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Direct energy consumption and CO_2 emissions in a Finnish broiler house – a case study

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Direct energy (electricity and heating) consumption was measured from one broiler house in southern Finland. CO_2 emissions were also calculated. Six broiler flocks were reared per year with an average of 26 000 birds per flock. Heating constituted the major energy input, averaging 1.3 kWh kg^{-1} of carcass weight. It varied greatly between seasons and was highest during the cold period. Using renewable energy for heating remarkably reduces CO_2 emissions compared to fossil energy. Electricity consumption averaged 0.08 kWh kg^{-1} of carcass weight. The greatest energy saving potential can be found in heating. CO_2 emissions can be lowered to similar levels as in warmer countries by using biofuels for heating. Ventilation control is one possibility for direct energy savings in broiler production. Feed production is one of the key elements when total energy consumption is considered.

Key words: broiler production, CO_2 emissions, energy consumption, energy measurement, energy efficiency

Introduction

Broilers are reared on approximately 190 farms in Finland (Siipikarjaliitto 2010). Most of these farms are centered regionally in the proximity of slaughterhouses (Harrinkari and Raukola 2009). Production is highly specialized and based on contracts between farmers and slaughterhouses. An all-in all-out system is used in Finnish broiler production. In this system all broiler houses on the same farm are concurrently empty. The aim is to guarantee high production hygiene. Birds arrive on a farm at a few hours of age and weighing approximately 35–45 g. Broiler rearing periods vary from 32 to 39 days. During the rearing period birds gain from 1.3 kg to 1.9 kg of carcass weight. The average broiler carcass weight was 1.6 kg in 2012 (Tike 2013a). Finnish broiler houses are typically highly automated, fully enclosed, insulated and mainly concrete element-structured buildings (Harrinkari and Raukola 2009). Heating is needed year-round to ensure the recommended temperature and relative humidity for broiler houses. Electricity is used mainly for ventilation, lighting and feeding.

One of the European Union's (EU) targets is a 20% reduction in greenhouse gas (GHG) emissions by 2020 compared to levels in 1990 (EC 2009, TEM 2013). In the Finnish agriculture sector this means a 13% reduction compared to levels in 2005 (TEM 2008). As part of this target the EU will increase its renewable energy use. The Finnish target is to increase final renewable energy usage from 28.5% in 2005 up to 38% in 2020 (EC 2009, TEM 2013). The EU is also obligated to increase energy efficiency by 20% by 2020 compared to projections made in 2007 (EU 2012, TEM 2013). A voluntary energy programme for farms exists in Finland. The aims of this programme are to increase renewable energy usage and energy usage efficiency in agriculture (Government regulation 2009) and to increase the energy efficiency of participant farms by 9% by 2016 (Government regulation 2009, EU 2012).

Approximately 10.4 TWh of direct energy was consumed by the Finnish agriculture and horticulture sector in 2010 (Tike 2012). This is approximately 3% of the total direct energy consumption of the country (Tike 2013b). Wood is the largest direct energy input on poultry farms followed by oil and peat (Tike 2012). Approximately 65% of the total direct energy input of poultry farms therefore comes from renewable energy. An increasing number of Finnish broiler farms use renewable energy for heating, but fossil energy is still used on many broiler farms around the world (e.g. Baughman and Parkhurst 1977, Liang et al. 2009).

Indirect energy is used mainly as feed, which is the largest energy input of broiler houses (e.g. Baughman and Parkhurst 1977, agrEE 2012). Studies have shown (Ahokas et al. 2014) that it is possible to considerably save energy in feed production e.g. with more efficient production methods and nutrient recycling. Heating is the largest direct energy input of broiler houses (Baughman and Parkhurst 1977, Barber et al. 1989, Katajajuuri et al. 2006, Hörndahl 2008). It is also the greatest CO_2 emission source of broiler houses when fossil fuel is used for heating. Biofuel usage for heating has increased in broiler production e.g. in Finland and Sweden during the last years (e.g. Sonesson et al. 2009). Biofuel combustion is traditionally assumed to be CO_2 neutral. Biofuel combustion hence reduces CO_2 emissions compared to the combustion of fossil fuels. The biofuel production chain causes emissions (Mäkinen et al. 2006), but that portion of the total GHG emissions is minor.

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Climate, bird mass, house type and insulation greatly affect heating energy consumption. It is higher during cold seasons than warm seasons due to higher heat loss from buildings and ventilation (e.g. Bokkers et al. 2010). Energy demand is lower at the beginning of the rearing period due to the low ventilation rate (Mannfors and Hautala 2011). Some previous studies (Baughman and Parkhurst 1977, Liang et al. 2009) showed that insulated and enclosed broiler houses (environmental houses) use less heating energy than curtain side-wall houses (Table 1). However, electricity consumption is usually higher in environmental houses due to artificial lighting and mechanical ventilation (e.g. Baughman and Parkhurst 1977, Liang et al. 2009). Several studies (Baughman and Parkhurst 1977, Katajajuuri et al. 2006, Hörndahl 2008, Liang et al. 2009) showed that the electricity consumption of broiler houses is minor compared to that of heating. Ventilation and lighting are usually the biggest electricity consumers (Hörndahl 2008, Liang et al. 2009, agrEE 2012).

Heating and electric energy consumption vary in different studies and countries (Table 1). Kivinen et al. (2013) calculated the theoretical heating energy consumption of one broiler house (1 600 m^2, with space for 28 000 birds). In their study the biggest heat losses occurred through ventilation. Greatest energy savings could be found in heat recovery from the exhaust air. Kivinen et al. (2013) also noticed that controlling ventilation CO_2 levels could save energy. Energy can be conserved e.g. by decreasing the ventilation rate during dark cycles, when broilers are not active. Katajajuuri et al. (2006) studied the heating energy consumption of 16 broiler houses in Finland. They also calculated the theoretical heating energy demand of a broiler house, which was found to be lower than the heating energy consumption of practical broiler farms. Studies by Katajajuuri et al. (2006) and Kivinen et al. (2013) indicate that the theoretical heating energy consumption was lower than the heating energy consumption in practical conditions on farms.

Table 1. Electricity and heating energy consumptions in broiler houses.

Heating kWh kg^{-1} of carcass weight	Electricity kWh kg^{-1} of carcass weight	Remarks	Reference
0.70[1]	0.12[1]	Measured energy consumption of the broiler house in Sweden.	Hörndahl (2008)
0.75	-	Theoretical energy consumption in Helsinki, Finland.	Kivinen et al. (2013)
0.95	-	Theoretical energy consumption in Jyväskylä, Finland.	Kivinen et al. (2013)
1.17	-	Theoretical energy consumption in Finland.	Katajajuuri et al. (2006)
1.31 (varied between 0.94 –1.64)	0.19 (varied between 0.08–0.35)	Consumption was based on interviews and complementary questions made to 16 broiler farms in Finland.	Katajajuuri et al. (2006)
0.53[1,2]	0.14[1]	Four enclosed, insulated houses in Northwest Arkansas, USA.	Liang et al. (2009)
0.62[1,2]	0.11[1]	Four open-curtain houses in Northwest Arkansas, USA.	Liang et al. (2009)
0.55–3.47[1]	0.17–0.26[1]	Conventional house[3)] in North Carolina, USA.	Baughman and Parkhurst (1977)
0.34–1.85[1]	0.51–0.57[1]	Environmental house[4)] in North Carolina, USA.	Baughman and Parkhurst (1977)

[1] Energy consumption per market weight converted to energy consumption per carcass weight using carcass-% of 74.
[2] Heating energy was originally presented as litres of liquefied petroleum gas (LPG). It is converted to kWh using the heating value 25 kWh m^{-3} of LPG and a gas-liquid -ratio of 240:1.
[3] Broiler house that is converted to drop-curtain side walls with no insulation or mechanical ventilation.
[4] Broiler house that is enclosed and insulated and has mechanical ventilation.

Broiler house heat balance can be calculated from heat flows within the building (Fig. 1). When room temperature is higher than the ambient temperature, heat flows from the building to its surroundings. Heat is conducted through the walls, ceiling and floor.

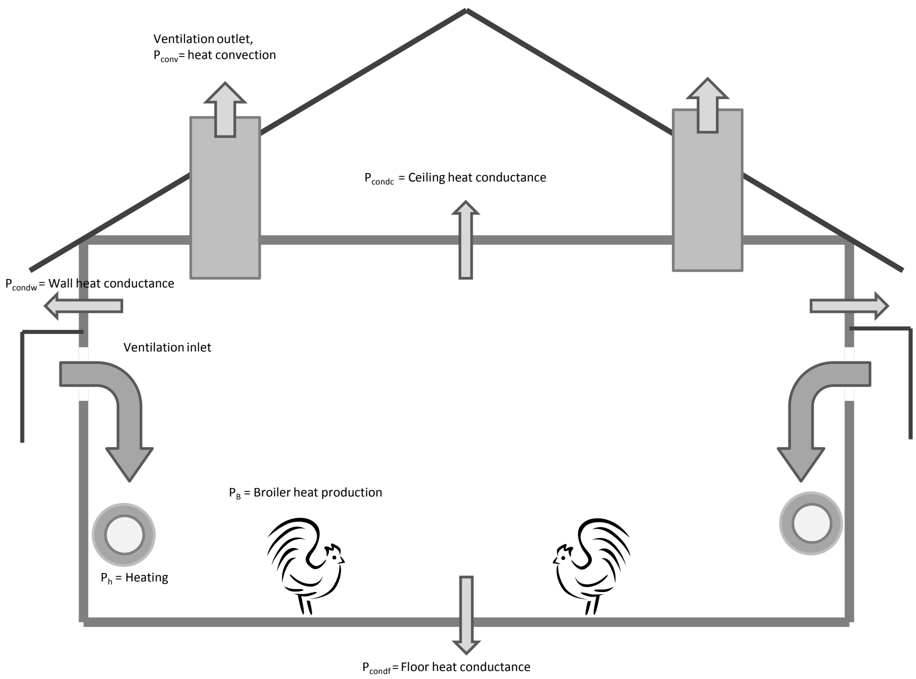


Fig. 1. Heat flows in a broiler house.

The heat flow power depends on structural thermal conductivity (U-value), structure area (A) and structure temperature difference (ΔT_s) between the inside and outside surfaces (Eq. 1).

$$P_{cond} = U \cdot A \cdot \Delta T_s \qquad (1)$$

P_{cond}	heat conductance
U	structural thermal conductivity
A	structure area
ΔT_s	temperature difference between inside and outside surfaces

Surface temperatures in the building are not the same as indoor and outdoor temperatures. An air boundary layer occurs on the surfaces, and this also has an insulating effect. The U-values of the boundary layers depend on radiation, surface air speed (wind) and surface properties. If the walls have effective heat insulation, then the boundary layers only have a minor effect, but this has to be taken into account with poor heat insulation.

The heat flow in convection is caused by ventilation. The ventilation rate must be high enough to insure a proper microclimate and animal welfare. If ventilation rate is high compared to microclimate requirements then energy is lost with convection. The heat power of ventilated convection (P_{conv}) can be calculated with the air mass flow (q_m), specific heat capacity of air (c_a) and the temperature difference of indoor and outdoor air temperatures (ΔT_a), Eq. (2).

$$P_{conv} = q_m \cdot c_a \cdot \Delta T_a \quad (2)$$

P_{conv} heat convection
q_m air mass flow
c_a specific heat capacity of air
ΔT_a temperature difference of indoor and outdoor air temperatures

The heating power (P_h) of the building can be derived from its heat balance, Eq. (3). This depends on the building`s heat losses and the heat production of the animals. Radiation heat power is not included here because broiler buildings in Finland do not have windows. Radiation however has an effect on outdoor surface temperatures, and in this way it also affects heat conduction.

$$P_h = \sum P_{cond} + P_{conv} - P_{bs} = \sum U \cdot A \cdot \Delta T_s + q_m \cdot c_a \cdot \Delta T_a - P_{bs} \quad (3)$$

P_h heating power
P_{cond} heat conductance
P_{conv} heat convection
P_{bs} broiler-sensible heat production
U structural thermal conductivity
A area
ΔT_s structure temperature difference between inside and outside surfaces
q_m air mass flow
c_a specific heat capacity of air
ΔT_a temperature difference of indoor and outdoor air temperatures

Broiler-sensible heat production can be calculated using the CIGR method (CIGR 2002), Eq. (4). According to this, the sensible heat power depends on broiler mass and temperature. Broiler house temperature is regulated according to broiler mass and the power increases with increasing mass heat.

$$P_{bs} = 10.62 \cdot m^{0,75} \cdot \left[0.61 \cdot (1 + 0,020 \cdot (20 - t)) - 2.28 \cdot 10^{-4} t^2\right] \quad (4)$$

P_{bs} broiler-sensible heat production
m broiler mass
t temperature °C

Figure 2 shows an example of how heating power demand changes when outdoor temperature and broiler mass change. Large amounts of heating power are needed when the weather is cold and the broilers are old. The largest heat power goes to heating the ventilated air, the requirement for which increases as the birds grow.

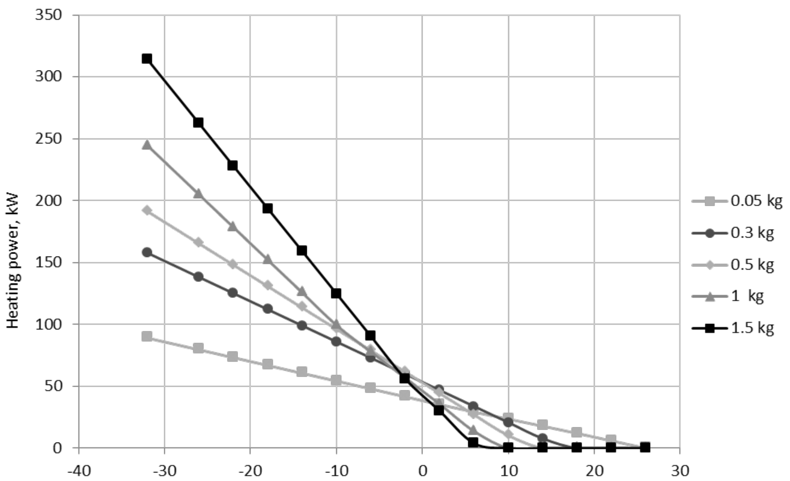


Fig. 2. Example of heating power demand during the rearing period of a broiler flock with different ambient temperatures and broiler weights. 27 000 birds with a density of 17 birds m^{-2} and with recommended ventilation rates and heat insulation materials (MMM-RMO 2001).

Figure 3 shows an example of the heating losses in the case presented in Figure 2. Heat is lost mainly through ventilation. Heat conduction losses are small compared to this. With young broilers the ventilation rate is low and heat losses through the walls, ceiling and floor are dominating.

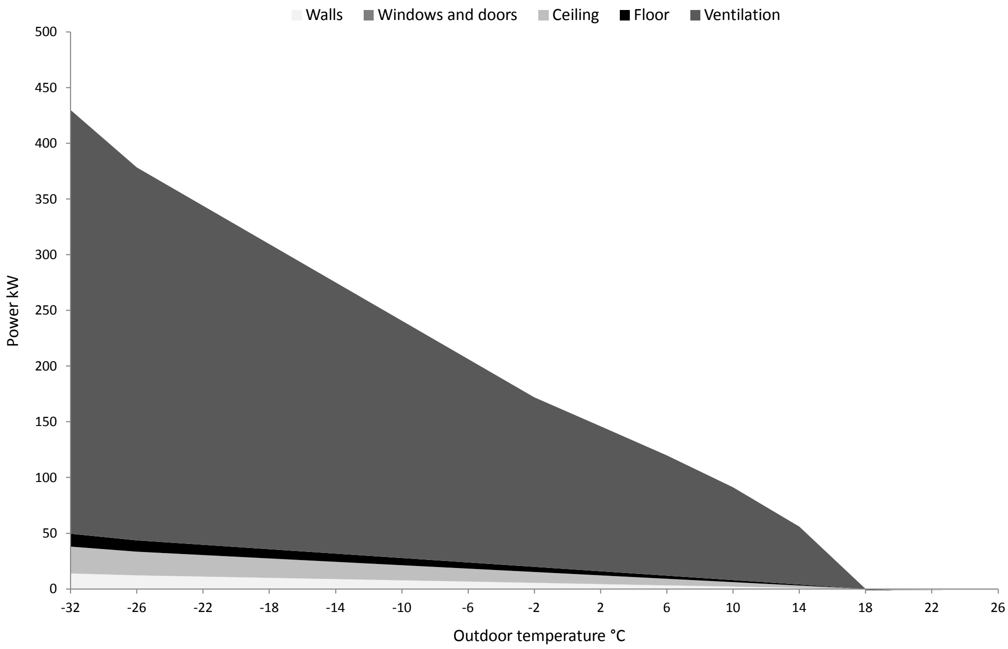


Fig. 3. Example of building heat losses when broiler mass is 1.5 kg.

Beef and milk production causes the highest GHG emissions of the EU livestock sector (Lesschen et al. 2011, Weis and Leip 2012). GHG emissions per kg of beef are multiple compared to emissions per kg of poultry meat (Table 2). Higher emissions produced by ruminants are caused mainly by higher CH_4 and N_2O emissions (Weis and Leip 2012). Poultry also has a better feed conversion ratio (kg feed kg^{-1} product) than beef (Pimentel 1980, Lesschen et al. 2011).

Table 2. GHG emissions of beef and poultry meat.

GHG emissions of beef, kg $CO_{2\text{-eq}}$ kg^{-1} of beef	GHG emissions of poultry meat, kg $CO_{2\text{-eq}}$ kg^{-1} of poultry	Reference
28.7	3.6	Weidema et al. 2008
22.6	1.6	Lesschen et al. 2011
21–28	5–7	Weis and Leip. 2012

Weis and Leip (2010, 2012) have calculated the GHG emissions of poultry meat for 27 EU member states (EU-27) using the CAPRI (Common Agricultural Policy Regionalised Impact) model, while Lesschen et al. (2011) have used the MITERRA-Europe model and Weidema et al. (2008) the LCA (life cycle assessment) system model. Figure 4 shows the total GHG emissions per kg of poultry meat in the EU-27 countries. According to Weis and Leip (2012) the main causes of GHG emissions (in poultry meat production in the EU-27) are land use and land use change (LULUC) (50%) and energy use (28%). LULUC included the following emission sources: soil cultivation (CO_2), carbon stock changes (CO_2), biomass burning (CH_4, N_2O) and emissions or removals of pastures, croplands and grasslands (CO_2). EU-27 GHG emissions vary between 3.3–17.8 kg $CO_{2\text{-eq}}$ kg^{-1} of poultry meat, with levels highest in Latvia and lowest in Ireland (Weis and Leip 2012). Emissions averaged 4.9 kg $CO_{2\text{-eq}}$ kg^{-1} of poultry meat in the EU-27 countries (approximately 10 kg $CO_{2\text{-eq}}$ kg^{-1} of poultry meat in Finland).

GHG emissions per kg of poultry meat were the second highest in Finland compared to other EU-27 countries. The main reason for this was the higher emissions from land use (high share of organic soils in Finland). CO_2 emissions from energy use in Finland were approximately 1.5 kg CO_{2-eq} kg^{-1} of poultry meat. This was higher than the average emission (1.4 kg CO_{2-eq} kg^{-1} of poultry meat) in the EU-27 countries. The reason behind this is probably that more heating is needed in broiler houses in Finland than in other EU-27 countries.

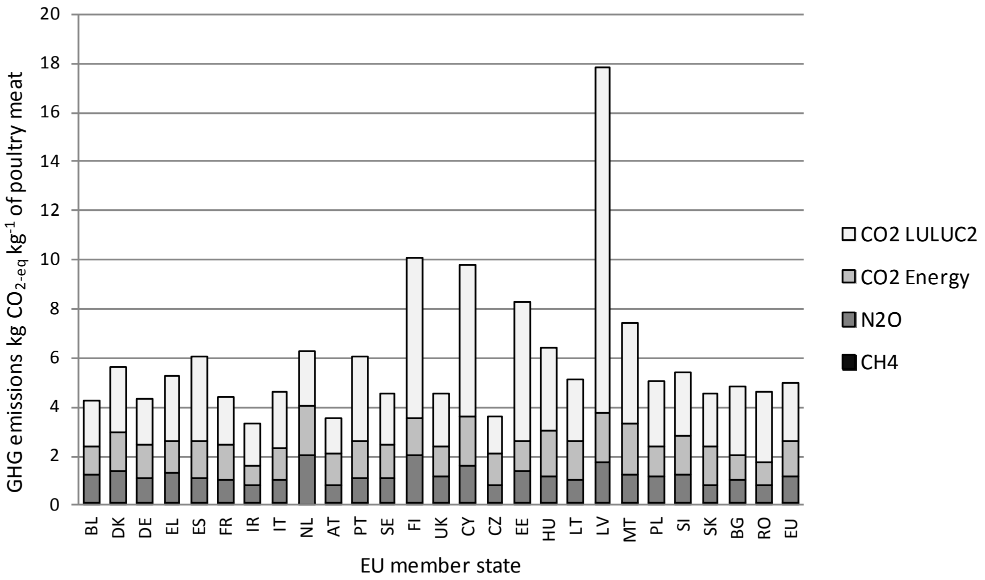


Fig. 4. Total GHG emissions per kg of poultry meat in the EU-27 countries. The figure is made from data by Weis and Leip (2010).

Our study focused on direct energy consumption and it´s CO_2 emissions in a modern broiler house. Direct energy consumption includes electricity and heating energy consumption. The aims of our study were 1) to investigate the heating and electric energy consumption of a broiler house 2) to identify the division of direct energy consumption inside a broiler house and 3) to explore the CO_2 emissions of combustion and electricity use when different fuel sources are utilised.

Material and methods

Electricity and heating energy consumption were measured in one insulated (wall U-value 0.3 W m^{-2} K^{-1}) concrete element broiler house located in southern Finland. The broiler house had two identical and fully enclosed rearing sections. The dimensions of one section were: height 3.5 m, width 19.8 m and length 81.4 m. The floor area is 1 615 m^2 and the volume 5 655 m^3. The broiler house was built in 2008. Energy consumption was measured from one rearing section (*later referred to as broiler house*), which constitutes half of the building. Information concerning production was collected from every broiler flock: feed and water consumption, number of birds, dead birds and carcass weight (a carcass weight of 73% of a live bird's weight was used in the analyses [Government regulation 2011]).

Ross breed broilers arrived at the broiler house at the age of a few hours and their weight was 35–45 g. The birds gained a carcass weight of 1.8 kg (live weight of 2.46 kg) within 38 days. Six flocks were reared per year, with an average 26 000 slaughter birds per flock. An all-in all-out production system was applied. A down time of approximately 2–5 weeks was implemented after each rearing period. During this time the house was cleaned and disinfected.

The broiler house had a central heating system and renewable energy (wood chips) was mainly used as fuel. There were two pipe radiators on the walls and four water to air heat radiators equipped with fans in the middle of the house. The heating energy consumption of both these systems was measured. The electricity consumption of four radiators with fans was included in a part of the miscellaneous electricity consumption. Heating was controlled by four thermostats, which measured the average temperature of the house. The house was pre-heated to 33 °C before the birds arrived. The temperature was decreased stepwise to 21 °C by the end of the rearing period. The broiler house needed heating year-round except on the hottest summer days.

The lighting consisted of 84 fluorescent tube lights (nominal power 36 W light^{-1}). The lights were brightest during the first days and were dimmed stepwise after two days. The lighting programme mainly began on day three. It included at least six hours of dark and 18 hours of light. The dark cycle was divided into two parts.

The house was equipped with a negative pressure ventilation system. The system included three on/off ventilation fans (diameter 0.80 m, nominal power 1.09 kW) in the ceiling, two ceiling fans (diameter 0.80 m, nominal power 0.91 kW) with adjustable speed and four belt-driven tunnel ventilation fans (diameter 1.27 m, nominal power 1.10 kW) in the gable. Ventilation inlets (12 pieces) were located in two lines in the ceiling. Ventilation control was based on the expected rearing curve, bird weight, humidity and temperature. Tunnel ventilation fans were used mainly during the summertime when extra cooling was needed.

Heating energy consumption was measured from May 2011 to May 2013. Data was collected from 12 broiler flocks. Heating energy consumption was measured using an energy meter. Heat losses in the heat canals and the furnace efficiency were were not considered.

Electricity consumption measurements were divided into three groups: total electricity consumption, ventilation and lighting. When the ventilation and lighting energy were subtracted from the total electricity consumption, the remaining part was denoted as miscellaneous energy consumption. This included e.g. an automatic feeding system and fans of four heat radiators. Electricity consumption of the broiler house was measured from May 2012 to May 2013. The energy consumption of the tunnel ventilation fans and lights was measured at 20-minute intervals and at 10-minute intervals for adjustable and on/off fans.

Indoor- and outdoor temperatures were also measured. Outdoor and indoor temperatures were measured at 20- and 30-minute intervals, respectively. Table 3 shows the instrumentation used for the measurements.

Data was collected with a data logger and uploaded and analysed after each rearing period. Energy consumption was calculated as kWh per 1 kg of carcass weight and as kWh per broiler flock.

Table 3. Instrumentation used in broiler house measurements.

Measured value	Instrumentation
Electricity consumption of on/off and adjustable fans	CHAUVIN ARNOUX - P01105109Z Mini current clamps, Chauvin Arnoux group, France and HOBO Pendant event data logger, Onset, USA
Electricity consumption of lights and tunnel ventilation fans	CHAUVIN ARNOUX - P01105109Z Mini current clamps, Chauvin Arnoux group, France and Datataker DT80 data logger, Australia
Total electricity consumption of the broiler house	Current transformer CTSCM40-100/5, Howard Butler Ltd, England, 3 phase Entes EPR-04S digital powermeter, Entes, Turkey and HOBO Pendant event data logger, Onset, USA
Energy consumption of heating	ACTARIS CF ECHO II heat meter, Actaris, France and HOBO Pendant event data logger, Onset, USA
Indoor temperature	PT1000 sensors and A-Lab aCG-100 data logger
Outdoor temperature	Tinytag Ultra TGU-1500 data logger, Gemini data loggers, UK

CO_2 emissions from combustion and electricity use were calculated for the broiler house. Emissions from combustion were calculated using the emission factors used in national GHG inventory (Table 4). Electricity emissions were calculated using the Motiva`s emission factors. Results were presented as kg of CO_2 per 1 000 kg of carcass weight.

CO_2 emissions from heating were calculated using the most commonly used fuels (wood chips and sod peat) in poultry production in Finland. The emissions from liquefied petroleum gas (LPG) and oil were also calculated as a point of comparison. Two electricity sources were used in the calculations; mean electricity purchasing in Finland as a 5-year moving average (mean electricity) and electricity from renewable energy sources (green electricity). Green electricity was included because some of the broiler farms have their own electricity production with windmills.

The consumed fuel amount must be known for CO_2 emission calculations. This was estimated from the broiler house heating consumption by adding the heat losses of the heating canals (located between the broiler house and the boiler room) and furnace efficiency losses. It was assumed that the central heating system was used for peat, wood chips and oil and the direct heating system for LPG. Furnace efficiency for wood chips and sod peat was 80% and 87% for oil and LPG, respectively (Motiva 2010). Heat losses of the heating canal vary from 20 W m^{-1} to 30 W m^{-1} in Finland (MMM-RMO 2001). CO_2 emissions from the production of wood chips were not included.

Table 4. Emission factors of heating fuels and electricity.

Energy source	Emission factor, g CO_2 kWh^{-1}	Reference
Wood chips	0	Tike 2014
Sod peat	367	Tike 2014
Heating fuel oil	263	Tike 2014
LPG	234	Tike 2014
Biomass from the field	0	Tike 2014
Green electricity (e.g. wind, hydropower)	0	Motiva 2014
Mean electricity (average of 5 years)	223	Motiva 2014

Results and discussion

Total electricity consumption

Total electricity consumption averaged 3800 kWh per flock and 0.08 kWh kg^{-1} of carcass weight. Electricity consumption was lower in our study than in previous in climatically warmer countries (Table 1) because of the lower ventilation demand in Finland during the year. Figure 5 shows the daily electricity consumption of the broiler house during a one-year period. Figure 5 clearly shows two electricity consumption peaks during each rearing period. The first electricity consumption peak occurs at the beginning of the rearing period and the second peak at the end of the rearing period. Electricity consumption of lighting is the main reason for the first peak because the lights were kept on almost 24 hours a day at the beginning of the rearing period. Increased ventilation demand explains the second electricity consumption peak during the latter part of the rearing period. Hörndahl (2008) showed that electricity peaks occur at the beginning and latter part of the rearing period. In his study the highest electricity consumption peak was at the beginning of the rearing period. This was most probably due to the lighting programme.

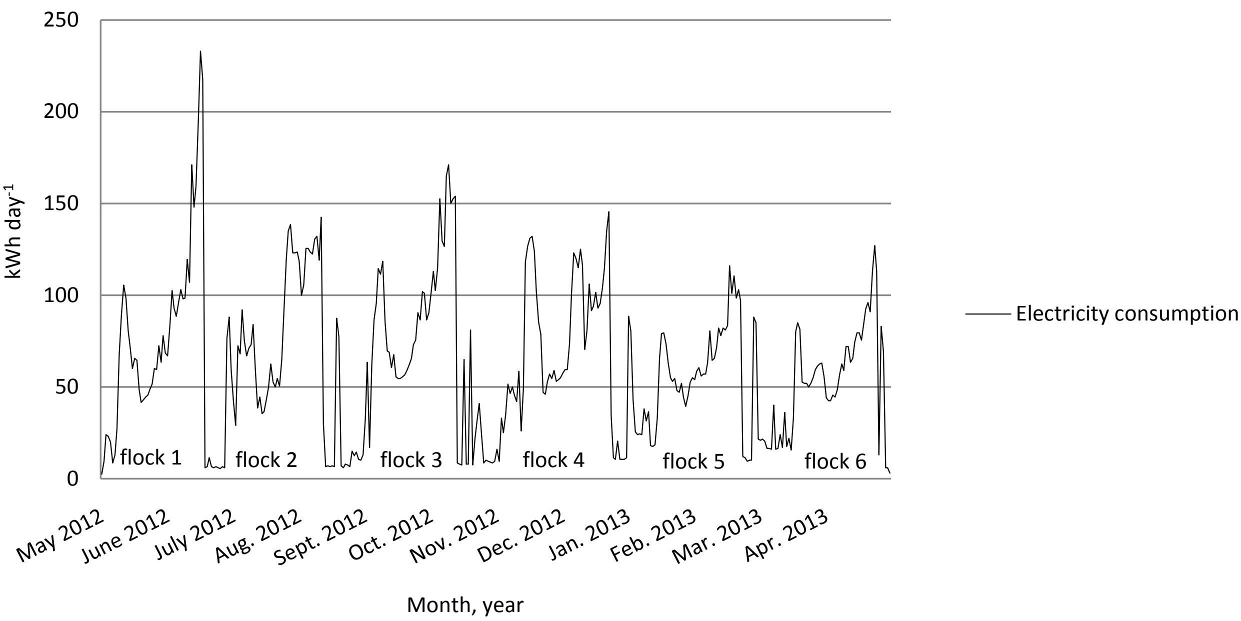


Fig. 5. Daily electricity consumption during the rearing of six broiler flocks.

Electricity consumption of the broiler house was highest during the warmest summer months. The main reason for this was the increased ventilation demand during the warmest days. Electricity is also consumed during the down time between flock rearing. The proportion of miscellaneous energy consumption increased in wintertime because four heat radiators with fans were used during this time.

Electricity consumption of ventilation

Figure 6 shows the weekly electricity consumption of ventilation fans during the rearing of six broiler flocks. The electricity consumption of on/off fans and adjustable fans averaged 1 200 kWh per flock and 0.025 kWh per kg of carcass weight. Their portion of the total electricity consumption during the rearing of a broiler flock averaged 37%. Ventilation electricity consumption was highest during the warmest summer months, when the maximum ventilation rate was needed to keep the inside temperature suitable for broilers. On/off and adjustable fans were used year-round for ventilation. Tunnel ventilation fans were mainly used during the warmest summer months. Ventilation demand increased along with broiler body mass and fan electricity consumption also increased during the latter part of the rearing period.

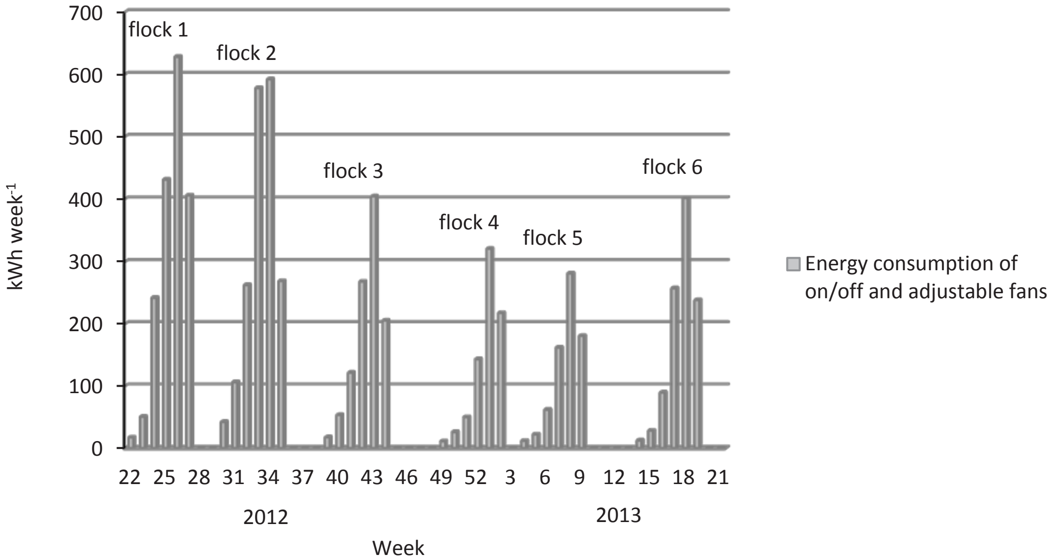


Fig. 6. Weekly electricity consumption of ventilation fans.

Electricity consumption of lights

The electricity consumption of lighting averaged 606 kWh per flock and 0.013 kWh per kg of carcass weight. It averaged 19% of the total electrical energy consumption during the rearing of a broiler flock. Energy consumption was highest during the first rearing week because lights were continuously on at the beginning (Fig. 7). After two rearing days the lights were dimmed stepwise and the broilers also experienced dark cycles.

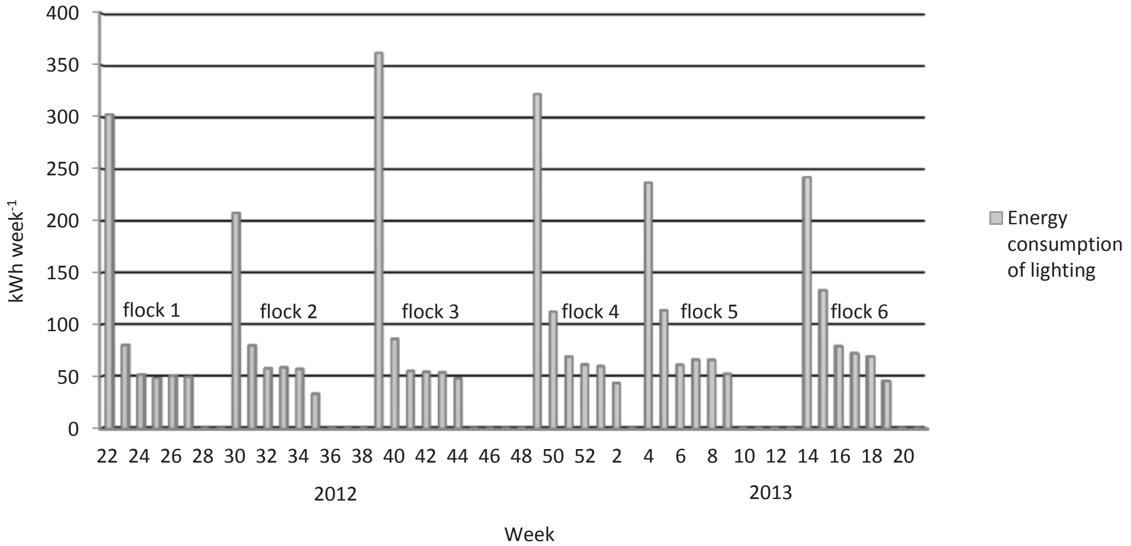


Fig. 7. Weekly lighting electricity consumption of six broiler flocks.

Heating energy consumption

The measured heating energy consumption of the broiler house (12 flocks) averaged 61275 kWh $flock^{-1}$ (range 16100–108500 kWh $flock^{-1}$) and 1.3 kWh kg^{-1} of carcass weight (range 0.35–2.23 kWh kg^{-1} of carcass weight). This consumption includes pre-heating prior to the rearing period and heating during the rearing period. When canal losses and furnace efficiency are taken into account the total heating energy consumption is approximately 30% higher than the measured energy consumption. Figure 8 shows the heating energy consumption of 12 broiler flocks from June 2011 to May 2013. Heating energy consumption varied highly between different seasons and broiler flocks.

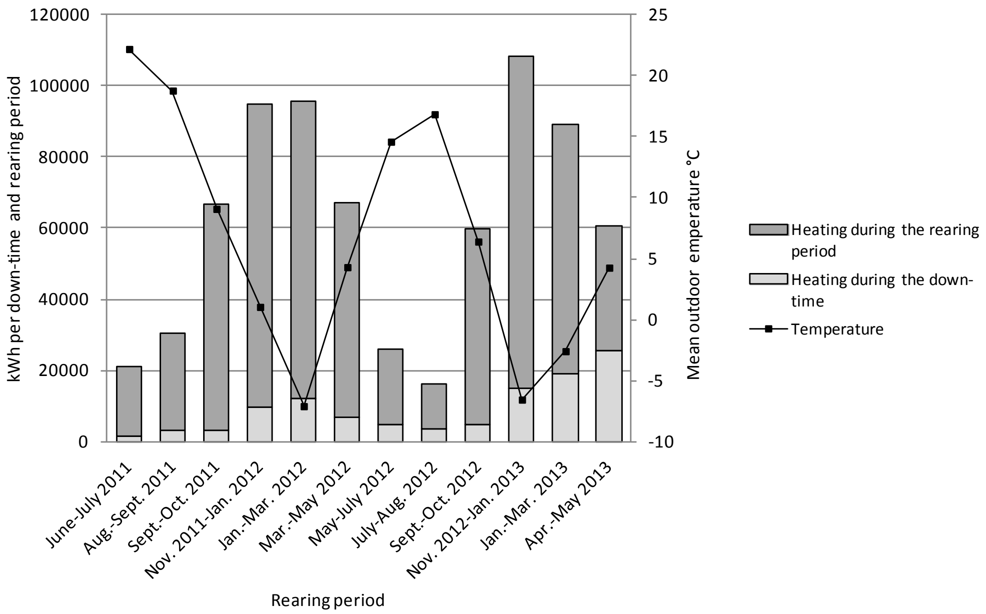


Fig. 8. Heating energy consumption during the rearing of 12 broiler flocks.

Figure 9 shows the weekly heating energy consumption and ambient temperature during the rearing of six broiler flocks from 30th of January 2012 to 7th of January 2013. Heating energy consumption followed seasonal temperature changes. The weekly heating energy consumption was mainly highest during cold days.

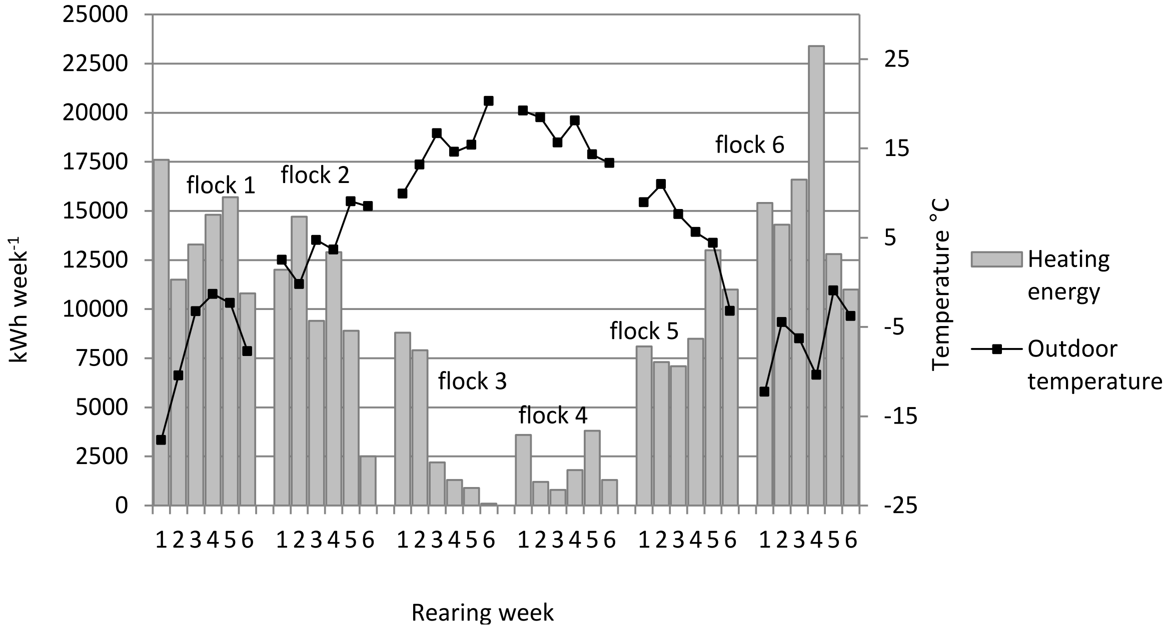


Fig. 9. Weekly average heating energy consumption and ambient temperature during the rearing of six broiler flocks from 30th of January 2012 to 7th of January 2013. The last rearing week of each flock only includes 3–5 days, depending on the length of the rearing period.

Heating energy consumption was larger in our study than in several previous studies (e.g. Hörndahl 2008, Liang et al. 2009). One reason for this is that heating is needed year-round in Finland and outdoor temperatures during the wintertime are low compared to many other countries. However, broiler houses are highly heat insulated. The recommended U-values for walls and ceilings are 0.3 W $m^{-2} K^{-1}$ and 0.22 W $m^{-2} K^{-1}$, respectively (MMM-RMO 2001). Heat insulation had more impact on heat losses at the beginning of the rearing phases than during the latter phase where more heat losses occurred through ventilation than through the structures.

Heating energy constituted 94% of the total direct energy consumption and according to Figure 3 this is mainly due to ventilation losses. Heat recovery from outlet ventilation air could be used to decrease heating energy input. There are still a few obstacles why heat recovery systems are not common in broiler housing in Boreal conditions. One reason is the challenging circumstances faced in broiler houses. Dust is a problem in all broiler houses. Wintertime freezing is another evident problem. Both of these can obstruct the heat exchanger. For these reasons many farmers cut their heating costs by using less expensive heating fuel, e.g. wood chips. Due to high heating energy consumption the total direct energy consumption in our study was higher than in previous studies from other countries. The theoretical heating energy consumption (Katajajuuri et al. 2006, Kivinen et al. 2013) is also lower in previous studies than the measured heating energy consumption in our study. This is probably because the theoretical calculations included several assumptions. They usually also ignored some air-flows (e.g. ventilation does not work identically, houses are not tight) and thermal bridges inside the house.

Total direct energy consumption

Figure 10 shows the energy consumption of heating and electricity of the broiler section during the six broiler rearing periods. The greatest total energy input amount of a broiler house is used for heating. Electricity consumption is only a minor part of the total direct energy consumption of a broiler house. The largest energy saving possibilities can hence be found in heating.

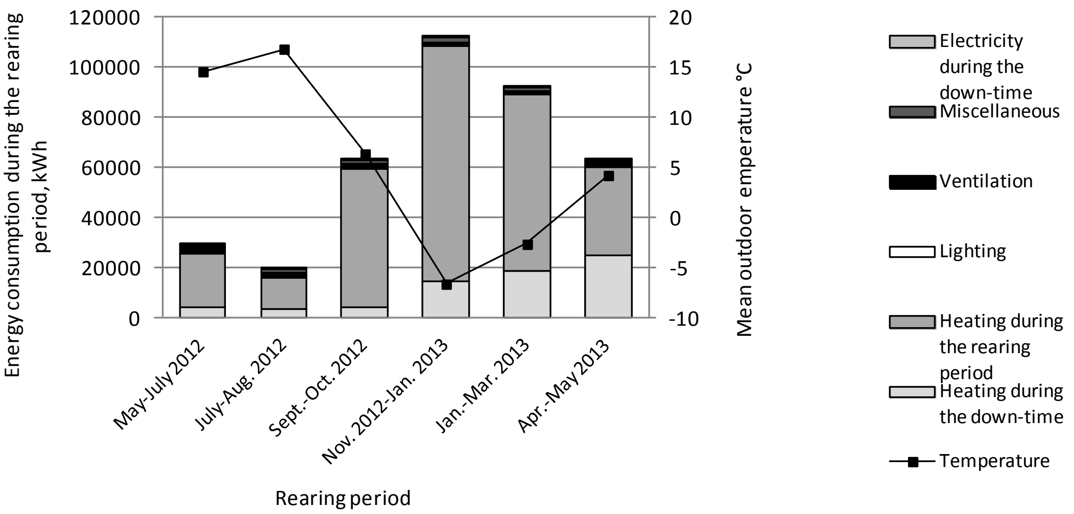


Fig. 10. Mean outdoor temperature during the rearing period and heating energy and electricity consumption during the whole rearing period.

CO_2 emissions

Figure 11 shows that the CO_2 emissions caused by electricity and heating vary between 0–631 kg CO_2 1000^{-1} kg of carcass weight. The combustion of sod peat and wood chips cause the highest and lowest CO_2 emissions, respectively. Green electricity use does not significantly affect the emissions because it´s share of the total direct energy consumption is low. Figure 11 shows that the high use of fossil energy in heating on a farm can lead to high CO_2 emissions compared to a farm that only uses bioenergy for heating. Using energy effectively is the most important aspect even if bioenergy is used more for heating in the future. Because bioenergy is lower in cost than fossil energy it can lead to energy being used less effectively.

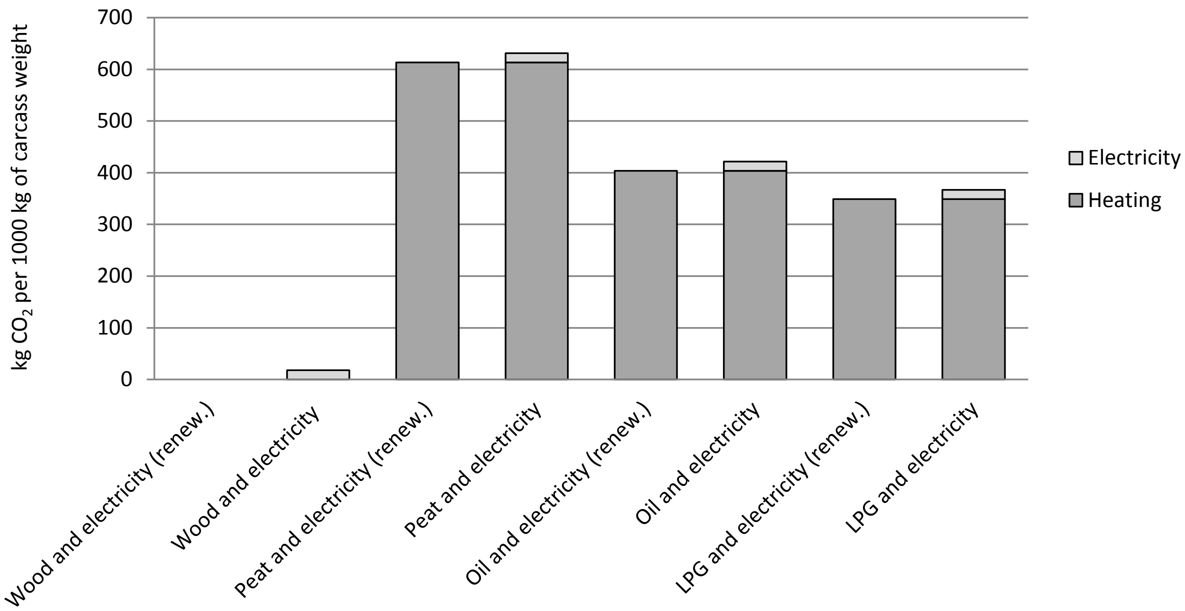


Fig. 11. CO_2 emissions of different fuel options.

Figure 12 shows the CO_2 emissions of combustion and electricity (mean electricity) for broiler flocks during the different seasons. Wood chips and sod peat were used as heating fuel in the first and second figures, respectively. The second figure shows higher CO_2 emissions of production periods during the cold weather. If biofuels are used then the high CO_2 emissions can be avoided.

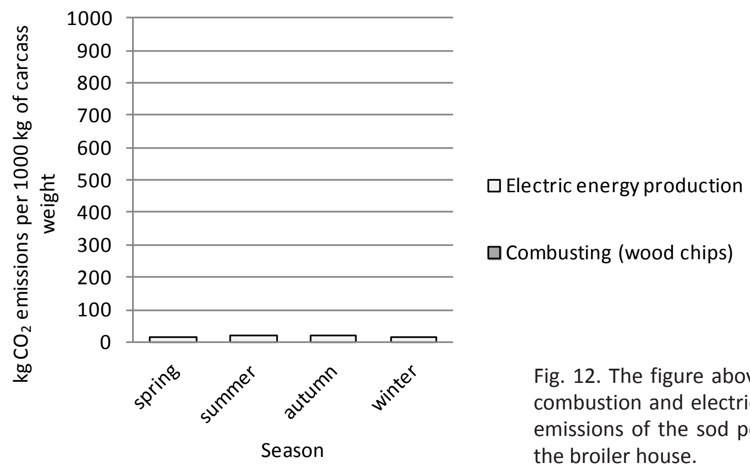
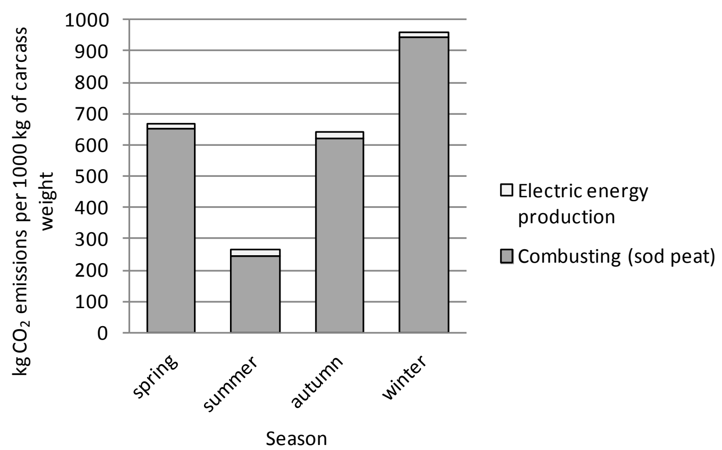


Fig. 12. The figure above shows the CO_2 emissions of wood chips combustion and electric energy use and the figure below the CO_2 emissions of the sod peat combustion and electric energy use of the broiler house.



Beef and dairy production causes the greatest GHG emissions in the animal production industry in the EU. Poultry emissions per produced meat kilogramme are lower than those of beef (e.g. Weidema et al. 2008, Lesschen et al. 2011, Weis and Leip 2012). This is because beef and dairy production cause more CH_4 and N_2O emissions than poultry production. Poultry is also more effective at converting feed energy to meat energy and less field area is needed for feed production. The greatest GHG emissions of broiler meat production come from land use and land use change (Fig. 4). Feed production therefore causes the largest GHG emissions when all production inputs are considered. CO_2 emissions from heating depend on the fuel source in questions. Emissions from electricity are only a small part of the total emission load of broiler production.

Conclusion

Results showed that heating energy was the highest direct energy input in the broiler house and that is where the largest direct energy saving potential of broiler houses can be found. Most of the energy is lost through ventilation. A heat recovery system, optimally working ventilation system and good insulation save heating energy. Finnish farmers are currently not interested in using heat recovery systems on broiler farms because no experience exists on the functionality of heat exchangers in cold climates. Heating also causes high CO_2 emissions when it is based on fossil fuels. Many Finnish broiler farms currently use bioenergy for heating. This means that the CO_2 emissions of combusting are low compared to countries with lower heating energy consumption that is produced by fossil energy.

Electricity was only a small portion of the total direct energy consumption of the broiler house. Ventilation and lighting consumed 37% and 19% of the total electricity consumption, respectively. Energy-efficient lights and fans hence have an important role in conserving electricity. Modern broiler house management is well organised. The houses have automated illumination, ventilation and feeding systems. These function effectively and no high energy saving potential can be found.

Feed production energy consumption has to be addressed when total energy consumption is inspected. When only direct energy consumption is looked at, ventilation control and heat recovery from ventilation are important. Energy efficiency should be taken into account, especially when new houses are built and when renovations are necessary in older broiler houses.

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