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Yi Liang
University of Arkansas, Fayetteville

G. Tom Tabler
University of Arkansas, Fayetteville

Susan E. Watkins
University of Arkansas, Fayetteville

Hongwei Xin
Iowa State University, hxin@iastate.edu

Ivan L. Berry
University of Arkansas, Fayetteville

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Abstract

Seventeen years of electricity and propane fuel use data collected from broiler production houses at the University of Arkansas Applied Broiler Research Farm (ABRF) in Northwest Arkansas were analyzed to quantify the relative effect of open-curtain versus totally enclosed housing systems on energy use. The ABRF consists of four commercial-scale 12- × 121-m (40-× 400-ft) houses and raises broilers under standard production contracts. After the first 15 years of production with open-curtain system, all houses were converted to the solid-wall enclosed system with drop ceiling, tunnel ventilation, and cooling pads in early 2006. The renovations led to reduction of the overall building heat loss factor (W·K-1) from 1389 to 586 for the two steel-frame houses and from 1022 to 428 for the two wooden-truss houses. Mean outside temperature (ranging from 14.7°C to 17.5°C or 58.5°F to 63.5°F in annual mean temperature during the 17-year period) and bird age were found to be the major factors affecting propane fuel usage and ventilation fan electricity usage. Electricity for ventilation and lighting comprised about 87% of the total electricity usage. Annual electricity usage was 27% higher with the enclosed system than with the open-curtain system (102 vs. 80 kWh per 1000-kg market bird weight or 46.4 vs. 36.4 kWh/1000 lb), due to loss of natural daylight and increased mechanical ventilation in the enclosed system. Propane use was comparable between curtain-sided and solid-wall housing schemes, averaging 76- and 65-L/1000 kg market bird weight (9.1 vs. 7.8 gal/1000 lb) before and after renovation, respectively. Higher fuel cost resulted in higher fuel expenditure for winter heating than electricity expenditure for summer cooling in this region. With increasing energy costs, analysis of energy use, as conducted in this study, will assist the decision making of growers to improve energy efficiency or explore alternative energy application.

Keywords

Broiler production, Electricity consumption, Energy cost, Fuel usage

Disciplines

Agriculture | Bioresource and Agricultural Engineering

Comments

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ENERGY USE ANALYSIS OF OPEN-CURTAIN VS. TOTALLY ENCLOSED BROILER HOUSES IN NORTHWEST ARKANSAS

Y. Liang, G. T. Tabler, S. E. Watkins, H. Xin, I. L. Berry

ABSTRACT. *Seventeen years of electricity and propane fuel use data collected from broiler production houses at the University of Arkansas Applied Broiler Research Farm (ABRF) in Northwest Arkansas were analyzed to quantify the relative effect of open-curtain versus totally enclosed housing systems on energy use. The ABRF consists of four commercial-scale 12- × 121-m (40-× 400-ft) houses and raises broilers under standard production contracts. After the first 15 years of production with open-curtain system, all houses were converted to the solid-wall enclosed system with drop ceiling, tunnel ventilation, and cooling pads in early 2006. The renovations led to reduction of the overall building heat loss factor (W ·K^{-1}) from 1389 to 586 for the two steel-frame houses and from 1022 to 428 for the two wooden-truss houses. Mean outside temperature (ranging from 14.7°C to 17.5°C or 58.5°F to 63.5°F in annual mean temperature during the 17-year period) and bird age were found to be the major factors affecting propane fuel usage and ventilation fan electricity usage. Electricity for ventilation and lighting comprised about 87% of the total electricity usage. Annual electricity usage was 27% higher with the enclosed system than with the open-curtain system (102 vs. 80 kWh per 1000-kg market bird weight or 46.4 vs. 36.4 kWh/1000 lb), due to loss of natural daylight and increased mechanical ventilation in the enclosed system. Propane use was comparable between curtain-sided and solid-wall housing schemes, averaging 76- and 65-L/1000 kg market bird weight (9.1 vs. 7.8 gal/1000 lb) before and after renovation, respectively. Higher fuel cost resulted in higher fuel expenditure for winter heating than electricity expenditure for summer cooling in this region. With increasing energy costs, analysis of energy use, as conducted in this study, will assist the decision making of growers to improve energy efficiency or explore alternative energy application.*

Keywords. *Broiler production, Electricity consumption, Energy cost, Fuel usage.*

Energy plays a significant role in the overall cost of operating a poultry production facility. Energy costs, including electricity and fuel, comprise more than 50% of the cash expenses of the growers (Cunningham, 2006). Due to the economical characteristics and operational activities of poultry production, farmers have a limited set of production variables to control and profitability is often enhanced through reducing operating costs.

In a typical commercial poultry house, electricity is used for feed delivery, lighting, ventilation, and cooling, and fuel is used for heating. Due to the dynamic nature of production cycles and seasonal variations in the climate, energy demand varies throughout the year. Typically, the grow-out period for broiler production ranges from 42 to 60 days, starting with day-old chicks and concluding with market-weight birds. Annually, five to eight flocks of birds are raised in a broiler house, depending on finished bird weight and market demand (Gates et al., 2008). Fuel is needed year-round to provide supplemental heat, while summer cooling constitutes the majority of the electricity demand. The relative proportions between fuel and electricity use depend largely on the local climate and bird age: with higher fuel demand for heat during cold season and younger birds, and higher electricity demand for cooling during warm season and older birds.

Data are lacking on energy use in poultry production across the nation. Byrne et al. (2005) reported about 20,000 kWh per year of electricity with normal lighting regime and tunnel ventilation systems for a typical broiler house in Delaware. A typical Delaware broiler house had a dimension of 12.2 × 152 m (40 × 500 ft) (Byrne et al., 2005) with a construction cost of $150,000 (Cunningham, 2006). Wheeler et al. (2000) reported average propane usage of 8,997 L (2,377 gal) per flock per house (15.2 × 122 m or 50 × 400 ft) with whole-house brooding and 5,344 L (1,412 gal) with partial-house brooding over three winter flocks from three Pennsylvanian broiler farms.

To derive correlation of fuel consumption to heating demand for poultry houses, heating degree day (HDD) as well as a variable-base HDD (Shelton and DeShazer, 1984) concept was explored. HDD data have traditionally found numerous applications in estimating heating energy usage for residential and agricultural buildings. They are generally calculated by summing the positive difference between a specified constant base temperature and the mean daily temperature. The commonly used base temperature is 18.3°C

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The authors are **Yi Liang, ASABE Member Engineer,** Assistant Professor, Department of Biological and Agricultural Engineering, **G. Tom Tabler,** Project Manager, Center of Excellence for Poultry Science, **Susan E. Watkins,** Associate Professor, Center of Excellence for Poultry Science, University of Arkansas, Fayetteville, Arkansas; **Hongwei Xin, ASABE Fellow,** Professor, Department of Agricultural and Biosystems Engineering, Iowa State University, Ames, Iowa; and **Ivan L. Berry, ASABE Member Engineer,** Professor Emeritus, Department of Biological and Agricultural Engineering, University of Arkansas, Fayetteville, Arkansas. **Corresponding author:** Yi Liang, Department of Biological and Agricultural Engineering, University of Arkansas, 211 Engineering Hall, Fayetteville, AR 72701; phone: 479-575-4862; fax: 479-575-2846; e-mail: yliang@uark.edu.

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(65°F) for estimating heating energy requirements. This assumes that supplemental heating to a building is required only when the mean daily outdoor dry-bulb temperature is lower than 18.3°C. The fixed-base HDD data are useful for building design and utility equipment planning for a region and evaluating the effectiveness of certain energy management techniques, such as increased insulation. However, the standard base temperature of 18.3°C may not be appropriate for estimating supplemental heat requirement for poultry buildings where a wide range of interior temperature and heat production rates are encountered. For example, poultry houses with modern strains are heated to 32°C to 33°C (90°F to 92°F) for day-old chicks, and gradually reduced to 21°C (70°F) by the 4th week. The heat demand is highest during the brooding phase (the first 10 to 14 days of grow-out), then decreases as the set-point temperature drops and heat production by the birds increases. The variable-base HDD reported by Shelton and DeShazer (1984) was a means to apply alternative base temperature for HDD calculation, but still not accommodating non-constant temperature set-points in broiler houses and the varying sensible heat production by the birds at different ages.

Sound data on energy consumption are needed for those who consider starting a poultry operation business or those who face a renovation decision. Ever-increasing fuel costs also stimulate the exploration for alternative energy sources, ranging from biomass, geothermal, wind and solar energy. Four commercial-scale research broiler houses, owned by the University of Arkansas, are equipped with the capacity of monitoring electricity and gas usage of individual houses (Xin et al., 1993a, b; Tabler et al., 2003). The broiler houses were constructed as curtain-sided houses in 1990 and completely renovated as solid-wall enclosed houses in early 2006 (Tabler, 2007a, b, c; Tabler et al., 2008). Flocks were raised under standard broiler production contracts. Electricity and fuel usage and cost data were available for all years.

The objectives of this article were: 1) to compare the fuel and electricity use for curtain-sided houses versus enclosed-wall houses; and 2) to identify major electricity consumption component and effective cost-reduction measures for poultry, particularly broiler, production.

Materials and Methods

Broiler Houses

The four commercial-scale broiler houses, each measuring 12×121 m (40×400 ft), are located 19 km (12 miles) west of Fayetteville, Arkansas. Two houses use steel frame structures (Houses 1 and 2) and the other two use wooden trusses (Houses 3 and 4). The houses are oriented east to west and spaced 23 m (75 ft) apart. Commercial pan feeders and nipple drinkers were used in all houses. About half of the total flocks were grown for 49 days or less while the other half were grown for more than 49 days. The youngest flock had a market age of 39 days while the oldest flock had a market age of 57 days. Average body weight of market birds ranged from 1.72 to 3.70 kg (3.8 to 8.2 lb). Partial house brooding was used for a period of 10 to 14 days in all flocks.

Before renovation, the two wooden truss houses (Houses 3 and 4) had drop ceilings with loose-fill insulation of 3.35 m^2·°C/W (19 ft^2·°F h/BTU or R19). The steel frame houses (Houses 1 and 2) had rigid-foam roof insulation of 1.76 m^2·°C/W (10 ft^2·°F h/BTU or R10), with about 12-in. deep above ground foundation. Houses 1 and 3 had side curtains (height of 75 cm or 2.5 ft) along the full length of both the south and north sides. Houses 2 and 4 initially had curtains along the full length of the north side. The south side had two 30.5-m L × 0.76-m H (100-ft L × 2.5-ft H) sections of cooling pads (one section at west end and one section at middle of house) with the remainder using curtain. Cooling pads in House 2 were later replaced with curtain when an experimental sprinkler system was installed in 1995. Sidewall below the curtains had rigid foam insulation (R7.5), corrugated sheet metal siding, and plywood interior. Before renovation, one house of each structure type had an environmental control system that mostly represented the conventional heating, cooling, and ventilation scheme used by the broiler industry in the 1990s. Four, equally spaced exhaust fans (91-cm or 36-in. diameter; 0.37 kW or ½ HP) were mounted in the north sidewall. Fourteen cooling fans combined with low-pressure misting nozzles were placed along the south curtain openings. Supplemental heating (404-kW or 1,380,000-BTU/h capacity) was provided by 30 pilot flame-ignited brooders and four electronically ignited space furnaces in the conventional houses. Commercial 6-stage thermostat poultry house environmental controllers were used. The other house in each structure type used a tunnel ventilation system. Ten tunnel ventilation fans (120-cm or 48-in. diameter; 0.75 kW or 1 hp) were located at east end of the houses. The tunnel houses had the same total supplemental heating capacity of 404 kW (1,380,000 BTU/h), provided by 12 brooders and six space furnaces. Electricity usage by cooling fans was measured as the fan component. Incandescent lighting was provided, with an intensity of up to 10 lux (0.9 foot candle) at bird level.

During renovation, drop ceilings were installed in the two steel truss houses and loose fill insulation was blown into the attic to match the R19 in the two wooden truss houses. The four houses were renovated into solid-sidewall (R11 wall insulation) tunnel ventilated houses with eight 1.27-m (50-in.) (Houses 1 and 2) or 1.2-m (48-in.) (Houses 3 and 4) (1.5-hp) tunnel fans located at the west end and four 0.9-m (36-in.) (1/2-hp) exhaust fans on the north side walls, and two sections of evaporative cooling pads (dimension of 70 ft × 4 ft × 6 in.) on both side walls on the east end. Six circulating fans (18-in. diameter, 1/18 HP) were installed in two of the steel truss houses. The thermal transmittance (U) and resistance values (R) of the houses before and after the renovation are shown in table 1. Programmable environmental controllers (40-stage) were used in all houses (Cumberland for Houses 1 and 2, ProTerra Systems for Houses 3 and 4). After renovation, each house contained 18 direct-ignite 12-kW (40,000-BTU/h each) infrared radiant brooders to provide supplemental heat (212 kW or 720,000 BTU/h). Electricity usage by circulation fans were measured as fan component together with the ventilation fans. In 2007, after four flocks were raised under incandescent light, light bulbs in Houses 2, 3, 4 were replaced with more energy-efficient bulbs [8-watt cold cathode fluorescent light (CCFL) or 23-watt dimmable fluorescent light] gradually. Details of light bulbs used in each house are shown in table 2.

Measurements and Analyses

The following variables were collected daily and compiled as weekly values from each house: propane use;

Table 1. The overall building heat loss factor (A/R, W/K), thermal transmittance values ($U_{envelop}$, W/m^2·K) and thermal resistance values (R, ft^2 F·h/BTU) of the steel frame and wooden truss broiler houses before and after renovation.

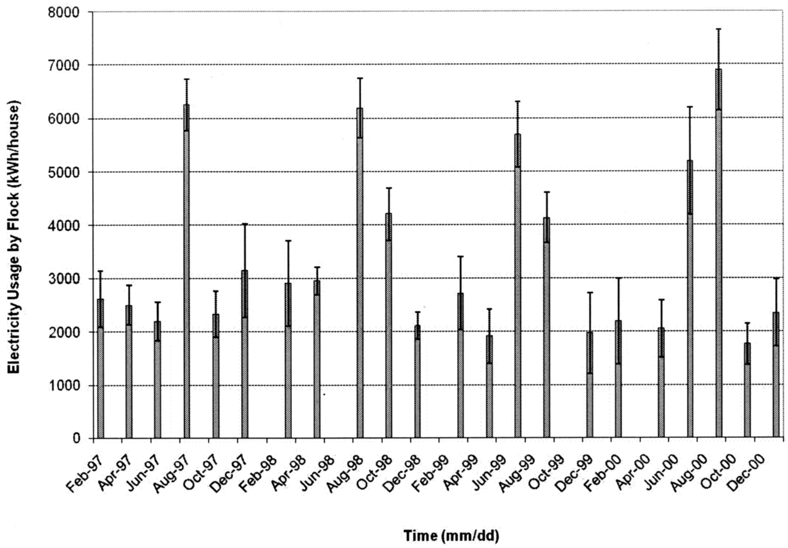
	Unit	Before Renovation		After Renovation	
		Steel Truss Houses	Wooden Truss Houses	Steel Truss Houses	Wooden Truss Houses
$\sum \frac{A_i}{R_i}$	W/K	1389	1022	586	428
$\frac{\sum \frac{A_i}{R_i}}{\sum A_i}$	W/m^2·K	0.63	0.47	0.26	0.20
R-values	ft^2 F·h/BTU	5.0	6.7	12.1	15.9

electricity use for fans, lighting, and total operation. Electricity and fuel usages were analyzed for each flock and on an annual basis. Due to variations in market size and stocking density among the flocks, electricity and fuel usages were standardized as 1000 kg of market weight. Whole-flock based energy usage was used to calculate annual energy use. Where a flock was raised across the two adjacent years, it was grouped into the year with higher relative proportion of fuel usage. Typically a year consists of five or six flocks, occasionally seven (years 1995 and 2001). Annual electricity

Table 2. Types of light bulbs used for four flocks (May 2007 to Feb. 2008) in all broiler houses.

Flock	House 1	House 2	House 3	House 4[a]
93	Incandescent	Incandescent	CCFL (2700)	CCFL (4000)
94	Incandescent	Incandescent	CCFL (4000)	CCFL (4000)
95	Incandescent	Dimmable fluorescent	CCFL (4000)	CCFL (4000)
96	Incandescent	Dimmable fluorescent	CCFL (4000)	CCFL (4000)

[a] CCFL refers to cold cathode fluorescent light with 2700 or 4000 Kelvin rating.



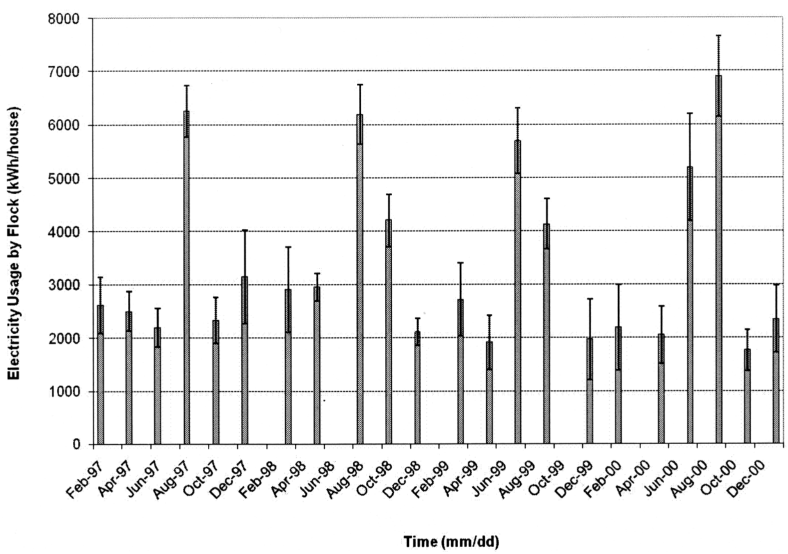


Figure 1. Total average electricity usage pooled over the four broiler houses (18,000 to 19,500 straight-run broilers per house) for flocks between years 1997 and 2000. Error bars represent standard deviation of the four houses. (a) Electricity use by house; (b) Electricity use by 1000-kg market weight.

and fuel costs were compared based on the actual charges by the local utility companies.

Daily mean outside temperatures were downloaded from the average daily temperature archive (www.weather.gov/climate/index.php?wfo=tsa). To derive correlation of fuel consumption to heating demand for the broiler houses, bi-weekly mean ambient temperature (weeks 1-2, weeks 3-4) were calculated and the corresponding fuel use (weeks 1-2 and weeks 3-4) was determined for each flock.

Regression analyses were conducted (SAS, 2002) to determine the relationship between weekly electricity usage by fans *vs.* weekly average outside temperature and bird age (week) for the two years after renovation.

Results and Discussion

Electricity Usage

Total electricity usage demonstrated seasonal cyclic patterns in that it was higher in warmer seasons and lower in colder seasons (fig. 1). The electricity usage peaked in summer 2007 (after renovation) at 9,356 kWh/flock-house or 160 kWh/ 1000 kg market weight (72.7 kWh/ 1000 lb market weight). On average, fans and lights accounted for about 87% of total electrical consumption, with fans accounting for 65% of the total amount (fig. 2). Annual total electricity usage ranged from 11,992 to 29,472 kWh and averaged 20,043 kWh per house. The two-year electricity usage after renovation

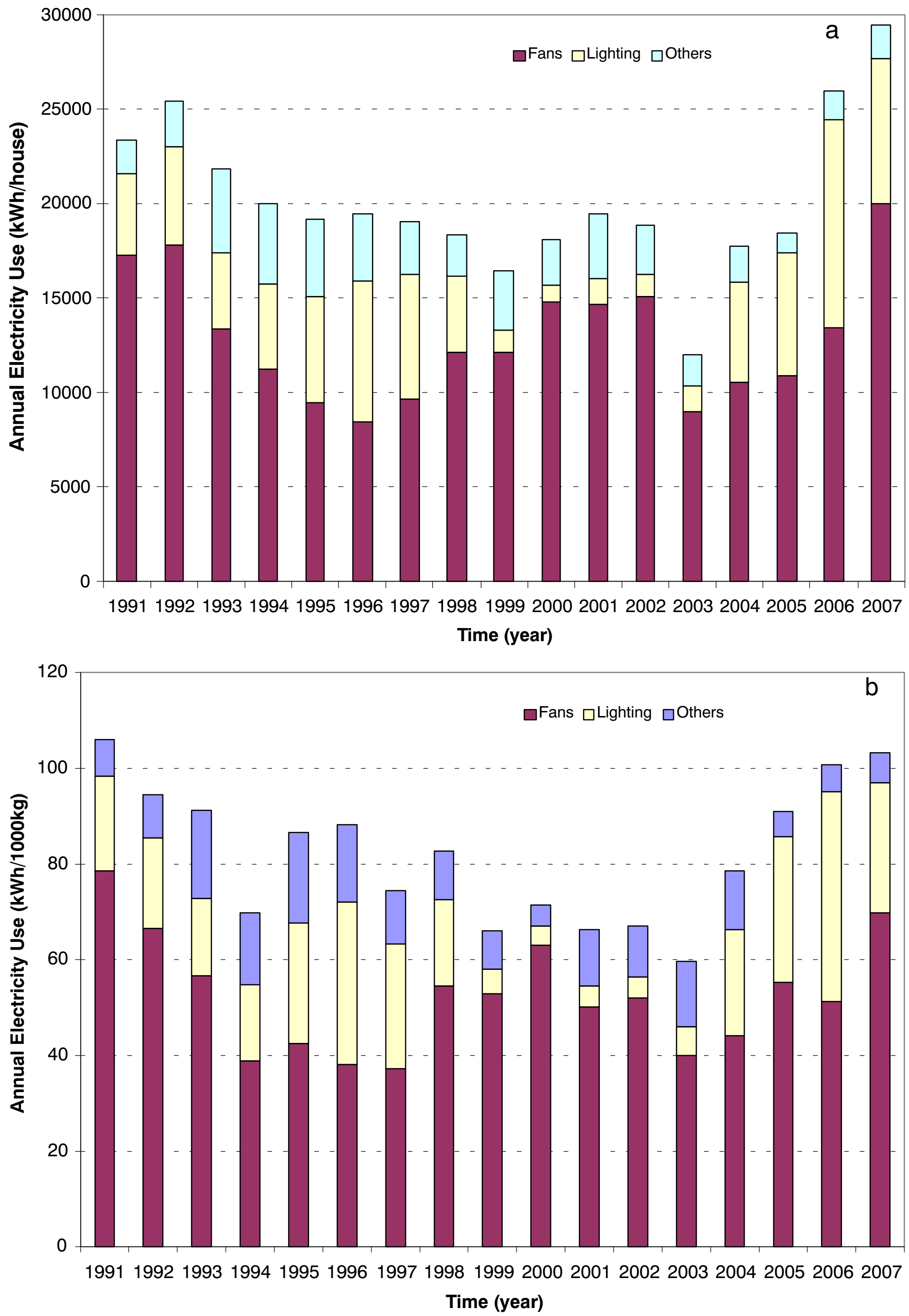


Figure 2. Annual electricity usage by fans, lighting and others. (a) usage by house; (b) usage by 1000-kg market live bird weight.

were 40% higher than farm average (annual mean of 27,745 kWh/house) for the past 17 years, due to loss of natural daylight as a light source and loss of natural ventilation during mild weather condition. However, when analyzed on the market weight basis, the apparent high electricity consumption after renovation was offset by the higher total market weight produced on this farm. Higher total market weight output was a result of heavier market birds and short down-time between flocks. Eight out of ten flocks after renovation had the market age of more than 48 days, with body weight between 2.8 and 3.7 kg. As a result, electricity usage after renovation (102 kWh /1000kg) was 27% (vs. 40% on a per-house basis) higher than the 17-year farm average (82 kWh /1000kg).

Regression analysis was conducted to analyze correlation between weekly electricity usage data after farm renovation (66 weeks of data from 10 flocks raised) and bird age by week and weekly outside temperature. As examples, fan electricity usage versus bird age by week was plotted for a summer flock and a winter flock (fig. 3). Bird age was a significant factor ($P<0.0001$) in affecting fan electrical use (R^2 of 0.37). Adding weekly average outside temperature improved R^2 to 0.77. This is in agreement with Byrne et al. (2005) who reported that total electricity use was most highly correlated with bird age ($r=0.745$ at $P<0.01$) and then with outside temperature. Heat production from older, fast-growing birds requires large air exchange to remove heat from the houses, regardless of season. However, flocks raised during summer months obviously use more electricity due to the higher ventilation and cooling demand as compared to winter flocks.

Lighting consumed about 20% of overall electricity usage on the farm before the lighting system was switched. In the totally enclosed houses, lighting accounted for 43% of the electrical consumption with traditional incandescent light bulbs being the primary lighting source. With the gradual replacement of incandescent lights by cold cathode fluorescent or dimmable fluorescent light bulbs, electricity consumption continuously declined, resulting in a reduction of 60% to 75% after switching to both types of energy-efficient lighting (fig. 4). Estimated payback of using energy-efficient lights largely depends on electricity charges of a region and is approximately one year (six flocks) calculated based on the local utility price ($0.07/kWh for the calculation).

Propane Fuel Usage

Annual propane usage per house ranged from 11,576 to 26,791 L (3,058 to 7,078 gal) for the past 17 years (fig. 5). Annual mean propane usage was 17,211 L (4,547 gal) per house between 1991 and 1999, but 21,262 L (5,618 gal) per house between 2000 and 2005, under comparable mean outside temperatures during the two periods (fig. 5b). This increase in fuel usage was likely due to air leaks in the houses and curtains as they aged and the higher brooding temperatures used in later years as required for rearing modern strains of broilers. The annual propane usage in years 2006 and 2007 averaged 17,213 L (4,548 gal) per house. Propane use for the two years under solid-wall production was comparable with those before renovation (18,471 L or 4,880 gal per house) when analyzed on a per-house basis. When analyzed based on per 1000 kg live weight birds, propane usage averaged 14% lower after renovation (65 L or 17 gal) than before renovation (76 L or 20 gal). Annual average outside temperature ranged from 14.7 (year 1993) to 17.5°C (year 2006) (fig. 5b). Propane saving achieved after renovation was mainly due to reduced air leakage by enclosing the houses, increased ceiling and roof insulation, raising heavier birds, and possibly due to slightly higher mean ambient temperatures (16.1°C before 2005 vs. 17.0°C after 2006). Lower than expected propane gas savings with increased insulation and tigher houses after renovation was observed partially due to

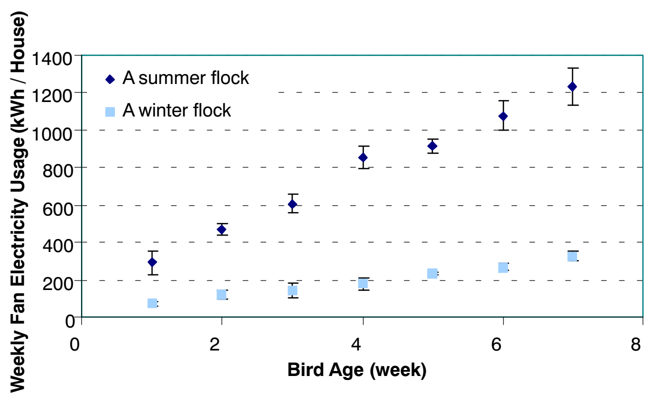


Figure 3. Sample weekly electricity use by ventilation fans of broiler houses during winter or summer.

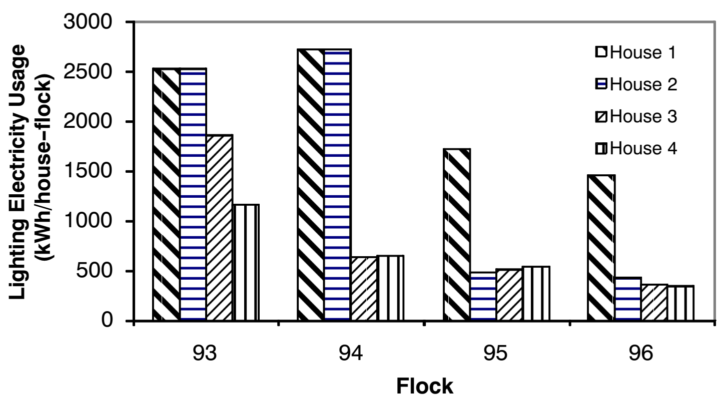
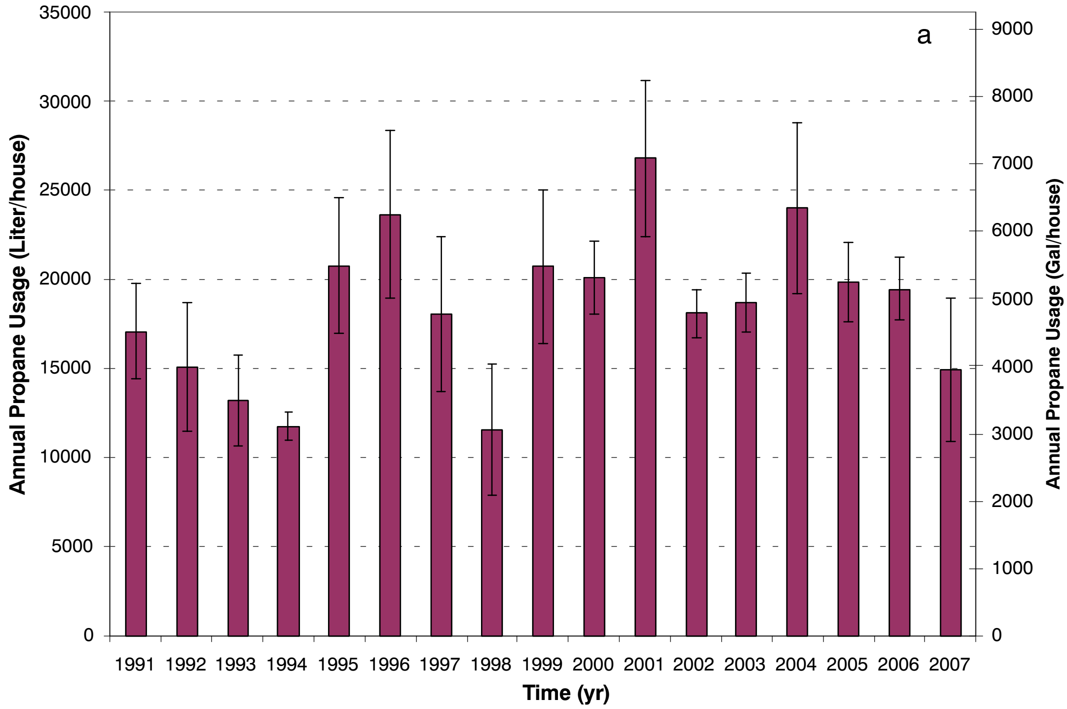


Figure 4. Lighting electricity usage for four broiler flocks (May 2007-Feb. 2008) from four houses using various types of light bulbs (table 2). House 1: incandescent; House 2: incandescent for flocks 93 and 94, dimmable fluorescent for flocks 95 and 96; House 3: cold cathode fluorescent light with 2700 Kelvin for flock 93 and 4000 Kelvin for flocks 94 to 96; House 4: cold cathode fluorescent light with 4000 Kelvin.



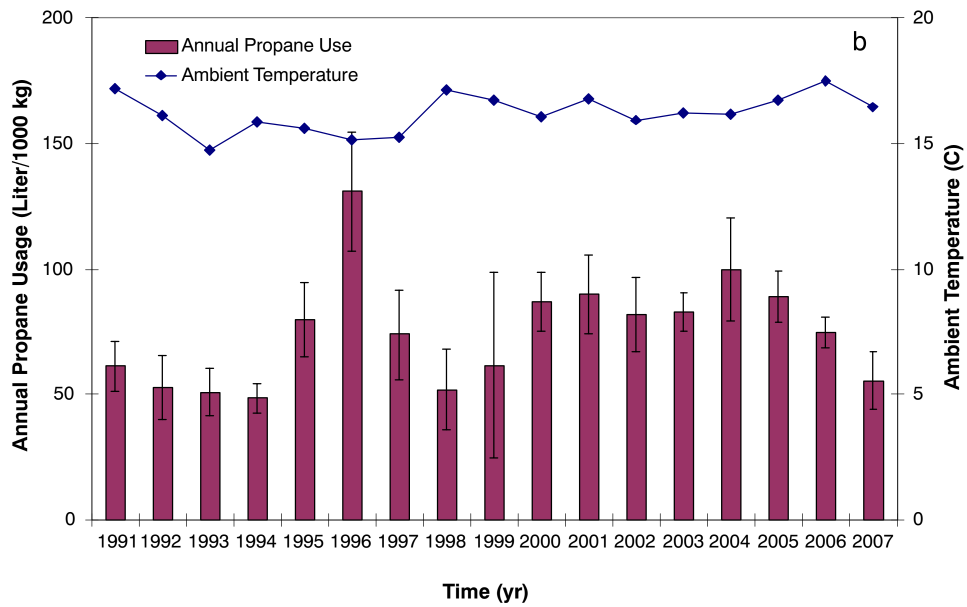


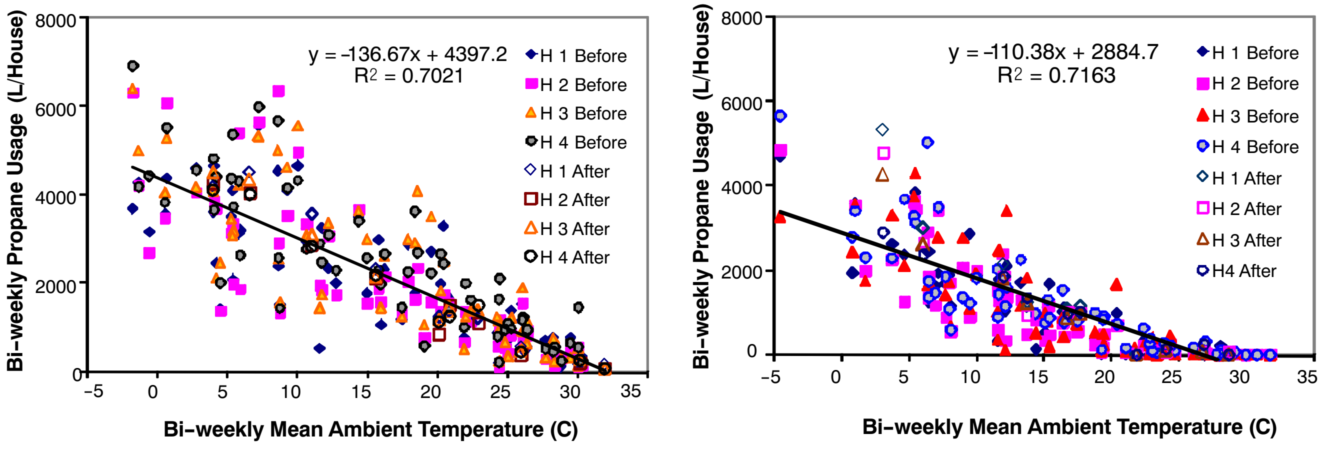
Figure 5. Annual propane usage and correspondent annual average outside temperatures (a) per house; (b) per 1000 kg market live weight. Error bars represent the standard deviation of the four houses.

the ventilation program provided by the integrator targeted for ammonia control. During this period, some winter flocks but not all received litter treatments. It is known that in certain situation litter treatments allow growers to reduce minimum ventilation rates in order to save fuel for brood period heating (Czarick and Fairchild, 2008).

Relationship of bi-weekly cumulative propane usage versus mean ambient temperature from all houses is presented in figure 6. Apparently flocks raised in the warmer season used less fuel than those raised in the colder season. Data from both bi-weekly segments showed strong linear correlation between fuel usage and outside temperature (R^2 of 0.70 and 0.71 for weeks 1 and 2, weeks 3 and 4, respectively). Linear equations reveal that no fuel would be needed for supplemental heating when mean ambient temperature exceeds 32°C (90°F) during weeks 1 and 2, or 26°C (78°F) during weeks 3 and 4. The lower fuel demand during weeks 3 and 4 is a result of the balance between heat production from heavier birds, building ventilation and conductive heat loss. Farm after renovation consumed less fuel than before renovation for weeks 1 and 2 (2242 L before vs. 1840 L after), but more fuel for weeks 3 and 4 (1048 L before vs. 1232 L after). The reason of higher fuel cost for week 3 and 4 after renovation was unclear.

Energy Cost

During the past 17 years, electricity and propane prices in the Northwest Arkansas area demonstrated different trends.



(a) (b)

Figure 6. Relationship of bi-weekly propane fuel use of broiler houses to bi-weekly mean outside temperature for Northwest Arkansas area. Solid legends depict those before renovation and hollow legends depict those after renovation. (a) Weeks 1 and 2; (b) Weeks 3 and 4.

Propane price was stable for the first 10 years but experienced a fast increase beginning in 2001 and more than tripled the original price in 2007 (fig. 7). This enormous price increase has occurred nationwide. However, electricity prices have been stable at approximately \$0.06 to \$0.07 per kWh since the first flock was raised in this region. As a result, the annual costs of propane increased dramatically but electricity costs remained relatively unchanged. Costs for both electricity and propane have increased since renovation due to higher usage of electricity and higher price of propane. However, performance data collected at the farm suggested that the renovation consistently resulted in a better environment for bird growth, better bird performance, and bigger settlement checks from the integrated company. Nonetheless, fuel expenditure for heating poultry houses became substantially more than electricity expenditure for ventilation and cooling. Heating poultry houses using conventional fuel sources is becoming increasingly expensive for poultry growers.

Summary and Conclusions

Energy use based on bird production data from four meat-type broiler houses were analyzed for Northwest Arkansas production conditions. The broiler houses were operated under curtain-sided housing scheme for 15 years (1991-2005), followed by solid-wall housing scheme for two years (2006-2007). Ambient temperature averaged 16.1°C (61.0°F) during the first 15 years and 17.0°C (62.6°F) during the following two years. The broiler houses had an overall building heat loss factor ($W \cdot K^{-1}$) of 1389 for the steel-frame structure and 1022 for the wooden-truss structure during the first 15 years, and were reduced to 586 and 428, respectively, after the renovation. Electricity use during the two-year solid-wall scheme was 40% higher than the farm average on per house basis (20,043 kWh), or 27% higher on per 1000 kg market bird weight basis (102 vs. 82 kWh/1000 kg market weight). Propane use was comparable between curtain-sided and solid-wall schemes, averaging 75-L/1000 kg (9.1-gal/1000 lb) and 65-L/1000 kg (7.8-gal/1000 lb) market weight. Lighting efficiency improvement currently offers the best saving opportunity for poultry growers. Renovation of the broiler houses from curtain-sided to solid sidewall scheme has partially led to improved bird productivity and increased payment from the integrators, possibly as a result of more uniform interior environment associated with certain modern broiler genetic strains. The cost of broiler production has significantly increased as a result of several factors, including the higher prices of feed grains and propane fuel.

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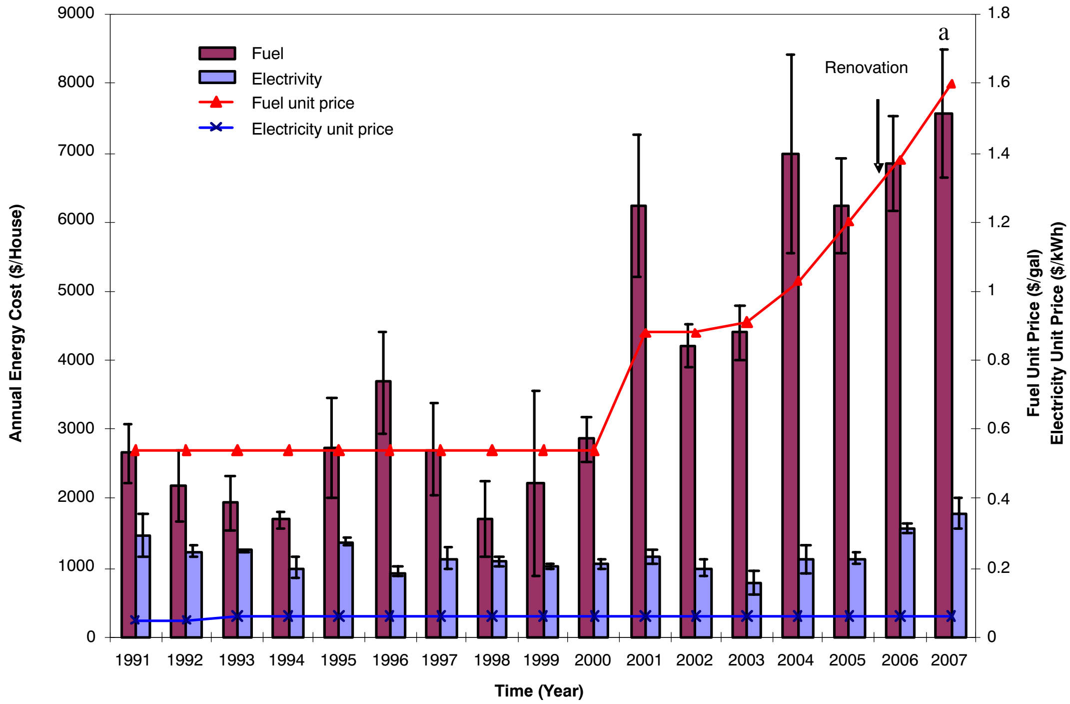

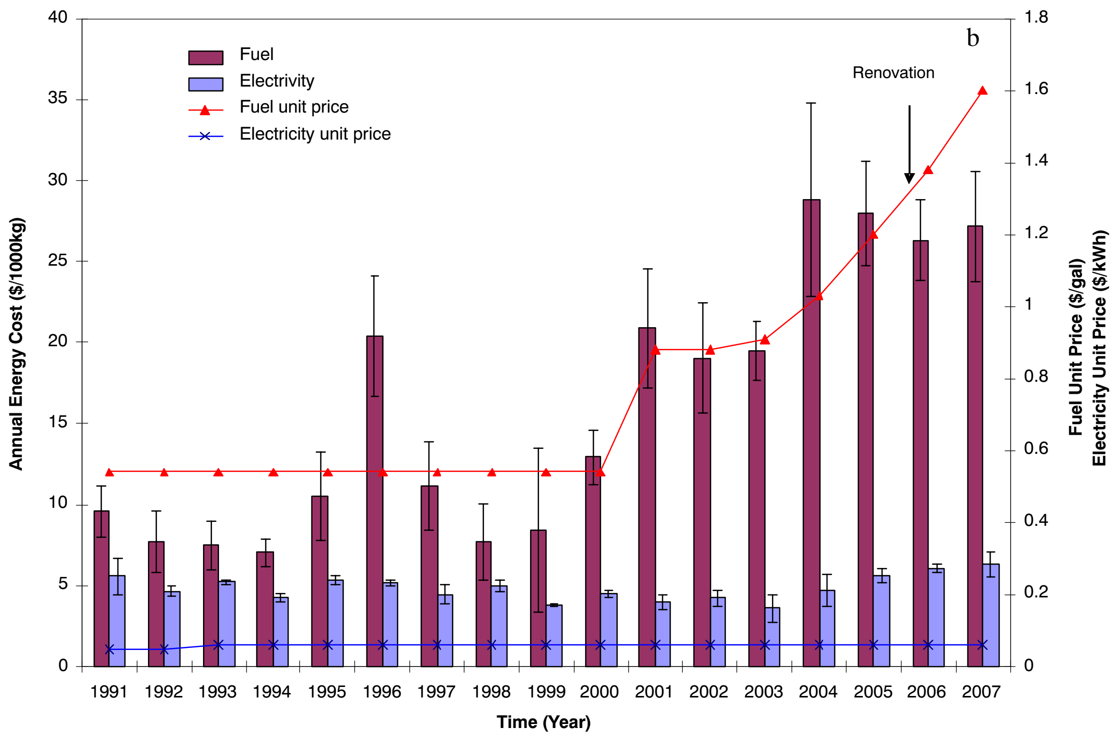

Figure 7. Annual costs of propane and electricity and the actual local energy charges (a) averaged per house; (b) average per 1000 kg live market weight. Error bars represent the standard deviation of the four houses.

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