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A case study of energy consumption measurement system in broiler production

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Abstract. Energy savings in animal production have become increasingly important due to climate change and rising energy prices. In order to find potential savings, the energy consumption and its allocation inside the production systems must be known.
The biggest energy input in broiler production is feed. To reduce this energy input the savings must be done in crop and feed production chain. This study focused on the direct energy consumption inside the broiler house. Ventilation, lighting, feeding and heating systems consume also a considerable large amount of energy. However, information of this energy consumption is incomplete, and variation between different locations, farms and broiler batches is large.
In this study, the energy consumption of broiler production was measured in one insulated broiler house in Southern Finland. Energy consumption was measured from ventilation, lighting, feeding and heating during broiler batches. Also environmental factors, such as indoor- and outdoor temperatures, carbon dioxide level and relative humidity were measured continuously, because they have an effect on energy consumption and the microclimate inside the building must be kept good. This data can also be used in calculations of ventilation heating demand.
Energy consumption of ventilation, feeding and lighting were measured with current clamps. Clamps were located in the electrical center, and energy consumption was calculated from the measured current and voltage. Data was saved on a data logger. Heating energy was measured from the heating pipes. Energy consumption was calculated from the temperature difference of incoming and outgoing water and water flow rate.
Measured data was uploaded from the data loggers after every broiler batch. Energy consumption was calculated for each broiler batch and per kg of slaughter weight.

Key words: energy consumption, energy measurement, broiler production.

Introduction

Energy savings have become increasingly important due to the climate change and rising energy prices. Today the largest economic cost in poultry production is feed (Tike, 2010). Fuel and electricity costs were still quite small compared to the cost of feed, but their share of total costs is predicted to increase in the future.

In order to optimize energy consumption and to find potential savings, the energy consumption and its allocation inside the production systems must be known. The most reliable way to find out energy consumption in broiler production is to measure it. For example Baughman & Parkhurst (1977), Tabler (2007), Hörndahl (2008) and Liang et al. (2009) have measured energy consumption in broiler production. Baughman &

Parkhurst (1977) measured direct (fuel and electricity) and indirect (feed) energy consumption in two broiler houses, one was insulated and ventilated (environmental house) and the other was uninsulated with drop curtain side walls (conventional house). Results showed that the conventional house used more energy in the form of liquefied petroleum gas than the environmental house. Electricity consumption was higher in the environmental house than in the conventional house. Energy consumption of feed was the major energy input in both houses. However, energy input of feed per kg of live weight was lower in environmental house because of better feed conversion. A conclusion was that environmental house was more energy efficient. Results showed that the electricity consumption of environmental house was 0.374 kWh per kg of live weight during the winter trial and 0.424 kWh per kg during the summer trial. Hörndahl (2008) measured direct energy consumption in two identical broiler houses in Sweden. The major energy input was the heating oil followed by lighting and ventilation. Energy consumption was highest during the first growing week of birds. Results showed that electricity consumption of five batches was 0.13 kWh per bird and energy consumption of heating and manure handling 0.78 kWh per bird.

Tabler (2007) and Liang et al. (2009) measured energy consumption of broilers houses before and after renovation. After renovation (open curtain production systems) all houses were converted to the solid wall enclosed system with drop ceilings, tunnel ventilation and cooling pads (Liang et al., 2009). Electricity consumption was higher in enclosed house than in open-curtain house. Liang et al. (2009) reported that electricity consumption after renovation was 0.102 kWh per kg of market bird weight. Fuel use per live weights of birds was lower after renovation than before. Energy consumption in broiler production can be calculated also theoretically. In that case the results do not include the variations of different housing systems.

Energy is used in broiler production directly as fuel and electricity and indirectly as feed. Previous studies show that feed is the major energy input in broiler production (e.g. Baughman & Parkhurst, 1977; Katajajuuri et al., 2006). Energy is used indirectly in feed production chain (e.g. grain drying, fuel and fertilizers). The biggest direct energy input in broiler production is energy for heating. Especially cold seasons increase the energy consumption of heating. Energy input of electricity is quite small compared to heating. Extra ventilation is needed in summertime and therefore the electricity consumption is higher than in wintertime. Energy consumption also varies a lot between regions, farms and broiler batches.

In Finland approximately 190 farms grow broilers (Siipikarjaliitto, 2010). Production is based on contract production. Growing circumstances are quite similar on all these farms. However, growing period of broilers varies from 32 to 39 days. At the moment the direct energy consumption figures on Finnish broiler farms are mainly based on theoretical calculations or information received from the farmers. Energy consumption measurements are needed to verify the calculations.

The aim of this study was to find out energy consumption in Finnish broiler production and the allocation of used energy inside the production system.

Materials and methods

Energy consumption was monitored in one broiler house (dimension of one section 3.5 x 20 x 81 m), which is located in Southern Finland. Inside the broiler house there are two identical enclosed broiler sections and all preliminary results are from one section (later broiler house). Broiler house is insulated (12 cm) and built from concrete. Approximately 6 broiler batches are grown per year with approximately 28,000 broilers per batch. Chicks arrive to the broiler house at the age of one day and weight of 40–45 g, and are slaughtered after 37–39 days growing period. Average slaughter weight of birds is 1.8 kg. After every broiler batch there is a down-time of 3–5 weeks in the production. During this time the broiler house is cleaned and disinfected.

Broiler house is totally enclosed system. All devices (feeding, ventilation, illumination, heating) are controlled by computer. Broiler house is heated mainly using renewable energy. There are two heating pipes on the walls of broiler house and also three heat exchangers in the middle of the house. Temperature is 33–34°C when birds arrive into the house and it is decreased stepwise to 21°C when broilers leave. Total 84 fluorescent lights (36 W per light) are used for lighting. Lighting program includes at least 6 hours dark and 18 hours light time. Lights are at the brightest when birds arrive and they are dimmed stepwise when the birds grow. Two adjustable-fans and three on-off –fans are managed basic ventilation. In summertime also tunnel ventilation is needed.

Energy measurements started during the year 2011 and they are still continuing. Energy consumption of ventilation (tunnel ventilation -fans) and lighting was measured at 20 minutes intervals and adjustable-fans and on-off -fans at 10 minutes intervals during the broiler batches. Energy consumption of heating was measured continuously at 2 minutes intervals. Total energy consumption measurement of broiler house and feeding devices started in January 2012. Energy consumption of feed was also calculated. Amount of used feed during the broiler batches was weighed by automatic feeding system. Also indoor- and outdoor temperatures, indoor relative humidity and carbon dioxide level were measured at 30 minutes intervals.

Table 1 shows the instrumentation which was used in the broiler house. Energy consumption of ventilation, lighting and feeding devices was measured with current clamps and voltage sensor and data was collected to the data loggers. Clamps were located in the electrical center, and energy consumption was calculated from the measured current and voltage in the electrical grid. Energy consumption of heating was measured from the heating pipes with an energy meter. Energy consumption of heating was calculated from the temperature difference of incoming and outgoing water and water flow rate. Data was uploaded from the loggers after every broiler batches. Energy consumption was calculated per broiler batch and per kg of slaughter weight. Energy consumption was presented as kWh.

Table 1. Used instrumentation in the broiler house

Measured value	**Instruments**
Electricity consumption of lights and tunnel ventilation –fans	CHAUVIN ARNOUX - P01105109Z Mini current clamps (sensitivity 100 mV A^{-1}, accuracy ≤10%) and Datataker DT80 data logger
Electricity consumption of ventilation (adjustable and on-off –fans)	CHAUVIN ARNOUX - P01105109Z Mini current clamps (sensitivity 100 mV A^{-1}, accuracy ≤10%) and HOBO Pendant data logger
Electricity consumption of automatic feeding system	Current clamps 533-0637, 3 phase Entes Powermeter and HOBO Pendant data logger
Total electricity consumption	Current clamps 533-0637, 3 phase Entes EPR-04S Powermeter and HOBO Pendant data logger
Heating energy consumption	Saint-Gobain ACTARIS CF ECHO II energy meter and HOBO Pendant data logger
CO_2 content of the broiler house	SenseAir K30 infrared sensor (accuracy ±5%) and A-lab aCG-100 data logger
Indoor temperatures	PT1000 sensors and A-Lab aCG-100 data logger
Outdoor temperatures	Tinytag Ultra TGU-1500 data logger (accuracy ±3%)
Relativehumidity	Honeywell HIH 4000 sensors and A-Lab aCG-100 data logger

Fig. 1 shows the measured values of the broiler house. The current was measured from each AC-phase and the voltage was measured between one phase and zero. The voltage was measured only from one phase because it was assumed that the voltage in each phase was the same. Power was calculated from current and voltage with equation 1. With this measurement system the total power was achieved. The load may introduce phase shift between voltage and current and the active power is then lower than total power.

$$P = U \cdot I \tag{1}$$

P = electric power
U = voltage
I = current

To find out the heat loss through the ventilation, the ventilation rate was calculated indirectly from broiler weight and their carbon dioxide production. Broiler growth during the period is linear and a mean daily weight gain was used in the calculations. The carbon dioxide production was calculated with CIGR1984 (Mannfors & Hautala, 2011) calculation method. The ventilation rate can, when we know the number of animals and the CO_2 production of one animal, calculated with equation 2

(Mannfors & Hautala, 2011). The values were calculated as daily average values because the CO_2 production is given as daily average value.

$$q_V = \frac{1000 \cdot P_{CO_2}}{C_{CO_2in} - C_{CO_2out}} \tag{2}$$

q_V = ventilation rate, $m^3\,h^{-1}$

P_{CO_2} = animal carbon dioxide production, $l\,h^{-1}$

C_{CO_2in} = measured CO_2 content in the broiler house, ppm

C_{CO_2out} = outdoor CO_2 content in the broiler house, 350 ppm

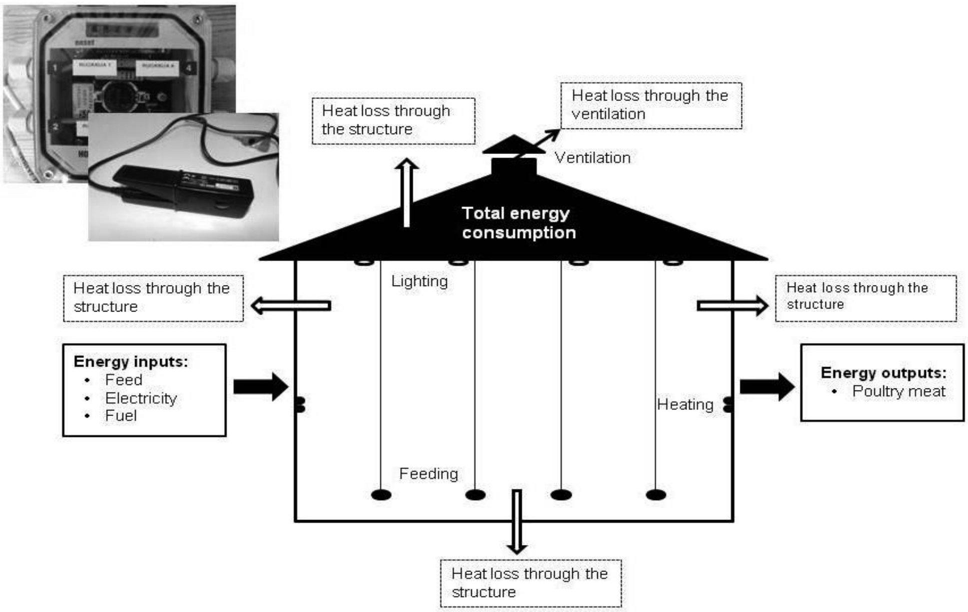

Fig. 1. Broiler house measurement system.

From the ventilation rate the heat loss power through ventilation could be calculated with equation 3.

$$P = c_i \cdot \rho_i \cdot q_V \cdot (T_{in} - T_{out}) \tag{3}$$

P = heat loss power through ventilation;
c_i = air specific heat capacity, 1,0 kJ $(kgK)^{-1}$;
ρ_i = air density;
q_V = ventilation volume flow;
T_{in} = indoor temperature;
T_{out} = outdoor temperature.

The broilers also produce heat, the sensible heat production was calculated with CIGR2002 method (Mannfors & Hautala, 2011), equation 4.

$$P_{sens} = 10.62 \cdot M^{0,75} \cdot \left[0.61 \cdot \left(1 + 0.020 \cdot (20 - T)\right) - 2.28 \cdot 10^{-4} \cdot T^2\right] \tag{4}$$

P = heat power [W];
M = broiler mass [kg];
T = temperature [°C].

Results and discussion

Table 2 shows measured energy consumption of illumination, ventilation and heating during the one broiler batch (from 28th of November, 2011 to 4th of January, 2012).

Table 2. Measured energy consumption of illumination, ventilation and heating

	Energy consumption kWh per batch	Energy consumption kWh per kg of slaughter weight
Lighting	443	0.009
Ventilation	974	0.021
Heating	85,300	1.8

Fig. 2 shows the microclimate inside the building during one batch. The batch starts with 32°C temperature and it ends with 20°C temperature. During the analyzed batch the outside mean temperature was 7.2°C. When the broilers gain weight, the temperature can be decreased and heavier broilers will produce more carbon dioxide, humidity and heat. The broiler house ventilation must be increased to move the excess carbon dioxide and humidity from the building.

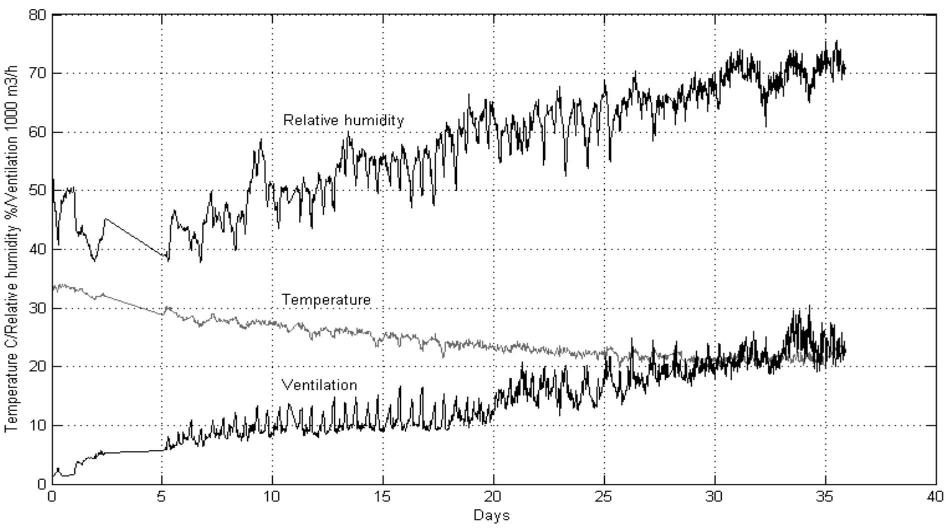

Fig. 2. Conditions inside the broiler house during one batch.

Fig. 3 shows the energy balance of the boiler house. Heating energy was the major direct energy input in broiler house. The main heat loss was building heat losses through structure, ceiling, floor and walls. Quite a lot energy was lost also through ventilation. These losses depend on the outdoor temperatures and the situation is quite different during winter and summer time. Heat losses could be reduced with better heat insulation or in the case of ventilation with heat recovery systems.

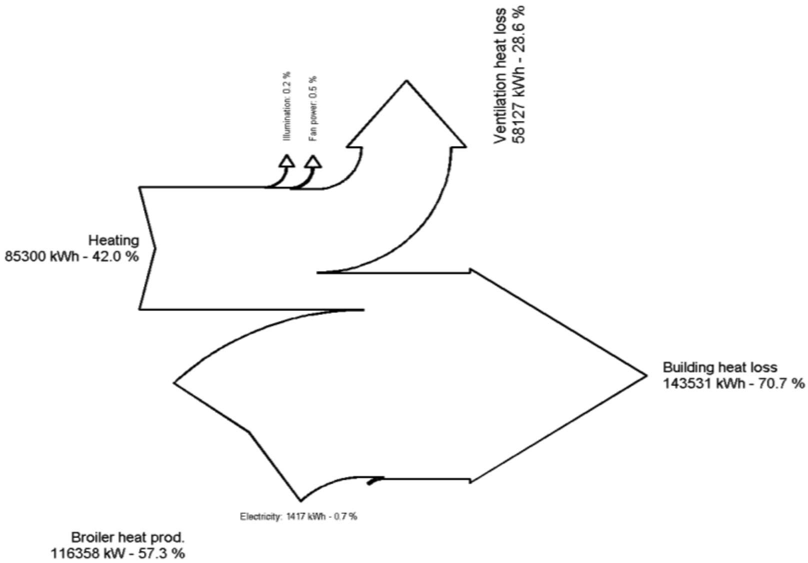

Fig. 3. Heat flows in broiler house.

Energy consumption of heating varied widely between broiler batches. Preliminary results of measurements showed that energy consumption during the broiler batches (six batches) varied between 0.4–2.0 kWh per kg of slaughter weight and 19,300–97,500 kWh per batch. Average energy consumption of heating was 1.2 kWh per kg of slaughter weight and 57,200 kWh per batch. If energy consumption of down time between broiler batches would be also included, energy consumption would be bigger (Fig. 4). Season had a big effect on energy consumption of heating. Especially during the cold seasons energy consumption was multiple compared to warmer seasons. Energy consumption of heating was highest during the first growing weeks of the birds and it decreased when birds grew. The result showed that weather and age of birds have biggest effect on energy consumption of heating. However, energy consumption of heating was also quite high during the last growing weeks in cold seasons because of heat losses thought the ventilation were quite large. Energy consumption of heating was higher in this study than previous studies (e.g. Hörndahl, 2008; Liang et al., 2009). Northern location and cold weather is probably reason for higher heating energy usage. Katajajuuri et al. (2006) have got almost similar results in Finnish broiler production than in this study. In their studies energy consumption of heating was on average 1.3 kWh per kg of slaughter weight (range 0.94–1.64 kWh per kg of slaughter weight).

Electricity for ventilation comprised the major part of total electricity usage. Energy consumption of ventilation was approximately 0.02 kWh per kg of slaughter weight (two broiler batches) during the winter season. Variation in energy consumption between batches was quite minor. Three on-off -fans and two adjustable-fans managed basic ventilation in broiler house. Fig. 5 shows measured electricity power of fans during one broiler batch. Extra ventilation was also needed (tunnel ventilation -fans) during the warmer seasons. Preliminary results were measured during the wintertime so energy consumption of ventilation was probably lower compared to summertime when extra ventilation was needed.

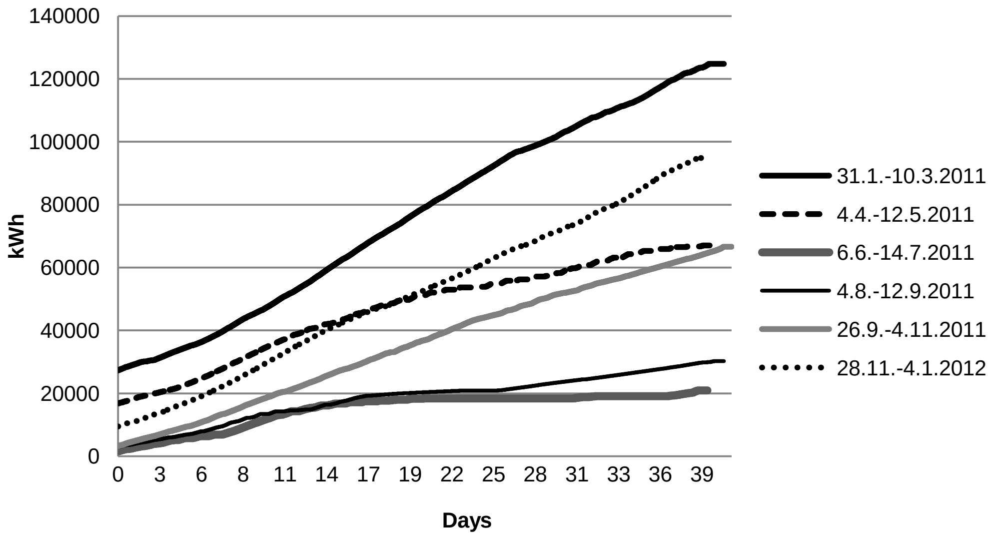

Fig. 4. Cumulated heating energy consumption during the six broiler batches.

Energy consumption of lighting was almost half of the energy consumption of ventilation. Preliminary energy consumption of lighting was 0.009 kWh per kg of slaughter weight during the one broiler batch. Fig. 6 shows electricity power of lights and lighting program during the 37 days growing period. Lights were switch on all the time during the first and the last growing days. After first growing days the lights were stepwise dimmed to normal stage. Every 24 hours cycle included at least six hours dark period. Dark period was divided into two parts in this broiler house.

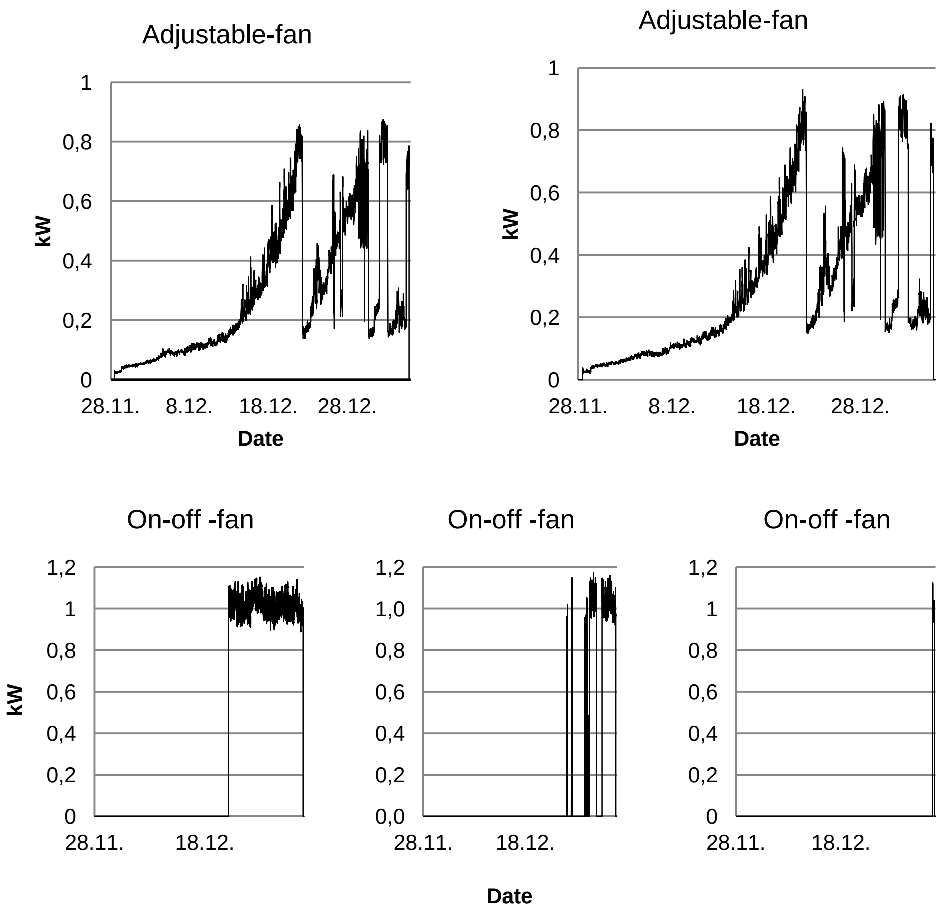

Fig. 5. Electricity power of on-off and adjustable -fans (median, n 6) during the one broiler batch.

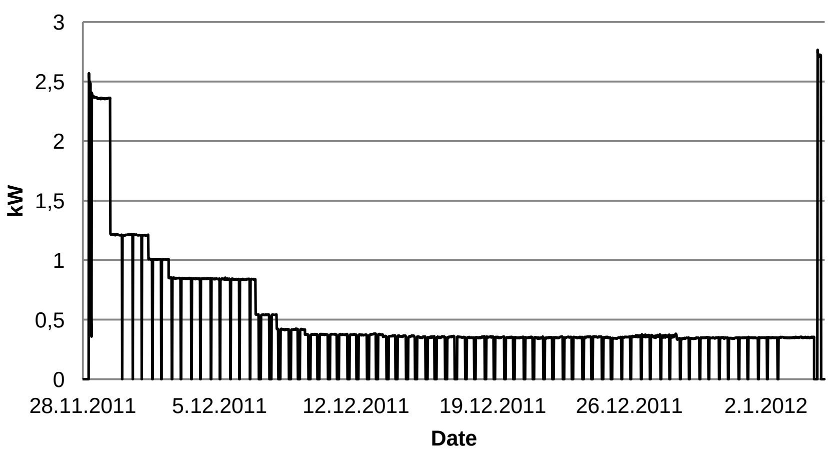

Fig. 6. Electricity power of lights during the one broiler batch.

Electricity consumption was minor compared to energy consumption of heating or energy input of feed. Ventilation consumed relatively more electricity than lighting. Also Liang et al. (2009) have got similar results. According to Hörndahl (2008) lighting consumed more energy than ventilation. Difference between electricity consumption seems to be result of different lighting program, building type and light type.

Conclusions

Energy consumption on individual farms varies lot. Many factors such as climate, season, building type, devices, broiler batches, practices and management skills have effect on energy consumption on individual farm. In order to find potential energy savings, the energy consumption and its allocation inside the production systems must be found out. Energy measurement and energy balance calculations are the most reliable way to find out energy consumption.

Major energy inputs in broiler house were feed and fuel for heating. Electricity consumption was quite minor compared the energy input of feed or heating. Age of birds and season had effect on energy consumption. Previous studies show also, that relatively portion of energy consumption depends on birds age and outdoor climate.

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