying an HE. The number of times one particular argument was given was counted to quantify the data and used for analysis.

RESULTS

Farm Characteristics

In total, 251 production cycles (102 with HE, 149 without HE) were included in this study. Experience of a farmer with an HE differed from 1 to 9 production cycles. In 87% of all production cycles, Ross broilers were grown. Other broilers that were grown were Cobb (12%) and Hybro (1%). The oldest broiler house was built in 1981 and the newest broiler house was built in 2008. Thirty-nine percent of the production cycles were finished in broiler houses with an insulated floor and 61% with a noninsulated floor. Forty percent of the production cycles were finished in broiler houses that had roof ventilation, 16% that had backwall ventilation, and 44% had a combined ventilation system. The total surface of the broiler house varied between 885 and 2,000 m^2, whereas stocking density varied between 19 and 27 broilers per m^2, with an average of 22 broilers per m^2 at the start of the production cycle. Broiler feed was obtained from 7 different feed suppliers, and 1-d-old chicks were obtained from 8 different hatcheries. All farmers used direct (i.e., exhaust gases were emitted within the house) gas heaters to warm up the broiler houses; propane heaters were used in 39% of the broiler houses and natural gas heaters in 61% of the broiler houses.

Broiler Performance

Eighteen farmers provided data of production cycles with and without an HE. The number of available data of production cycles varied per variable (Table 1). A significant farm effect was found for cumulative feed intake after 3 and 7 d, total water intake, BWG, and FCR. The use of an HE tended to increase BWG ($P = 0.07$) but had no effect on other performance variables.

Energy Use

Thirteen farms provided data that were useful to analyze total gas use per production cycle. Total gas use per m^2 was reduced by 38% (25.7 MJ) per production

Table 1. Effect of a heat exchanger (HE) on broiler performance (least squares means)

	n		HE			P-value	
Item	Farm	PC[1]	With	Without	SEM	HE	Farm
Cumulative mortality (%)							
Day 3	9	76	0.70	0.68	0.08	0.70	0.12
Day 7	12	137	1.19	1.19	0.10	0.89	0.08
Day 14	10	78	1.82	1.81	0.17	0.83	0.14
Total	16	171	4.14	3.56	0.30	0.16	0.15
Cumulative feed intake (kg/bird)							
Day 3	6	51	0.07	0.07	0.00	0.63	<0.001
Day 7	6	53	0.18	0.19	0.00	0.72	<0.05
Day 14	6	53	0.57	0.59	0.01	0.40	0.08
Cumulative water intake (L/bird)							
Day 3	6	50	0.11	0.11	0.01	0.38	0.09
Day 7	6	52	0.34	0.34	0.02	0.94	0.46
Day 14	6	52	1.06	1.06	0.03	0.95	0.46
Total	6	52	6.54	6.61	0.13	0.70	<0.01
BW gain (g/d per bird)	10	146	55.97	54.98	0.34	0.07	<0.01
Feed conversion ratio	8	108	1.73	1.75	0.01	0.38	<0.05

[1]PC = production cycle.

cycle when using an HE (upper part of Table 2). Four farmers were able to provide gas use data per week. Although gas use per m^2 was reduced in all weeks, a significant reduction (72%) was found only in wk 3 and a trend (24%) in wk 1. A farm effect was found for gas use in wk 1 and over the total production cycle.

Three farms provided enough detailed data to be able to calculate gas use and electricity use of production cycles with and without an HE (lower part of Table 2). For these 3 farms, no effect of the HE was found for gas use, electricity use, or total energy use. However, a farm effect for total energy use was found.

CO_2 Emissions

For 13 farms, CO_2 emissions due to gas combustion could be computed. Emission of CO_2 was reduced significantly (30%) in production cycles that used an HE (Table 3, upper part) compared with production cycles without an HE.

For 3 farms, total CO_2 emissions per production cycle could be calculated because these farmers were able to provide both electricity and gas use per production cycle. Emission of CO_2 due to gas combustion tended to be reduced using an HE (33%; $P = 0.05$), whereas CO_2 emission due to electricity use and total CO_2 emissions were not affected when using an HE (lower part of Table 3). A significant farm effect was found for CO_2 emission due to gas combustion and total CO_2 emission (Table 3).

Experiences of Farmers

General Statements. Twenty-four farmers were interviewed. Since installation of the HE, job satisfaction of 83% of the farmers increased (Table 4). For 83% of the farmers expectations about the HE were fulfilled, and 83% were satisfied with the way the HE functioned. Noise pollution due to the HE was not experienced by 88% of the farmers and 67% of the farmers thought that the HE did not made the barn less attractive (i.e., appearance of the HE was acceptable). According to 88% of the farmers, broiler house climate was improved after the HE was installed, and 75% thought that temperature and air circulation were more uniformly distributed in the broiler house. According to 83% of the

Table 2. Effect of a heat exchanger (HE) on gas use, electricity use, and total energy use (least squares means)

	n		HE			P-value	
Item	Farm	PC[1]	With	Without	SEM	HE	Farm
Farms that provided gas use only							
Gas use (MJ/m^2)							
Week 1	4	35	24.2	31.8	0.4	0.06	<0.05
Week 2	4	35	6.1	17.9	0.1	0.15	0.39
Week 3	4	31	0.8	2.9	0.1	<0.05	0.09
Week 4	4	29	1.1	2.1	0.5	0.40	0.71
Week 5	4	22	1.6	2.1	0.4	0.60	0.48
Total	13	145	41.8	67.6	4.8	<0.01	<0.01
Farms that provided gas and electricity use							
Gas use (MJ/m^2)	3	35	29.4	40.7	2.0	0.17	0.11
Electricity use (MJ/m^2)	3	35	10.1	7.8	0.1	0.40	0.17
Total energy use (MJ/m^2)	3	35	39.5	48.5	0.9	0.10	<0.05

[1]PC = production cycle.

Table 3. Effect of a heat exchanger (HE) on CO_2 emissions due to on-farm gas and electricity use expressed in kilograms of CO_2 per 100 broilers (least squares means)

	n		HE			*P*-value	
Item	Farm	PC[1]	With	Without	SEM	HE	Farm
Farms that provided gas use data only							
Gas (kg of CO_2)	13	124	11.5	16.6	1.0	<0.01	<0.001
Farms that provided gas and electricity use data							
Gas (kg of CO_2)	3	34	7.0	10.5	0.6	0.05	<0.05
Electricity (kg of CO_2)	3	34	8.1	5.4	0.9	0.17	0.06
Total (kg of CO_2)	3	34	15.1	15.9	0.3	0.21	<0.01

[1]PC = production cycle.

farmers, litter quality had improved since the installation of the HE. Opinions among farmers were divided with respect to recovering the initial costs within 5 yr (a selling point of the HE supplier), user-friendliness related to climate control, and ability to clean the HE.

Broiler Health. Since installation of the HE, 58% of the farmers observed no difference in the number of broilers with respiratory problems, whereas 42% of the farmers observed a decrease (Table 5). The farmers observed no differences in the number of broilers with bacterial infections (67%), coccidiosis (71%), or nasal discharge (63%). Of the farmers, 63% observed a decrease in the number of dirty broilers, whereas 37% of the farmers observed no differences. A decrease in the number of broilers with contact dermatitis was observed by 54% of the farmers, whereas no differences were observed by 46% of the farmers. In addition, 63% of the farmers observed a reduction in medicine use, but 33% did not observe any difference.

Broiler Activity. According to 58% of the farmers, broilers were more active in wk 1 and wk 2 when an HE was installed, whereas 37% of the farmers observed no differences. No difference in broiler activity from wk 3 to 6 was observed by 83% of the farmers. Eighty-eight percent of the farmers observed that broilers were more equally distributed across the house.

Broiler Performance. Based on the farmer interviews, no differences in FCR were observed by 71% of the farmers. Most farmers indicated no differences for the number of broilers that died from wk 1 to wk 2 (71%), from wk 3 to wk 4 (91%), and from wk 5 to wk 6 (91%) following installation of the HE. Slaughter weight of broilers remained the same according to 54% of the farmers, whereas an increase in slaughter weight was observed by 46% of the farmers.

Litter Quality. Seventy-five percent of farmers observed an improvement in litter quality during wk 1 and wk 2, whereas 25% of the farmers thought it remained the same following installation of the HE. An improvement in litter quality from wk 3 to wk 4 was observed by 54% of farmers, whereas no differences were observed by 46% of the farmers. Of the farmers interviewed, 71% observed an increase in litter quality from wk 5 to wk 6.

Climate Control. Sixty-three percent of farmers noted that the HE had a positive effect on controllability of T_a in broiler houses. Of the farmers who measured CO_2 on a regular basis (n = 17), 82% noted a decrease in CO_2 concentration in the house after installing the HE. Opinions among farmers varied on the effect of the HE on dust in broiler houses.

Energy Use. One farmer thought that the number of heating hours in a broiler house with an HE was reduced by between 11 and 20%. Four farmers thought they achieved a reduction between 21 and 30%, 6 farmers between 31 and 40%, 9 farmers between 41 and 50%, 3 farmers between 51 and 60%, and 1 of more than 60%.

Reason for Buying the HE. In response to the open question, all farmers responded that the most impor-

Table 4. Responses to general questions concerning a heat exchanger (HE) asked of farmers that purchased an HE (n = 24)

Question	Disagree	Neutral	Agree
Job satisfaction of farmer increased because of the HE	1^b	3^b	20^a
My expectations about the HE are not fulfilled	20^a	0^b	4^b
The HE does not function properly	20^a	2^b	2^b
The HE causes noise pollution	21^a	2^b	1^b
Appearance of the HE is insufficient	16^a	5^b	3^b
Climate in broiler house improved because of the HE	2^b	1^b	21^a
Ambient temperature in broiler house is more uniformly distributed because of the HE	3^b	3^b	18^a
Air circulation is less uniformly distributed because of the HE	18^a	3^b	3^b
Litter quality in broiler house improved because of the HE	2^b	2^b	20^a
In 5 years I recovered the cost of my HE	11	6	7
Complexity related to climate control increased because of the HE[1]	10	4	9
The HE is easy to clean	7	9	8

[a,b]Numbers within a row lacking a common superscript differed ($P < 0.05$).

[1]n = 23.

tant reason to buy the HE was to reduce energy use and thus energy costs. Other important reasons for buying the HE were to improve climate control in broiler houses, litter conditions, and broiler performance.

DISCUSSION

Broiler Performance

This study showed that the use of an HE had no effect on broiler performance variables such as mortality, feed intake, water intake, or FCR, but tended (P = 0.07) to increase average BWG per day (range: −1.35 to 3.59 g/d). Eight farms out of 10 had an increase in average BWG after installing an HE (data not shown), indicating that an HE can have a beneficial effect on growth rate. However, the significant farm effect illustrates that farmers have a greater effect on BWG than does an HE. The sample size was too small to use covariates such as ventilation type, floor type, stocking density, feed supplier, and hatchery, although it is expected that those covariates could affect the results. Heier et al. (2002), for example, concluded that stocking density and the interaction between type of ventilation, drinking system, and floor insulation affected mortality during wk 1. Age of the broiler house and the hatchery affected mortality from wk 2 to 5 (Heier et al., 2002). Considering that some of the farmers had only recently bought the HE at the time data were collected and therefore had little experience with using an HE, the results for broiler performance may improve when the farmer has more experience in working with the HE.

Energy Use

Installation of an HE led to a reduction of total gas use on commercial broiler farms, which is in agreement with the experimental results of Selders et al. (1989) and Kennedy et al. (1991). The average reduction was close to that observed by farmers because most farmers estimated a reduction of gas use between 41 and 50%. Based on data from 4 farms, gas use tended ($P = 0.06$) to be reduced in wk 1 and was reduced in wk 3 when an HE was used. Although based on data of only 4 farms,

Table 5. Responses from farmers on questions related to their experiences with a heat exchanger (HE; n = 24)

	Response		
Questions by topic	Agree	Neutral	Disagree
Broiler health			
No. of broilers with respiratory problems decreased	10[a]	14[a]	0[b]
No. of broilers with bacterial infection decreased	7[a]	16[a]	1[b]
No. of broilers with coccidiosis increased	2[b]	17[a]	5[b]
	Increased	Equal	Decreased
No. of broilers with dirty spots is ...	0[b]	9[a]	15[a]
No. of broilers with contact dermatitis is...	0[b]	11[a]	13[a]
Amount of medicines used is...	1[b]	8[a]	15[a]
No. of broiler with nasal discharge is ...	0[b]	15[a]	3[b]
Broiler activity	Increased	Equal	Decreased
Activity of broilers in wk 1 and wk 2 is...	14[a]	9[a]	1[b]
Activity of broilers in wk 3 and wk 4 is...	3[b]	20[a]	1[b]
Activity of broilers in wk 5 and wk 6 is...	3[b]	20[a]	1[b]
	More equal	Equal	Less equal
Distribution of broilers is ...	21[a]	3[b]	0[b]
Broiler performance	Increased	Equal	Decreased
Feed conversion ratio of broilers is...	2[b]	17[a]	5[b]
No. of broilers that died during wk 1 and wk 2 is ...	0[b]	17[a]	7[b]
No. of broilers that died during wk 3 and wk 4 is...	0[b]	22[a]	2[b]
No. of broilers that died during wk 5 and wk 6 is...	1[b]	22[a]	1[b]
Slaughter weight of broilers is...	11[a]	13[a]	0[b]
Litter quality	Dryer	Equal	Wetter
Litter quality during wk 1 and wk 2 is ...	18[a]	6[b]	0[c]
Litter quality during wk 3 and wk 4 is ...	13[a]	11[a]	0[b]
Litter quality during wk 5 and wk 6 is ...	17[a]	7[b]	0[c]
Climate control	Easier	Equal	More difficult
Controllability of temperature in broiler houses is...	15[a]	3[b]	6[b]
	Increased	Equal	Decreased
CO_2 level in broiler houses is ...[1]	0[b]	3[b]	14[a]
Dust level in broiler houses is ...	9	9	6

[a–c]Numbers within a row lacking a common superscript differ ($P < 0.05$).

[1]n = 17.

it seems that an HE can contribute to considerably lower gas use during the first weeks of a production cycle. The positive effect of an HE on gas use declined every week, because the required T_a decreased with increasing broiler weight and because conventional ventilators were turned on from wk 3 onward to provide sufficient ventilation capacity. The HE used in this study ventilates 0.35 m^3/h per broiler, which meets the needs until the broilers reach a weight of approximately 350 g at around d 12 (Ross performance objectives; Ross, 2009). When the BW of the broilers increases, the ventilation rate of conventional ventilators increases, resulting in a lower contribution of the HE to climate control. The lower T_a and higher ventilation rate of conventional ventilators when broilers get older explains why the HE did not reduce gas use in wk 4 and 5.

Based on the data from only 3 farms, it seems that an HE had no effect on gas use, electricity use, or total energy use. Nevertheless, examination of the results indicates that the reduction of gas use based on these 3 farms was in agreement with the reduction of gas use of 13 farms after an HE was installed. Electricity use seems to be higher after an HE has been installed, which makes sense because at least 4 extra ventilators are needed when using an HE. Second, an HE makes it possible to increase the ventilation rate because the HE prewarms the outside air before it enters the broiler house, resulting in smaller differences between the outside temperature and T_a (Selders et al., 1989; Kennedy et al., 1991). Climate conditions in broiler houses can be improved by this increased ventilation rate, but it also leads to higher electricity use. Without data from a greater number of farms, it is not possible to give reliable conclusions on the effect of an HE on electricity use and total energy use.

Farmers were positive about the reduction of gas use. Their opinions differed, however, about the expectation that they would recover the initial costs within 5 yr of purchase. The time required to earn back the cost of an HE obviously depends on the ratio between gas and propane prices on the one hand and the electricity price on the other hand. In addition to energy prices, weather conditions, durability of an HE, management of the farmer, and performance of the broilers are important factors that determine final profitability of investing in an HE.

CO_2 Emission

Total calculated CO_2 emission, based on 3 farms, was not reduced significantly. However, the actual reductions per farm were 0.6, 3, and 21.6%. This range suggests some potential for the HE to contribute to CO_2 reduction, but more data from different farms are needed to confirm this. For now, the fact that the production and transport of 1 MJ of electricity results in greater CO_2 emission than the production and transport of 1 MJ by combusting gas affected the results decisively. It has to be kept in mind, however, that CO_2 emission on-farm is the result of direct energy use, which covers only 25% of the total CO_2 emission for broiler production (Spedding et al., 1983). Indirect energy use (e.g., for the cultivation and transport of concentrates) accounts for 70% of CO_2 emission for broiler production (Spedding et al., 1983). Similarly, the production and transport of an HE needs energy and will therefore emit CO_2, which should be taken into account when making an accurate comparison. In addition, CO_2 is not the only greenhouse gas emitted in broiler production. Methane and nitrous oxide are greenhouse gases emitted from manure (CH_4) and from application of fertilizer during cultivation of feed ingredients (N_2O; Bokkers and de Boer, 2009). The total emission of greenhouse gases per 1 kg of live weight of chicken is estimated at 2.0 to 2.3 kg of CO_2 units (IPCC, 2006). A reduction of the total emission of greenhouse gases from broiler production can be achieved only partly on the farm.

Experiences of Farmers

According to the experiences of farmers, an HE improved climate conditions in broiler houses. The improved broiler house climate following installation of an HE was expressed by farmers as a more uniform distributed temperature and air circulation, decreased CO_2 concentration, more equal distribution of broilers, and an improved litter quality. The more uniform temperature and air circulation could be the result of the increased ventilation rate and the extra fans installed at the ridge of the broiler house. The observed decrease in CO_2 concentration after installing an HE could be the result of the higher ventilation rate, improved air circulation, and the decrease in heating hours, because gas heaters emit CO_2 directly in the broiler house. The observed improvement of uniform spread of broilers among the house could be a result of the more uniform temperature and air circulation throughout the broiler house (Wheeler et al., 2003). Farmers observed an improvement in litter quality from wk 1 until wk 6. Poor litter conditions are mostly a result of poor ventilation (Weaver and Meijerhof, 1991; Haslam et al., 2006), which supported the perception of the farmers that the climate in broiler houses was improved. The improved litter quality could explain why some farmers had the perception of fewer dirty broilers, less contact dermatitis, and increased broiler activity. The decrease in the number of broilers with contact dermatitis because of improved litter quality was also found by Haslam et al. (2006) and Meluzzi et al. (2008).

The increased activity of broilers during wk 1 and wk 2 due to improved litter quality, as perceived by farmers, is in agreement with Heier et al. (2002), who stated that a decrease in broiler activity could be caused by a floor that is cold, wet, and drafty due to uneven movement of air throughout the broiler house. This again is in agreement with the perception of farmers who noted an improvement of uniformity of temperature, air circulation, and equal distribution of broilers in the house. The observed increased slaughter weight of broilers tended to be in accordance with the broiler performance based on the data analysis; average daily BWG tended ($P = 0.07$) to be higher in production cycles with an HE. This increased BWG per day could be the result of the improved climate conditions in broiler houses observed by the farmers (see also Reece and Lott, 1980; May et al., 2000; Akşit et al., 2008). Because data from the present study covered more than 1 yr, genetic improvement of the broilers may also have had an effect on increased BWG.

It seems that farmers were satisfied with the purchase of an HE, because they expressed increased job satisfaction and their expectations were fulfilled. Furthermore, they were satisfied with the way an HE functions, almost no noise pollution was experienced, and they thought the appearance of the HE was acceptable. A large number of farmers, however, mentioned that the ability to clean the HE satisfactorily was limited, which is a major factor in accepting an HE as a functional piece of equipment (Selders et al., 1989; Kennedy et al., 1991). Farmers' experiences about the effect of an HE were largely in accordance with analyzed data. Farmers observed an effect of an HE on broiler performance and observed a reduction in gas use, which was in agreement with the provided data on gas use.

Based on the field data collected and analyzed for this study, we concluded that the use of an HE reduces gas use and has the ability to improve broiler weight gain. It appears, however, to have no effects on other broiler performance variables, and effects on total CO_2 emission are unclear. Farmers were generally positive about using an HE at their farm, because it improved the broiler house environment and job satisfaction of the farmer.

ACKNOWLEDGMENTS

We thank Victor van Wagenberg and Lotte van de Ven from Agro Supply B.V. (Eersel, the Netherlands) and Vencomatic (Eersel, the Netherlands) for their help and support during this study and the farmers for participating in this study. Imke de Boer from the Animal Production Systems Group of Wageningen University is acknowledged for critical reading of an earlier version of the manuscript and for her advice concerning environmental effects related to the use of a heat exchanger.

REFERENCES

Akşit, M., Ö. Altan, A. B. Karul, M. Balkaya, and D. Özdemir. 2008. Effects of cold temperature and vitamin E supplementation on oxidative stress, Troponin-T level, and other ascites-related traits in broilers. Arch. Geflugelkd. 72:221–230.

Baarendse, P. J. J., B. Kemp, and H. van den Brand. 2006. Early-age housing temperature affects subsequent broiler chicken performance. Br. Poult. Sci. 47:125–130.

Blahova, J., R. Dobsikova, E. Strakova, and P. Suchy. 2007. Effect of low environmental temperature on performance and blood system in broiler chickens (*Gallus domesticus*). Acta Vet. (Brno) 76:17–23.

Bokkers, E. A. M., and I. J. M. de Boer. 2009. Economic, ecological, and social performance of conventional and organic broiler production in the Netherlands. Br. Poult. Sci. 50:546–557.

Chepete, H. J., and H. Xin. 2002. Heat and moisture production of poultry and their housing systems: Literature review. Am. Soc. Heat., Refrig. Air Cond. Eng. Trans. 108:448–466.

Feddes, J. J. R., E. J. Emmanuel, M. J. Zuidhof, and D. R. Korver. 2003. Ventilation rate, air circulation, and bird disturbance: Effects on the incidence of cellulitis and broiler performance. J. Appl. Poult. Res. 12:328–334.

Haslam, S. M., S. N. Brown, L. J. Wilkins, S. C. Kestin, P. D. Warriss, and C. J. Nicol. 2006. Preliminary study to examine the utility of using foot burn or hock burn to assess aspects of housing conditions for broiler chicken. Br. Poult. Sci. 47:13–18.

Heier, B. T., H. R. Hogasen, and J. Jarp. 2002. Factors associated with mortality in Norwegian broiler flocks. Prev. Vet. Med. 53:147–158.

Heslinga, D. C., and A. K. van Harmelen. 2006. Vastellingsmethodieken voor CO_2-emissiefactoren van aardgas in Nederland. [Verifying methods for CO_2 emission factors of natural gas in the Netherlands]. TNO-report 2006-A-R0079/B. TNO, Apeldoorn, the Netherlands.

IPCC. 2006. Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories. Accessed June 2010. http://www.ipcc-nggip.iges.or.jp/publicgl/index.htm.

Jones, T. A., C. A. Donnelly, and M. Stamp Dawkins. 2005. Environmental and management factors affecting the welfare of chickens on commercial farms in the United Kingdom and Denmark stocked at five densities. Poult. Sci. 84:1155–1165.

Kennedy, D. A., J. J. Leonard, and J. J. Feddes. 1991. Field test of a PVC plate heat exchanger for animal housing. Appl. Eng. Agric. 7:457–460.

May, J. D., B. D. Lott, and J. D. Simmons. 2000. The effect of air velocity on broiler performance and feed and water consumption. Poult. Sci. 79:1396–1400.

Meluzzi, A., C. Fabbri, E. Folegatti, and F. Sirri. 2008. Survey of chicken rearing conditions in Italy: Effects of litter quality and stocking density on productivity, foot dermatitis and carcass injuries. Br. Poult. Sci. 49:257–264.

Reece, F. N., and B. D. Lott. 1980. Effect of carbon dioxide on broiler chicken performance. Poult. Sci. 59:2400–2402.

Ross. 2009. Broiler performance objectives: Ross 308. Accessed June 2009. http://67.20.64.230/ss/assets/Tech_Center/Ross_Broiler/Ross_Broiler_Manual_09.pdf.

Savory, C. J. 1995. Broiler welfare: Problems and prospects. Arch. Geflügelkd. Special Issue:48–52.

Selders, A. W., G. H. Carpenter, and D. J. Workman. 1989. Prototype broiler house heat exchanger performance. Appl. Eng. Agric. 5:589–594.

Simmons, J. D., B. D. Lott, and D. M. Miles. 2003. The effects of high-air velocity on broiler performance. Poult. Sci. 82:232–234.

Spedding, C. R. W., A. M. M. Thompson, and M. R. Jones. 1983. Energy and economics of intensive animal production. Agro-ecosystems 8:169–181.

Weaver, W. D., and R. Meijerhof. 1991. The effect of different levels of relative humidity and air movement on litter conditions, ammonia levels, growth, and carcass quality for broiler chickens. Poult. Sci. 70:746–755.

Wheeler, E. F., J. L. Zajaczkowski, and N. C. Sabeh. 2003. Field evaluation of temperature and velocity uniformity in tunnel and conventional ventilation broiler houses. Appl. Eng. Agric. 19:367–377.