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Impact of direct and indirect heating systems in broiler units on environmental conditions and flock performance

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Abstract
This study compared the impact of three indirect heating systems to direct gas flame heaters on a selection of flock performance and environmental indicators in commercial broiler units. No statistically significant differences ($P \geq 0.05$) were found in flock mortality rates, bird weight, water consumption, stress response, carbon dioxide, ammonia, temperature, relative humidity, litter quality, within-flock *Campylobacter* levels or mean *Campylobacter* counts when flock data from any of the three indirect heating systems were compared to flocks reared in houses with direct heating systems. Differences in litter quality were observed between upper and lower litter layers in all houses, regardless of heating type, which may have implications for bird health and welfare. Carbon dioxide concentrations in houses with direct heating systems were significantly higher than those in houses with indirect heating systems during the first 10 days of bird life ($P \leq 0.05$). This was due to the increased use of heating systems during this period of the flock cycle. Differences in CO_2 concentrations had no effect on flock performance, possibly due to the fact that concentrations did not exceed known safe levels. A statistically significant increase in stress response was observed in birds as a result of partial depopulation (thinning) within houses, irrespective of heating system type used ($P \leq 0.05$). Stress associated with thinning may have consequences for bird welfare and food safety. In conclusion, the results of our study suggest that indirect heating systems do not appear to negatively impact on flock performance, stress response, within-flock *Campylobacter* levels or mean *Campylobacter* counts and do not appear to significantly alter environmental conditions within broiler houses when compared to houses equipped with direct heating systems. Indirect systems are a viable alternative for heating broiler houses in terms of flock performance, bird welfare and food safety.

Keywords: litter quality, welfare, stress, poultry production, campylobacter, environmental conditions

1. Introduction

In recent years with increasing energy costs, the broiler industry has sought to assess the potential efficiency of indirect heating systems for broiler houses. Several indirect heating systems have been developed and available as alternatives to conventional gas heating systems. However, there is little knowledge of the impact that any indirect heating system could have on flock performance, bird welfare and food safety.

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At present, broiler houses in Ireland are equipped with direct gas heating systems which consist of open gas burners and a fan that blows heat from the flame directly into the broiler house. These direct heaters produce high concentrations of carbon dioxide (CO_2) and moisture. Prolonged exposure to high concentrations of CO_2 may affect weight gain in birds (Reece and Lott 1980). Increased air moisture content can react with faeces resulting in increased ammonia production which may impact negatively on bird welfare (Estevez 2002). Environmental conditions within broilers houses can significantly impact on stress levels within flocks (Humphrey 2006) and may adversely affect flock performance. Stress may also be an important consideration for *Campylobacter* transmission given that a previous study demonstrated increased stress in chickens induced by transportation resulted in higher levels of *Campylobacter* shedding in faeces (Whyte *et al.* 2001).

Indirect systems heat and transfer air into houses without additional CO_2 and water vapour. As a result, manufacturers claim indirect heating systems could improve environmental conditions by reducing CO_2 concentrations, moisture and ammonia within broiler houses when compared with direct heating systems. The objectives of the current study were to evaluate the impact of broiler house heating systems on (i) flock performance (mortality and weight gain), (ii) environmental conditions within the house (carbon dioxide (CO_2), ammonia (NH_3), and relative humidity (RH), litter quality), (iii) bird stress responses, and (iv) *Campylobacter* flock levels.

2. Materials and methods

2.1. Farm selection

Three multi-house broiler farms (farms A, B and C) located in Counties Cavan and Monaghan in Ireland were selected for the study. Each farm was a contracted grower for a large integrated broiler processing company stocked with Ross 308 birds (Aviagen, Midlothian, Scotland). Farm A consisted of four broiler houses each with a capacity of approximately 35 000 birds. Three houses were equipped with direct gas heating systems. The fourth house on farm A was equipped with a "Cubo" heating system (Choretime, United States). In the "Cubo" system, air was heated indirectly by a gas-fired water heat exchanger located within the house. The heated air was distributed *via* a centrifugal fan. Combustion fumes were exhausted to the exterior of the house. This system recycled air within the broiler house by drawing warm air from the upper air space, reheating it and then distributing it back out at floor level within the house (Fig. 1-A).

Farm B consisted of five broiler houses each with capacity of approximately 28 000 birds. Four houses were heated using the direct fan-assisted gas heating type system. The fifth house on Farm B had a "Blackheat" system installed (Robert's Gordon, United States). Combustion of gas took place within a single steel duct running along the top of the house. The house was then heated by radiant heat from the steel duct and the fumes were exhausted to the outside (Fig. 1-B).

Farm C consisted of three broiler houses each with a capacity of 27 000 birds. Two houses had direct gas heating systems, while the third house was heated *via* a "Wood Pellet" burner (Lee Energy Solutions, United States). The pellet burner was located in a purpose built annex room on the side of the house. Air was passed over the heat exchanger then transferred and distributed within the house *via* an inflatable tube (Fig. 1-C). Farms were sampled from June 2013 until June 2014.

2.2. Flock performance analysis

Production recording sheets were kept for all flocks raised in all six houses during the sampling period. Weight gain, bird mortality rates and water consumption were recorded daily on these sheets.

2.3. Environmental sampling

Carbon dioxide (CO_2) and ammonia (NH_3) concentrations in air within the houses were monitored using a Dräger pump and disposable Dräger tubes as per manufacturer's instructions (Dräger, United Kingdom). Readings were taken at the head height of chickens in order to accurately ascertain the concentrations which birds were exposed to. Readings were taken from two locations along the length of the house to give an average concentration for each house. Two readings were taken for both CO_2 and NH_3 every 3 days for the first 10 days of flock life, then once per week thereafter (Fig. 2). Temperature and relative humidity (%) for each house were recorded on a daily basis using the computerised monitoring systems in the houses.

2.4. Assessment of pH and moisture in the litter

Litter samples were collected at least once every 7 days from four broiler flocks from each of farms A and B and three broiler flocks for farm C over a period of 12 months. Six litter samples were collected from the surface layer at different locations within the house. A further six samples were collected from the bottom layer of the litter 25–75 mm deep once the flock reached 25 days of age (Fig. 2). Litter pH was evaluated *via* pH meter (pH 211 microprocessor pH meter, Hanna Instruments, United Kingdom). Litter moisture (%) was evaluated by weighing 20 g of litter samples then drying the samples in an oven at 100°C for 48 h. Litter samples were then reweighed and litter moisture (%) was calculated.

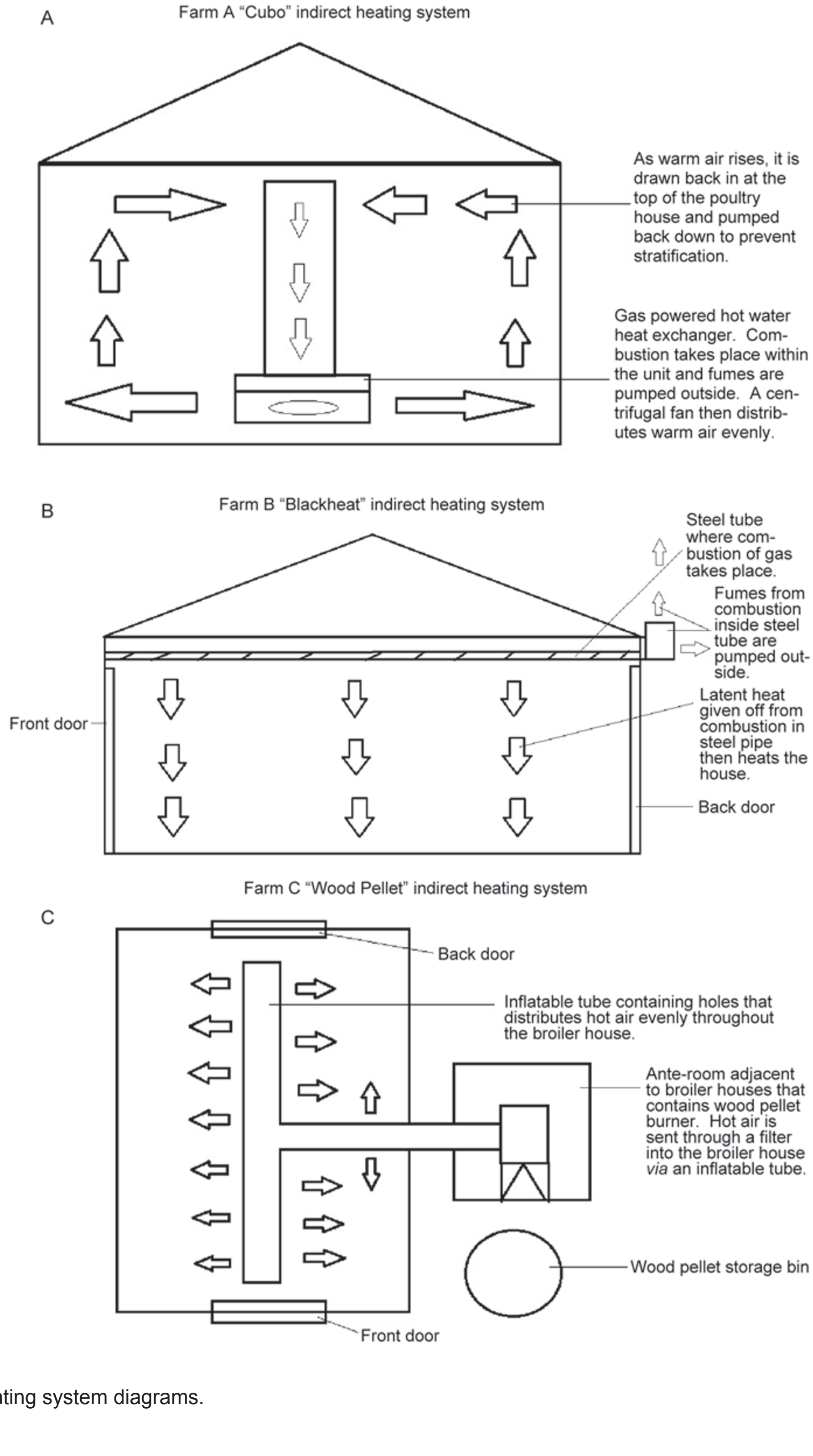

Fig. 1 Indirect heating system diagrams.

2.5. Stress responses

Six blood samples were collected before and after thinning from each broiler flock (farm A, *n*=5; B, *n*=4; C, *n*=3 flocks) in each house. Blood smears were prepared immediately after sampling and stained using Leishmans Stain (Santa Cruz, Germany). The heterophil:lymphocyte ratio was then estimated by counting a total of 100 cells and applying the following formula as previously reported (Gross and Siegel 1983): Number of counted heterophils/Number of counted lymphocytes.

2.6. Isolation and enumeration of *Campylobacter*

Ten fresh faecal droppings were collected from various locations within each house during all sampling occasions (Fig. 2). Samples were processed within 6 hours of collection and *Campylobacter* spp. were isolated and enumerated according to ISO methods (ISO 2006a, b). *Campylobacter* isolates were confirmed using a previously published multiplex PCR method (Wang *et al.* 2002). Mean *Campylobacter* concentrations (log_{10}CFU g^{-1}) and within-flock detection levels (% samples positive) were calculated for each house and sampling occasion based on 10 faecal samples per sampling occasion.

2.7. Statistical analysis

A single factor ANOVA was used to test for statistically significant differences in water consumption, bird mortality and weight gain, *Campylobacter* detection levels, mean *Campylobacter* counts, litter moisture (%), litter pH, heterophil:lymphocyte ratios, % humidity, CO_2 and NH_3 concentrations between each house equipped with indirect heating system and the corresponding directly heated house for all flocks sampled. A one-way ANOVA was also used to compare the overall impact of heating systems (direct *vs*. indirect) on the factors listed above by season and flock age. A *P*-value of ≤0.05 was considered statistically significant.

3. Results

3.1. Flock performance

Indirect heating systems did not adversely impact on bird weight gain, flock mortality or water consumption for farms A, B and C compared with direct heating systems ($P≥0.05$). By 31 days of bird age, mean total flock mortality rates ranged between 1 to 2%, total water consumption was between 5–6 000 L and mean bird weights ranged from 1.3–1.7 kg for both direct and indirect heating systems on all farms.

3.2. Impact of Indirect heating systems on environmental conditions

No statistically significant differences ($P≥0.05$) were found in relative humidity (mean ranges 62–64%), temperature (27–32°C), ammonia (8–9 ppm (parts per million or mg L^{-1}) or carbon dioxide (1 200–1 600 ppm) concentrations overall for all heating system types investigated (Table 1). There were also no differences ($P≥0.05$) in ammonia concentrations, temperature or relative humidity when indirect and direct heating systems were compared on a seasonal or flock age basis. Similarly, no differences in carbon dioxide levels were observed when compared by season ($P≥0.05$). A significant difference ($P≤0.05$) in CO_2 levels between direct and indirect heating systems was observed in the first 10 days of bird life (Table 2). Within the first 10 days of flock life average CO_2 concentrations in the indirectly heated houses were 1 391, 1 700 and 1 325 ppm compared to 2 000, 2 041 and 1 950 ppm in the directly heated houses for farms A, B and C, respectively.

3.3. Litter pH and % moisture

There were no statistically significant differences ($P≥0.05$) in the % moisture or pH of litter between the directly and indirectly heated houses on all farms. However, litter moisture (%) was significantly higher ($P≤0.01$) in the top layer

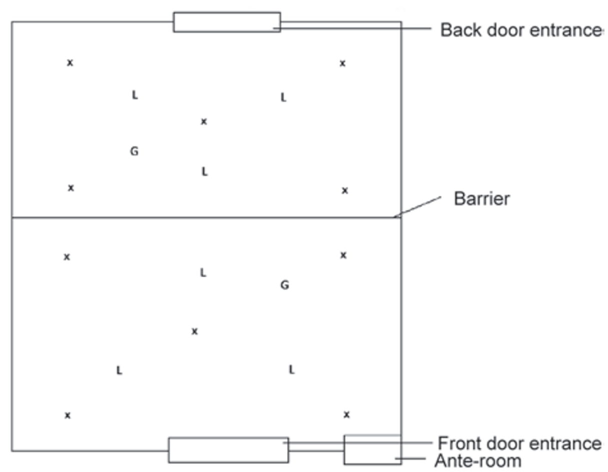

Fig. 2 Illustration of sampling locations within houses for carbon dioxide, ammonia and *Campylobacter*.

Table 1 Comparison of mean environmental parameters in broiler houses fitted with indirect or direct heating systems on three farms

Heating system	Farm A		Farm B		Farm C		Overall (direct *vs*. indirect)	
	Direct	"Cubo"	Direct	"Blackheat"	Direct	"Wood Pellet"	Direct	Indirect
CO_2 (ppm)	1306±645	1247±634	1663±787	1545±781	1507±566	1575±610	1505±712	1442±709
NH_3 (ppm)	8±3	7±3	7±3	10±5	8±5	8±4	8±3	9±5
% relative humidity (RH)	62±5	58±5	68±8	71±9	65±4	66±5	64±10	62±10

Data are means±standard deviation (SD). The same as below.

Table 2 Comparison of carbon dioxide concentrations between direct and indirect heating systems on three farms by bird age

Farm	*n*	Carbon Dioxide Concentrations (ppm)							
		Day 1–10		Day 11–21		Day 22–slaughter		Overall	
		Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect
A	124	2000±419 a	1391±835 b	1600±543	1560±497	862±404	997±558	1306±645	1247±634
B	136	2041±904 a	1700±889 b	1916.6±542	1733±661	1190±625	1287±753	1663±77	1545±71
C	96	1950±57 a	1325±434 b	1366±671	1583±584	1352±549	1735±762	1507±566	1575±610

Values with different letters indicate statistically significant differences ($P \leq 0.01$) in carbon dioxide (CO_2) concentrations within farms between direct and indirect heating systems.

compared with the bottom layer within each of the six houses irrespective of heating system type. Litter moisture levels in the bottom layers were between 9–22% higher than in corresponding top layers (Tables 3 and 4). The pH of the top litter layer was significantly higher ($P \leq 0.01$) than the corresponding bottom layer within both houses on farms A and B but not farm C. Litter pH values ranged from 5.6 to 6.5 in the bottom layers of houses compared with 7–7.6 in corresponding top layers.

3.4. Stress response

Bird stress responses, as measured by the heterophil:lymphocyte (H:L) ratio, did not differ significantly between any of the indirect heating systems and the corresponding direct system at first or final thin ($P \geq 0.05$) (Fig. 3). A significant increase in bird stress response (H:L) was observed between the first thin (range: 0.3–0.5) and the final thin (range: 0.7–0.8) in all houses irrespective of heating system ($P \leq 0.01$) (Fig. 3).

3.5. Campylobacter detection & mean *Campylobacter* concentrations

Differences in heating system design did not impact on the overall *Campylobacter* detection or mean concentrations (range 5.9–6.7 $\log_{10}$CFU g^{-1}) over the duration of this study. Further analysis of the data by season or flock age did not demonstrate any difference in *Campylobacter* detection levels (Number of positive samples/Total number of samples taken) due to heating systems ($P \geq 0.05$) on any farm (Table 5).

4. Discussion

Indirect heating systems were found to have no adverse impact on flock performance, environmental conditions, bird stress or *Campylobacter* levels within Irish broiler houses when compared to direct heating systems. Both heating system types maintained similar mean temperature and humidity levels which provide optimal conditions for broiler production units. A previous study found that optimal growth and welfare conditions for broiler chickens consisted of 18–20°C and 60–65% RH (Yahav 2000). Consequently, indirect heating systems could be used as an alternative to direct heating systems should they prove to be more economical and/or energy efficient. There was a significant difference in moisture (%) between the top and bottom litter layers within the same house on all farms. There was also a significant difference in the pH between the top and bottom litter layers within the same house for farms A and B but not for C. Mean litter moisture (%) in the bottom layer was between 9–22% higher when compared to the corresponding top layer in all six houses. Furthermore the mean pH in the bottom layer was more acidic (pH 5–6) compared to the pH of the corresponding top layers (pH 7) in all four houses on farms A+B, but not on farm C. Increased acidity in the bottom litter layer may

Table 3 Comparison of moisture (%) in the upper and lower layers of litter in broiler houses with indirect or direct heating systems on three farms

Farm	*n*	Direct	Indirect
		Top litter layer mean % moisture	
A	192	20.55±7.95 a	19.72±6.30 d
B	208	20.35±8.85 b	21.76±6.50 e
C	168	20.64±8.92 c	20.13±8.40 f
		Bottom litter layer mean % moisture	
A	90	33.46±6.63 a	33.77±9.82 d
B	72	42.32±8.01 b	34.85±9.14 e
C	60	34.99±11.13 c	29.13±13.79 f

Values with the same letters indicate statistically significant differences between the top and bottom layers of litter within the same house on each farm ($P \leq 0.01$). The same as in Table 4.

Table 4 Comparison of litter pH in the top and bottom layers in broiler houses with indirect or direct heating systems on three farms

Farm	*n*	Direct	Indirect
		Top litter layer mean pH	
A	192	7.1±0.9 a	7.3±1.0 c
B	208	7.0±0.9 b	7.6±0.8 d
C	168	7.0±0.9	7.4±0.9
		Bottom litter layer mean pH	
A	90	6.5±0.8 a	6.2±1.3 c
B	72	5.6±0.6 b	6.6±1.3 d
C	60	6.9±1.5	6.9±1.4

be due to the age of this layer and microbial degradation of nutrients in faecal and bedding material. As aerobic/anaerobic digestion occurs organic acids are produced which lower the pH of the litter over time (Kelleher *et al.* 2002; Sellars *et al.* 2002). Anaerobic digestion of faeces by microbes also raises ammonia nitrogen concentrations over time (Sellars *et al.* 2002). The differences in litter pH and moisture may have important implications for bird welfare and *Campylobacter* survival. Litter moisture is associated with increased ammonia production which in turn impacts negatively on bird welfare. A previous study demonstrated broiler chickens exposed to air ammonia concentrations of 16–54 ppm resulted in significant reductions in body weight and increased arterial pH. The effects were more dramatic as ammonia concentrations increased while birds exposed to the lowest concentrations showed higher feed conversion and growth rates (Yahav 2004). The effects of ammonia on bird health and welfare include ascites, gastrointestinal irritation, respiratory diseases, stress levels, increased mortalities and higher incidence of dermatitis (Reece *et al.* 1979; Martland 1985; Estevez 2002; Humphrey 2006; Meluzzi *et al.* 2008). Higher moisture levels in the litter may also aid *Campylobacter* survival given the organisms susceptibility to desiccation (Park 2002). The increased moisture levels on the bottom layer of the litter highlights the need for good litter management to protect bird welfare.

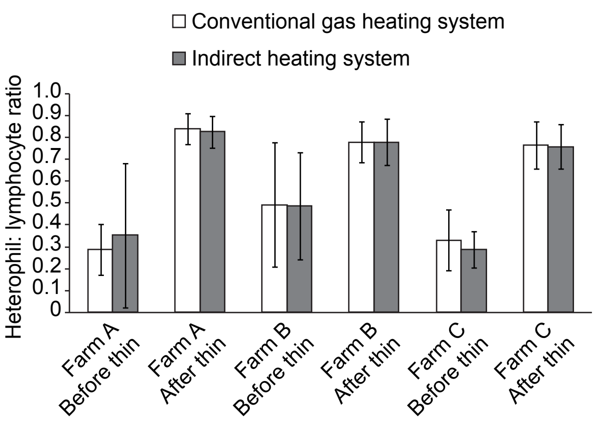

Fig. 3 Differences in heterophil:lymphocyte ratio in birds raised in houses fitted with indirect and direct heating systems before and after thin. Sample numbers: farm A, *n*=60; B, *n*=48; C, *n*=36 at first thin and farm A, *n*=60; B, *n*=4; C, *n*=36 at final thin. Error bars, standard deviation.

A statistically significant difference in carbon dioxide concentrations was found between direct and indirect heating systems when compared by bird age. Within the first 10 days, carbon dioxide concentrations were found to be significantly ($P\leq0.05$) lower in all three indirect heating systems compared with their direct counterparts. After 10 days of age, carbon dioxide concentrations were similar irrespective of heating system type for the remainder of the production cycle. This was likely due to the heating systems being used most intensively during the first 10 days of life with minimal ventilation and therefore the highest concentrations of CO_2 were detected in this period. During this phase, the indirect heating systems did not introduce additional carbon dioxide into their respective houses, as the fumes were not produced (Cubo) or were exhausted outside (Wood pellet, Blackheat). In contrast, the direct gas heaters produced high concentrations of carbon dioxide *via* an open gas flame. From approximately day 10 of the rearing cycle, when birds had grown and developed feathers, the use of heating was scaled down and the birds became the primary producers of CO_2 within the broiler house (Cooper and Washburn 1998; St-Pierre *et al.* 2003). This resulted in similar CO_2 concentrations within houses with either heating system installed from 11–21 days of flock life. Pedersen *et al.* (2008) reported that broiler carbon dioxide production increases with body mass and respiration quotient demonstrating that as birds grow they begin to exhale larger amounts of CO_2. This may explain why CO_2 concentrations between direct and indirect heating systems level out at approximately 10 days of age. Once birds approached slaughter age (approximately 35 days), the use of heating was further reduced and ventilation was increased to maintain an ambient temperature. The increased ventilation resulted in a drop in CO_2 concentrations. The difference in carbon dioxide concentrations between heating systems during the first 10 days of flock

Table 5 *Campylobacter* levels and mean concentrations of positive samples ($\log_{10}$CFU g^{-1}) by bird age in broiler faeces from direct and indirectly heated broiler houses on three farms

Farm	*Campylobacter* levels and mean concentrations of positive samples							
	Day 0–21				Day 22–slaughter			
	Direct		Indirect		Direct		Indirect	
	n+/Total[1)]	Mean log[2)]	*n*+/Total[1)]	Mean log[2)]	*n*+/Total[1)]	Mean log[2)]	*n*+/Total[1)]	Mean log[2)]
A	9/240	5.4±0.5	0/240	Neg	37/100	6.7±0.8	30/100	6.9±0.9
B	9/110	5.7±0.9	18/130	5.8±0.6	40/50	6.7±1.0	60/80	6.5±0.8
C	0/120	Neg	0/120	Neg	29/60	6.0±1.2	30/60	5.98±1.0

[1)] *n*+/Total=Number of positive samples/Total number of samples
[2)] *Campylobacter* mean log calculated on positive samples only.
Neg, no positive *Campylobacter* samples.

life did not adversely impact on bird performance. For all houses monitored, irrespective of heating system type, CO_2 concentrations during the first 10 days of flock life did not exceed acceptable welfare levels (2007/43/EC; Reece and Lott 1980; Fairchild and Czarick 2012). Furthermore, research has shown that long term exposure to CO_2 levels of up to 6000 ppm did not significantly impact on bird weight. However, CO_2 concentrations in excess of 12000 ppm have been shown previously to result in significant reductions in body weight (61 g) (Reece and Lott 1980). Therefore whilst differences in carbon dioxide concentrations were observed in our study for the different heating systems, they did not reach levels likely to affect flock performance.

Whilst heating system type had no impact on bird stress responses, thinning or partial depopulation was found to significantly affect such responses in birds from all houses. Prior to thinning bird H:L ratios were found to be between 0.3–0.5 which is considered normal. However, once thinning occurred H:L ratios were found to increase to between 0.7–0.9 in birds in all houses, which indicates a stressed state (Gross and Siegel 1983; Campo and Dávila 2002a, b). This is likely due to noise and activity associated with personnel and equipment during thinning as a well as the catching and handling of birds. A previous study found that rough handling of poultry caused plasma corticosterone levels to significantly increase within 30 min compared to birds that were handled gently. Furthermore that study found evidence that rough handling increases incidence of bone breakage, bruising and death (Knowles and Broom 1990). The increased stress response caused by thinning is not only a welfare concern but also has potential implications for the spread of *Campylobacter*. A previous study demonstrated that stress can increase shedding of *Campylobacter* in broilers (Whyte *et al.* 2001). Further studies have demonstrated that stressing birds causes release of noradrenaline which scavenges iron aiding *Campylobacter* growth in the intestinal tract and may also aid the organisms' motility (Cogan *et al.* 2007; Aroori *et al.* 2014). This could facilitate the spread of *Campylobacter* within flocks and increase the risk of carcass contamination with consequences for public health. The practice of thinning may need to be re-evaluated to consider its effects on bird welfare and *Campylobacter* transmission (EFSA 2011; Koolman *et al.* 2014). Stress resulting from partial depopulation may compromise bird immunity possibly resulting in increased susceptibility to *Campylobacter* colonization (Niu *et al.* 2009; Shini and Kaiser 2009; Yang *et al.* 2011).

With the exception of farm A, no differences in *Campylobacter* concentrations or numbers of positive samples were observed on any farms irrespective of age or season. *Campylobacter* was detected before 21 days of age in one of four flocks in the directly heated house on farm A (Table 5). The difference could possibly be attributed to breaches in biosecurity rather than an effect of heating system type (Gibbens *et al.* 2001).

5. Conclusion

This study demonstrated that indirect heating systems did not impact bird welfare, flock performance or *Campylobacter* levels. However, the significant differences in litter quality, carbon dioxides concentrations and bird stress responses associated with farm management practices have implications for optimal poultry production. *Campylobacter* was more likely to establish itself in broilers in the later stages of flock life (≥22 days) than in young birds regardless of heating system. Factors such as thinning and/or breaches in biosecurity are also critical factors in the onset of *Campylobacter* infection.

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