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Electricity and Fuel Usage of Aviary Laying-Hen Houses in the Midwestern United States

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Keywords
Aviary, Energy Use, Electricity, Propane, Ventilation Efficiency

Disciplines
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Electricity and Fuel Usage of Aviary Laying-Hen Houses in the Midwestern United States

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Abstract. Recently, there has been much interest in and movement toward alternative housing systems for laying hens. Associated with the movement are many questions to be addressed concerning sustainability of such systems. This study quantifies electricity and propane usage in two side-by-side aviary hen houses each holding 50,000 laying hens, located in Iowa, USA. Electricity usage was also partitioned into different housing components, including ventilation, lighting, and manure-drying. Electricity for ventilation is most variable in that it was the largest of all the components with 60% of the total electric energy in summer but only approximately 5% in winter. The mechanical ventilation efficiency was approximately 25.5 m³/(hr-Watt) (15 CFM per Watt) at static pressure of 12.5 Pa (0.05 inch water column). The continuously running manure-drying blowers accounted for the largest proportion of electricity use in winter with approximately 350 kWh daily consumption. Over the 15-month monitoring period, both houses had an average electricity cost of 3.6 cents per kg of egg produced (based on the rate of $0.09/kWh). The fuel usage was minimal (less than 425 liters of propane in one year), although the winter weather during the monitoring period was milder than the historical climatic conditions.

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Introduction

In the past decade there has been increased pressure to move from conventional laying-hen cage houses (both high-rise and manure-belt systems) to cage-free and/or enriched cage housing. With this pressure there are many questions about the performance of these alternative housing systems. One concern in this transition to the much lower stocking-density housing systems is what will happen with utility costs, including electricity and fuel use.

It has been reported that the largest electricity usage in egg production comes from mechanical ventilation (Stout, 1984, Flout and Baird, 1980). Most data on electricity use in the US are from earlier studies which reflect conventional housing with high-rise manure management and incandescent lighting. Changes in modern housing and management practices make it necessary to collect more up-to-date data. Understanding the efficiency of mechanical components in the houses may affect purchasing consideration, particularly with the major electricity consumers. A recent study conducted in the European Union (Sonesson et al., 2009) indicates or suggests the following: a) similar to earlier studies ventilation and lighting are a large portion of electricity consumption; b) to improve energy efficiency, energy-efficient lighting should be used, but normal fluorescent lighting should be avoided due to flickering; c) do not dry manure unless it is necessary for transporting/stacking due to energy demands; d) up to 10% of the energy savings could be achieved by cleaning and following good maintenance of the houses and fans in particular. The objectives of this study were to quantify the electricity and fuel use in two aviary laying-hen barns in the Midwestern US.

Materials and Methods

Two aviary hen houses in a double-wide building located in Iowa were used in this field study. Each house measured 168 m x 19.8 m (550 ft x 65 ft) with a capacity of 50,000 hens (Hy-Line Brown) and had a production cycle from approximately 17 to 80 weeks of age (new flock started in late April 2010 in barn 3 and middle September 2010 in barn 2). A cross-sectional schematic of the houses is shown in figure 1. The houses had open litter floor, nest boxes, and perches.

![Cross-sectional view of the aviary hen house](image)

Figure 1. Cross-sectional view of the aviary hen house (one side of the double-wide house).

To minimize floor eggs and improve manure management, the hens were trained to be off the floor and return to the aviary colonies at night and remained in the colonies until the next morning. Each row had three tiers and manure belt with a manure-drying air duct was placed underneath the lower two cage tiers. The three tiers were divided into nest, feeding, and drinking area from top to bottom. Each house had 20 exhaust fans, all on one sidewall, including twelve 1.2 m, four 0.9 m, and four 0.5 m fans. Ceiling box air inlets were used (75 bi-directional
Compact fluorescent lighting was used in the inspection and litter floor aisles. Four 73.25 kW (250,000 BTU/hr) heaters were placed equidistant on the sidewall to provide supplemental heat. Ventilation for the barns was controlled by management software (Command III, Poultry Management Systems, Inc., Saranac, MI). Based on a selected setpoint temperature, if the house temperature deviated more than 1.1°C (2°F) from the setpoint, every 2 minutes the controller would turn on or off the next stage of fans. If at minimum ventilation the house temperature was still 2.2°C (4°F) from setpoint, the heaters would operate.

This site had two 240V 3-phase delta supplies into each house. There was also one 240V supply between the houses and manure storage used to run all manure belts. Three panels were involved: the first panel covered lower ventilation stages, two of the manure belt blowers, and some lighting; and the second and third panels covered feed and egg systems, remaining lighting, the remaining blower, 20 mixing fans, electrical outlets, and the automatic curtains.

Fan, lighting, manure blower, and total house current were measured every second using inductive current sensors (AcuAmp ACTR 200) that were interfaced with a data acquisition system (DAQ, Compact Fieldpoint, National Instruments, TX). The 1-second data were averaged to 30-second values and output to the on-site PC. The data for whole house current came from 6 current sensors, each meter measuring one phase of a supply. The eight ventilation stages were measured with each leg of all eight stages through one of three current sensors. The lighting was run through a seventh current sensor, and the three legs of one blower were run through the eighth current sensor. All three blowers operated continuously in the same manner.

While these meters gave us continuous current, to calculate electricity use, a relationship had to be developed. A Fluke 1735 power logger (Fluke, Everett, WA) was used to develop this relationship. The power logger collected data from each independent electricity source for 4 days. The power logger recorded current and voltage from each leg as well as power factor, total, reactive, and apparent power for the whole circuit. These data were used first to verify current measurements from the current sensors. Then the data were used to develop proper power factors to use in calculating electricity use from the current sensors. After logging the supply power consumption for the whole house, individual circuits were checked for short periods of time (~10 minutes per circuit to identify power consumption by individual systems).

![Image of power logger and current sensor](image_url)

Figure 2. Left: the power logger (right oval) used to verify and develop power relationships for the inductive current sensors (left oval). The electric conduit cover was temporarily removed for making the measurement. Right: close-up view of the current sensor.

For fuel monitoring, temperature-compensated diaphragm gas meters (AM-205, Elster American, Nebraska City, NE) were placed in-line between the propane tanks (1890 liter or 500 gallons each) and the two 73.25 kW (250,000 BTU/hr) supplemental heaters along the sidewall of the house that they serviced. There were two tanks for each house, hence two meters. The
gas meters had digital counters that were read weekly. In addition, each meter had pulse output collected at 1-second intervals to the data acquisition system (DAQ, Compact Fieldpoint, National Instruments, TX). The data, similar to current meter readings, were output as 30-second averages.

Heater operation was determined by the management program (Command III, PMS, Inc., Saranac, MI) which had an input for the setpoint of the house. If the temperature dropped below the set point by more than 1.1°C (2°F), every 2 minutes the controller would turn off another stage. The heaters ran when the house temperature dropped by 2.2°C (4°F) from the setpoint at minimum ventilation. This means heater runtime was controlled exclusively by house temperature. To assess if the heaters were running at the necessary moments, balance temperature ($T_{bal}$), i.e., the outside temperature below which supplemental heat is needed to maintain target indoor temperature and RH, was calculated for the building and operational characteristics. The $T_{bal}$ equation is of the following form,

$$T_{bal} = t_i - \frac{3.6 \times 10^6 \cdot SHP \cdot BW \cdot n \cdot (W_i - W_o)}{MP \cdot BW \cdot C_p + 3.6 \times 10^6 \cdot (W_i - W_o) \cdot (BHLF)}$$

[1]

Where:

- $t_{bal}$ = ambient temperature below which supplemental heat is used to maintain setpoint of indoor temperature and RH
- $t_i$ = indoor setpoint temperature (21.7; 23.6 °C)
- SHP = house-level sensible heat production (4.1 W/kg)
- BW = average body weight (1.79; 1.78 kg)
- $n$ = house population (48,875; 47,125 hens)
- $W_i, W_o$ = humidity ratio inside and outside (ambient) (kg water/kg dry air)
- MP = moisture production (1.25 g/kg-hr)
- $C_p$ = specific heat (1006 J/kg-°C)
- BHLF = building heat loss factor (1140 W/°C)

The values for $t_i$, BW, and $n$ were based on average production values for Dec 2010-April 2011 (house 2; house 3). The BHLF was calculated based on information from the barn design. SHP and MP values were adopted from Hayes et al. (2012). The humidity ratios varied based on the RH setpoint.

**Results and Discussion**

Both houses held fairly constant temperatures over the winter months. House 2 had a setpoint that was 1.6 to 2.8°C (3 to 5°F) lower than house 3. The setpoint of house 2 was increased in mid-February, while the setpoint of house 3 increased in December and again in mid-February. The higher temperatures in house 3 corresponded to lower ventilation rate (VR). RH in both houses was below 80% through most of the winter, but was consistently above 70%. Figure 3 shows these trends. VR was generally between 0.6 and 11 m$^3$/hr-bird.

From the power logger, the amperage and power factor for some specific circuits were identified. Power factors ranged from 0.82 for the 1.2-m diameter ventilation fans to 0.45 for the lighting. The current values give some valuable insight in power requirements by the systems. In these houses some portion of ventilation fans and manure-drying blowers ran continuously. The lights were on ~16 hours each day. The mixing fans ran intermittently. The egg belts ran
for just under two hours per day and the feed system ran for 15 to 20 minutes per feeding, 4
times a day. The manure-belt runtime depended on how often the belt was cleared (every 3
days in winter and every 7 days in summer). The manure belts were on a separate power
supply and therefore not included in the continuous current monitoring values calculated below.
From the individual circuit demands and the whole house power logging, the continuous current
monitoring can be converted to power use. Figure 4 shows the breakdown of monthly electricity
use for the monitoring period by major components. The ventilation was the most variable user
of electricity, ranging from 32 kWh per day to almost 750 kWh per day. Electricity use for the
blowers was consistent at about 345 kWh per day. Lighting and feeding systems were also
consistent at approximately 30 kWh and 20 kWh per day, respectively. The final component
included mixing fans, electrical outlets, the egg belts, and the curtains on ventilation fans that
were used in place of shutters. Figure 5 displays the percentage of total consumption by each
component on a monthly basis. Stout (1984) broke down energy use for egg production as 64%
in mechanical ventilation, 17% in lighting, 5% in operation of feeders, 5% in miscellaneous, and
9% in operation of egg coolers. These values were from housing systems without manure belts
and with incandescent lighting. Although the two sets of data between the current study and the
report by Stout (1984) are not directly comparable, the general relationship agreed. Figures 4
and 5 show the average of both houses. For each month, the difference in total electricity use

Figure 3. Daily temperature and relative humidity (RH) of the two aviary houses monitored and
the ambient.
between the two houses is less than 10%. The exception is for September and October 2011, where house 3 was repopulated with a new flock and had ventilation demands that nearly doubled those in house 2. When ventilation power consumption was removed, the houses' monthly total consumption difference was less than 3%.

Figure 4. Monthly mean daily electricity use (kWh/day) partitioned into major components for the monitored aviary hen houses (~50,000 hens per house). Other components include egg belts, mixing fans, curtains on fans, and electrical outlets.

![Figure 4](image1.png)

Figure 5. Electricity use distribution among major components (as % of monthly total) for the monitored aviary hen houses (~50,000 hens per house). Other components include egg belts, mixing fans, curtains on fans, and the electrical outlets.

![Figure 5](image2.png)

From the monthly values, total electricity use of both houses for the 15-month period can be calculated. This results in a total power usage of approximately 365 mWh/house over the 15 months. In order to calculate the electric energy use on the basis of per kg egg, farm production data were used to obtain the monthly egg production of 60,575 kg egg/house. A summary of European studies by Sonesson et al. (2009) suggested electricity demands between 175 and 450 kWh per metric ton of egg. The current study showed 402 kWh per metric ton of eggs. Assuming an electricity rate of 9 cents per kWh, the electricity cost amounted to 3.6 cents per kg egg (64 g/egg). With the Hy-Line Brown hens used in this current study, this equates to 2.8 cents per dozen eggs. The European Union has been in transition toward alternative housing...
systems for a number of years. The ten European countries involved show an average increase of 20% in utility cost when moving from traditional cage housing to cage-free barn housing. Although our value cannot be directly compared, a recent value for conventional cage barns in the Midwestern US has been estimated to be 1.6 cent/kg egg based on a producer survey for life cycle analysis of egg production and processing (Ibarburu, 2012, Personal Communication).

Because the ventilation was monitored using current sensors, a relationship between building VR and power usage can be identified. The VR was determined based on in situ calibrated fan curves with fan assessment numeration systems (FANS) sized 0.9 m (36 inch), 1.2 m (48 inch), and 1.35 m (54 inch) (Gates et al., 2004). Individual fan curves were established for each stage (1-8) including operational ranges of the variable speed control of the lower stages. As well the current and power factors were determined for the variable speed fans at various speeds and operating static pressures (Table 1). For the larger fans the m³/hr and m³/(hr-W) (CFM per fan and CFM/W) were determined at the static pressures of 12.5 and 25 Pa (0.05 and 0.1 inches W.C.). These values were compared to Bioenvironmental and Structural Systems Laboratory (BESS) fan performance data. For the stage 2 fans the on-farm VR was calculated as 18,250 m³/hr at 12.5 Pa (10,740 CFM at 0.05 inch W.C), while BESS lab reports 18,700 m³/hr (11,000 CFM). For stages 3-8, the on-farm VR was 38,105 m³/hr (22,428CFM) while BESS reports 39,900 m³/hr (23,500 CFM). Both sets of fans performed well in the field. However, the CFM per Watt relationship, namely, fan efficiency, was not as strong. Stage 2 had an efficiency of 15.3 and 13.9 CFM/Watt whereas BESS lab reports 20 and 17.5 CFM/Watt for 0.05 and 0.1 inch W.C. static pressure, respectively. For stages 3-8 the 15.7 and 14.5 CFM/Watt were also less than the BESS lab reporting values of 20 and 18 CFM/Watt for 0.05 and 0.1 inch W.C. static pressure. Overall, the CFM per Watt was 75-80% of the BESS Lab reported values.

Table 1. The ventilation rate (m³/hr & CFM) to power (W) relationship.

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<th>Hz</th>
<th>SP (Pa)</th>
<th>m³/hr-stage*</th>
<th>CFM-stage</th>
<th>Amp-stage</th>
<th>Power Factor</th>
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* Air flow rate per fan calculated using in-situ performance curves; highlighted values relate to BESS Lab fan performance data.

The final consideration in this paper is fuel usage. Both barns used heaters throughout the winter 2010-2011 and spring 2011. There was no heater use in fall 2011 because the heaters...
were intentionally turned off at the electrical panel. Over the entire monitoring period house 2 had lower fuel use than house 3. The set-point temperature for house 2 averaged 1.7°C lower than house 3 over the 6 months reported for propane fuel use (Fig. 6). It is important to note the propane usage was not greatest during the coldest periods, but instead in the later spring when there were major swings in daily temperature. Overall house 2 used less than 75 liters (20 gal) of liquid propane while house 3 used approximately 400 liters (110 gal).

Based on the $T_{\text{bal}}$ equation [1] described above, the daily $T_{\text{bal}}$ averaged -2.4°C (27.7°F). The average daily ambient temperature generally fell below $T_{\text{bal}}$ (64 out of 96 monitored days $T_{\text{amb}} < T_{\text{bal}}$) for the months Dec. 1, 2010 through March 31, 2011. However, the heaters only ran 8 days over this period. As was stated above, the ventilation control in this barn was managed to maintain indoor temperature, not RH. Because the heaters did not regularly run over the winter months, the minimum ventilation designed was lower than the ventilation needed for RH management. When the humidity ratios were adjusted from maintaining 60% to 80% RH, the $T_{\text{bal}}$ dropped by 5.4 °C ($T_{\text{bal}} = -7.8°C$). With this drop, the number of days when supplemental heat was needed was reduced to 13 days. The 8 days heaters did run belonged to these 13 days. Based on an energy content of 7.1 kWh/liter of propane (DOE, 2011), the propane needs in each barn to maintain $T_{\text{bal}}$ was 1003 liters at 80% RH. Again this number is much higher than the monitored fuel use. Because the heater runtime was not actually determined by setpoint temperature, but instead it was run 2.2°C lower, this difference was not unexpected. Overall, the VR in this barn was managed for barn temperature. The minimum VR was lower than that needed to maintain RH, as evidenced by the lower propane usage.

![Propane Usage By Month](image)

Figure 6. Propane usage per aviary hen house during winter and spring 2010-2011.

Conclusions

Ventilation system is the most variable user of the monitored aviary laying-hen houses in that in summer it accounted for almost 60% of the total electric energy, while in the winter it accounted for approximately 5%. The efficiency of the ventilation system (26 m³/hr-Watt) was less than 80% of the reported fan performance efficiency. The manure-drying blowers were the second major user of electricity (largest in winter), accounting for 25% to 60% of the monthly electricity use. Electricity cost over the 15-month production period averaged 3.6 cent per kg of egg produced (i.e. 0.39 kWh/kg egg at a cost of $0.09/kWh). The propane fuel usage was minimal (0.26 mL/kg egg); meaning that the ventilation scheme was successful in maintaining setpoint temperature using the birds sensible heat. However, because the ambient temperatures were below $T_{\text{bal}}$ and the heaters were not running regularly, RH in the barns was consistently between 70 and 80%, with 23 days having a portion of the day above 80%. Over-ventilation may be occurring on days (in spring) where there are large swings in ambient temperature.
Acknowledgements

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