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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 relative effect of open-curtain vs. enclosed housing systems on energy use. The ABRF consists of four commercial-scale 12 x 121 m (40 x 400 ft) houses and raise broilers under standard production contracts. After the first sixteen years of production under open-curtain system, all four houses were converted to solid-wall enclosed system with dropped ceiling, tunnel ventilation and cooling pads in early 2006. Energy use data collected from each house included propane fuel use for heating and electricity use for ventilation fans, lighting, and total. Analyses of energy use before and after the renovation were made on a flock or yearly basis.

Heating degree days are the major factor affecting propane fuel usage, as expected. Bird age and outside temperature were found to be the major factors affecting fan electricity usage for the enclosed system. Electricity for ventilation and lighting comprised about 85% of total usage. Annual electricity usage was higher with the enclosed system than with the open-curtain system due to loss of natural daylight and increased mechanical ventilation in the enclosed system. Higher cost of fuel than electricity 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 prove conducive to improving energy efficiency or alternative energy application.

Keywords

Broiler production, electrical energy, energy cost, fuel usage

Disciplines

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Comments

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Introduction

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 cost-cutting.

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 delivery of day-old chicks and concluding with the removal of market-size birds. Annually, five to six flocks of birds are raised from a broiler house. Fuel is needed year-round to provide supplemental heat, while summer cooling consumes 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 during cold season and younger birds but higher electricity demand during warm season and older birds.

Data are lacking on energy use by poultry growers across the nation. Byrn 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 40 × 500 ft in size (Byrn et al., 2005) with a construction cost of \$150,000 (Cunningham 2006). Wheeler et al. (2000) reported average propane usage of 2,377 gallon per flock per house (50 × 400 ft) with whole-house brooding and 1,412 gallon with partial-house brooding over three winter flocks from three Pennsylvanian farms.

To derive correlation of fuel consumption to heating demand for poultry houses, heating degree day (HDD) 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 base temperature and the mean daily temperature. The commonly used base temperature is 18.3 °C (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.

Scientific data on energy consumption are needed for those who consider starting a poultry operation business or those who face a renovation decision. The high fuel cost also brings a great interest of exploring 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 paper were: 1) to compare the fuel and electricity use for curtain-sided houses vs. enclosed-wall houses; and 2) to identify major electricity consumption component and offer guidance for better management of the poultry production.

Materials and Methods

Broiler Houses

The four commercial-scale 40×400 ft broiler houses are located 12 miles west of Fayetteville, AR. 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 was 39 days at harvest while the oldest flock was harvested at 57 days. Partial house brooding were used.

Before renovation, the two wooden truss houses (Houses 3 and 4) had drop ceilings with loose-fill insulation of 19 ft²·°F hr/BTU (R-19). The steel frame houses (Houses 1 and 2) had rigid-foam roof insulation of 10 ft²·°F hr/BTU (R-10). Houses 1 and 3 had side curtains (height of 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 100-ft sections of cooling pads (one section at west end and one section at middle of house) with the remainder in 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 (R=7.5), 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" diameter; 0.4 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 window. Supplemental heating (404 kW or 1,380,000 BTU/hr capacity) was provided by 30 pilot flame-ignited brooders and four electronically ignited space furnaces in the conventional houses. Commercial six-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; 0.7 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/hr), 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 0.9 foot candle at bird level.

During renovation, drop ceilings were installed in the two steel truss houses and loose fill insulation blown into the attic to match the R-19 in the two wooden truss houses. The four houses were renovated into solid-sidewall (R-11 wall insulation) tunnel ventilated houses with eight 50" (Houses 1 and 2) or 48" (Houses 3 and 4) (1.5 HP) tunnel fans located at the west end and four 36" (1/2 HP) exhaust fans on the north side walls, and two sections of evaporative cooling pads (dimension of 70 ft x 4 ft x 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. Environmental programmable controllers were used in all houses (¹Cumberland for Houses 1 and 2, Proterra Systems for Houses 3 & 4). After renovation, each house contained 18 direct-ignite 12 kW (40,000 BTU/hr each) infrared brooders to provide supplemental heat (212 kW or 720,000 BTU/hr). Electricity usage by circulation fans were measured as fan component together with the ventilations fans. After four flocks were raised under incandescent light, light bulbs in

¹ Mention of product or company names in this publication does not imply endorsement by the authors or their affiliations, nor exclusion of other products that may be suitable.

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 1.

Table 1. Types of light bulbs used for four flocks (May 07 to Feb 08) in four houses.

Flock	House 1	House 2	House 3 [†]	House 4 [†]
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)

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

Measurements and Analysis

The following variables were collected daily and compiled as weekly values from each house: propane use; electricity use for fans, lighting, and total operation. Electricity and fuel usages were analyzed for each flock and on an annual basis. Whole-flock based energy usage was used to calculate annual energy consumption. When a flock was raised across the adjacent years, it was grouped in either year if the relative proportion of fuel usage was higher in that year. Typically a year consists of five or six flocks, occasionally seven (years 1995 and 2001). Annual costs of electricity and fuel were compared based on the actual charge 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 compare fuel usage for each flock of curtain-sided houses (before renovation) and solid-wall houses (after renovation), compensation for weather conditions must be made. Heating degree days (HDD) using base temperature of 18.3 °C (65 °F) were calculated for each flock to determine the relationship between fuel consumption and weather condition. Specifically,

$$HDD = \sum_n (65 - T_o)$$

Where: T_o is mean daily outside temperature (°F), and n is the age of market birds in days.

Regression analyses were conducted (SAS version 9.1) to determine relationship between weekly electrical usage by fans and weekly average outside temperature, and bird age by week for the two years after renovation.

Results and Discussion

Electricity Usage

Total electricity usage demonstrated seasonal cyclic patterns as shown in Figure 1. Electricity usage was higher in warmer seasons and lower in colder seasons.

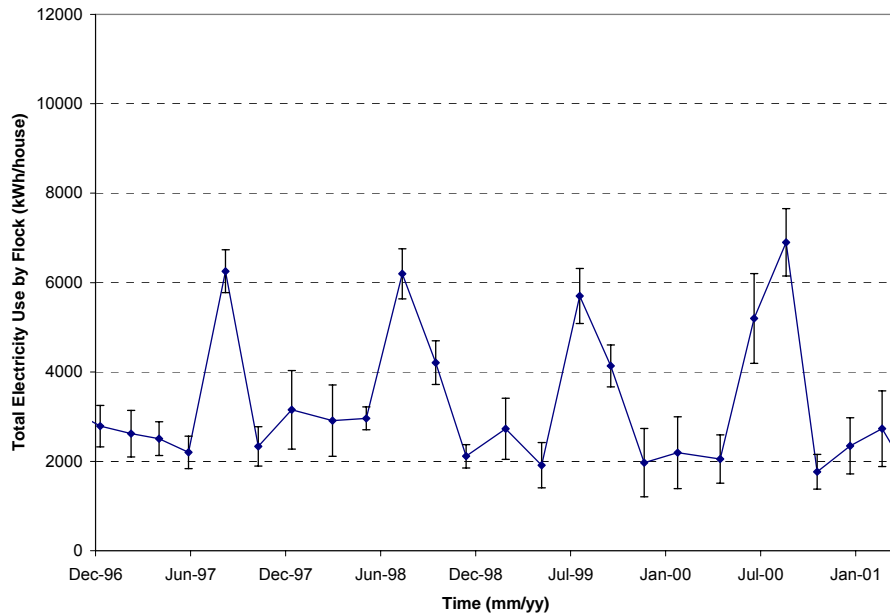


Figure 1. Total average electricity usage over the four houses for flocks between years 1997 to 2000. Error bars represent the standard deviation of the four houses.

Annual electricity usage for fans, lighting, and others are shown in Figure 2. On average, fans and lights accounted for an average of 85% of total electrical consumption, while fans used an average of 64% of the total amount. Annual total electricity usage ranged from 13,327 to 29,472 kWh and averaged 20,303 kWh per house. The two-year electricity usage after renovation were 40% higher than farm average (annual mean of 27,745 kWh) for the past 17 years, due to loss of natural daylight as a light source and loss of natural ventilation during mild weather condition.

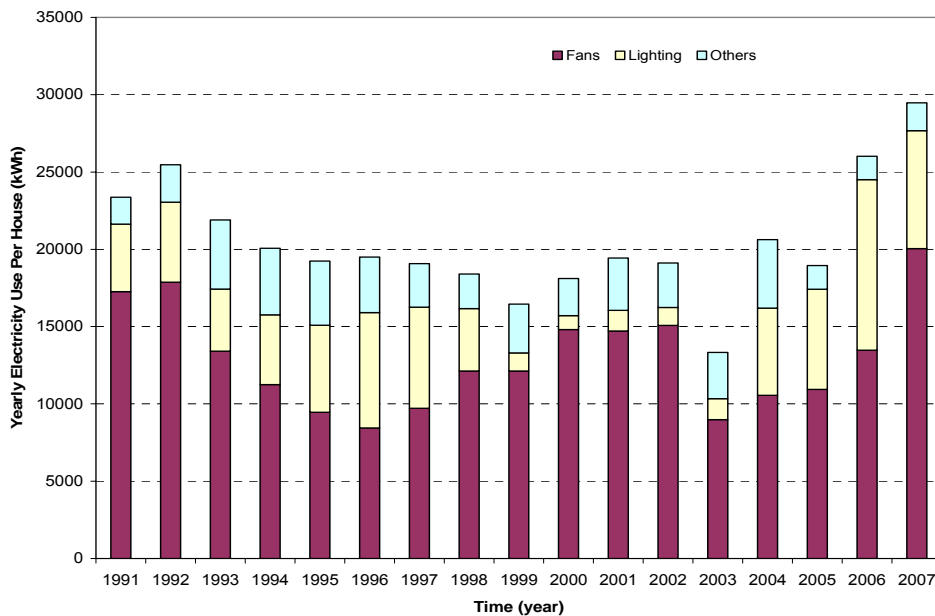


Figure 2. Annual electricity usage by fans, lighting and others for each house

Regression analysis was conducted to analyze correlation between weekly electricity usage data after farm renovation (66 weeks or ten flocks raised), bird age by week and weekly outside temperature. Fan electricity usage was plotted vs. bird age by week for a summer and a winter flock (fig. 3). Bird age was a significant factor ($P < 0.0001$) in explaining fan electrical use (R^2 of 0.37). Adding weekly average outside temperature raised the R^2 to 0.77. This is in agreement with Byrn et al. (2005) reporting 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, no matter during winter or summer. However, flocks raised during summer months obviously use more electricity due to the higher ventilation and cooling demand as compared to the winter flocks.

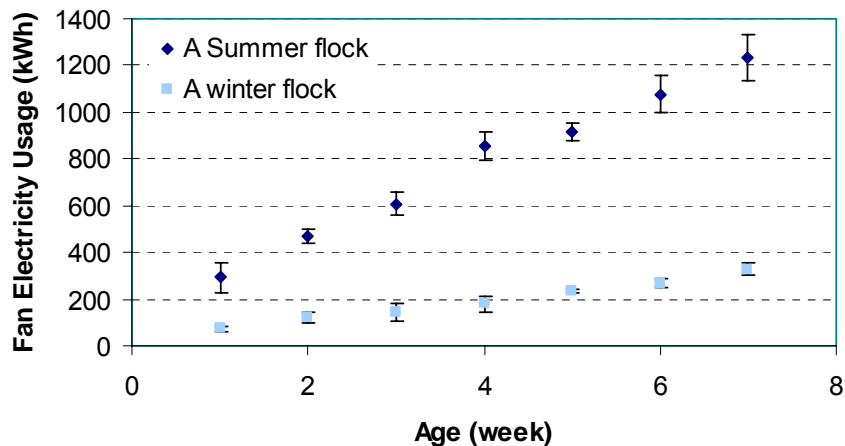


Figure 3. Sample weekly electricity use by ventilation fans of broiler houses in winter or summer.

Lighting consumes about 20% of overall electricity usage on the farm before lighting system changes. With the gradual replacement of incandescent lights by cold cathode fluorescent or dimmable fluorescent light bulbs starting summer 2007, electricity consumption was significantly reduced by 60-75% from both types of energy-efficient lighting (fig. 4). Estimated payback of using energy-efficient lights will largely depend on electricity charges of a region, and is approximately one year (five flocks) calculated based on the local utility price.

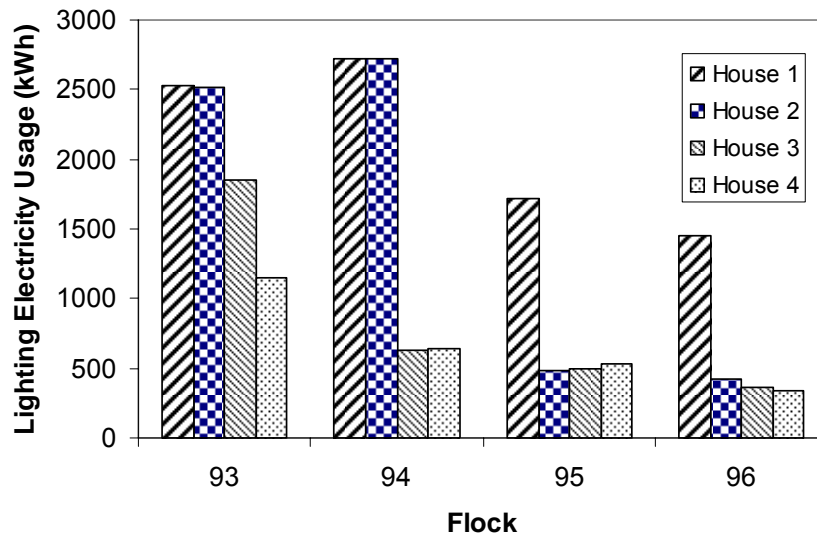


Figure 4. Lighting electricity usage for four flocks (May 2007- February 2008) from four houses using various types of light bulbs as shown in Table 1.

Propane Fuel Usage

Annual propane usage per house ranged from 11,559 L (3,058 gal) to 26,754 L (7,078 gal) for the past 17 years (fig. 5). Annual mean propane usage between 1991 and 1999 was 17,188 L (4,547 gal) per house, while that between 2000 and 2005 was 21,236 L (5,618 gal) per house. This increase in usage was likely due to air leaks in the houses and curtains as they aged and higher brooding temperatures used in later years. The annual propane usage in years 2006 and 2007 averaged 17,191 L (4,548 gal) per house. Propane use for the two years under solid-wall production was comparable with those before renovation (18,446 L or 4,880 gal per house). More long-term post-renovation data will likely strengthen this preliminary analysis.

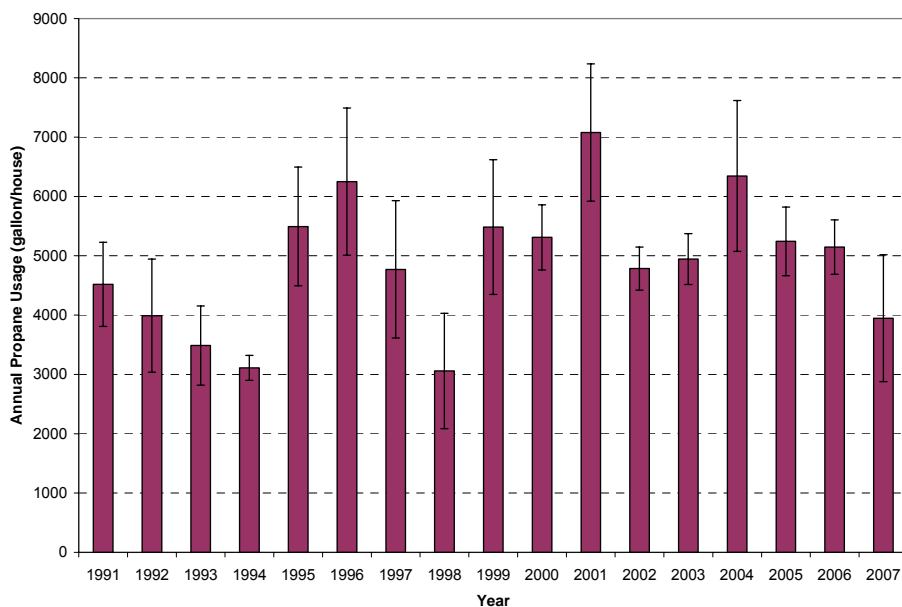


Figure 5. Annual propane usage per house. Error bars represent the standard deviation of the four houses.

Relationship of propane usage for each flock with HDD was presented in Figure 6. Propane usages before and after renovation were plotted separately. The dense area around zero HDD in Figure 6 mainly resulted from summer flocks when propane was mostly consumed during the brooding phase even though outside temperature was higher than 65 °F (HDD close to 0). Flocks raised in the warmer season (with lower HDDs) used less fuel than those raised in the colder season (with higher HDDs). In comparing fuel usage before and after renovation, no substantial different fuel consumption pattern can be observed between curtain-sided and totally enclosed houses.

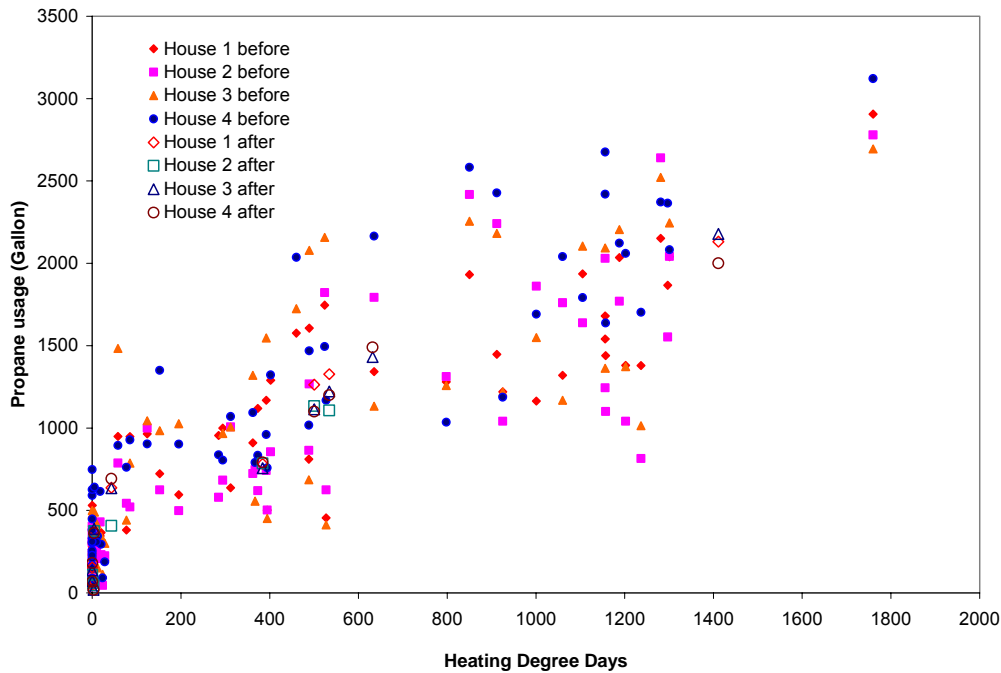


Figure 6. Propane fuel use in relation to heating degree days (HDD) of each broiler house per flock. Higher HDD means colder weather. Solid or empty symbols represent flocks before or after renovation of the houses.

Energy Cost

During the past 17 years, electricity and propane prices in the Northwest Arkansas area demonstrated different trends. Propane unit price was stable for the first 10 years but experienced a fast increase starting 2001 and more than tripled the original price in year 2007 (fig. 7). This has been observed nation wide. However, electricity price has been stabilized around \$0.06 per kWh since the first flock was raised in this region. As a result, 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 renovation resulted in a better environment for bird growth, better bird performance and bigger

settlement check on a consistent basis. Nonetheless, fuel expenditure for heating poultry houses became substantially more than electricity expenditure for ventilation and cooling. Heating poultry houses using conventional fuel sources becomes increasingly expensive for poultry growers.

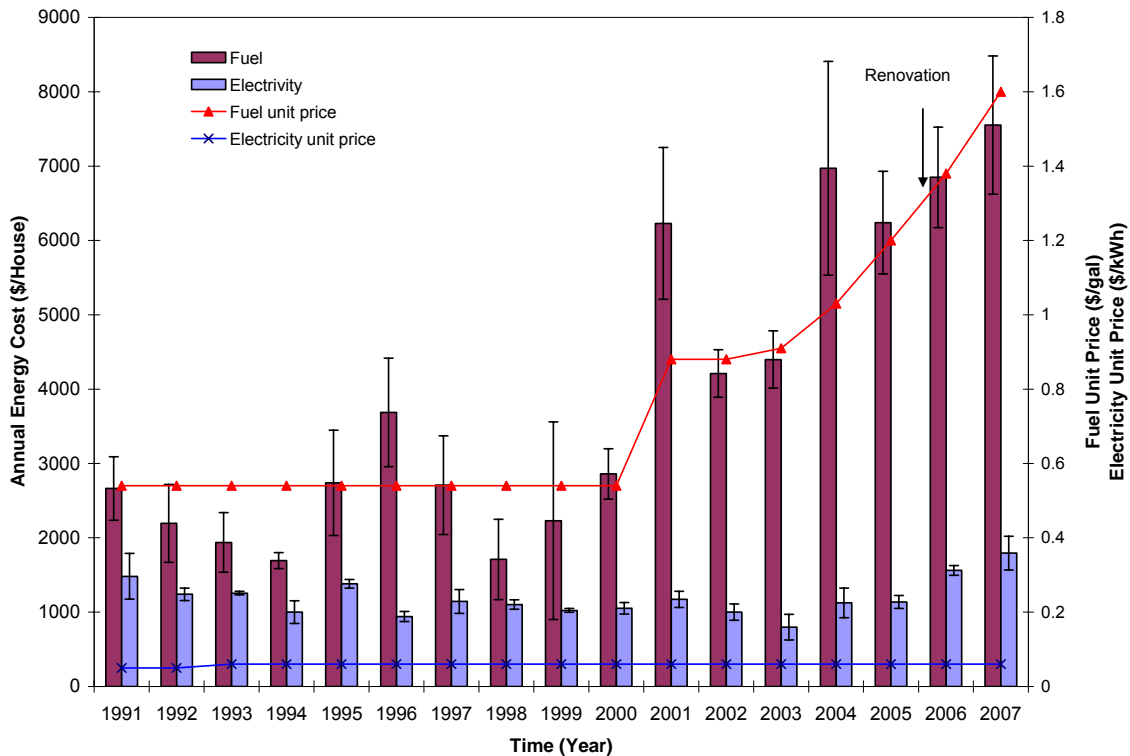


Figure 7. Annual costs of propane and electricity averaged per house and the actual local energy charges. Error bars represent the standard deviation of the four houses.

Conclusions

Data of broiler production under 16-year curtain-sided scheme and two-year solid-wall scheme were analyzed for electrical and fuel use. Electricity use under solid-wall scheme was 40% higher than farm average, while propane use was comparable with that under curtain-sided scheme. Lighting efficiency improvement offers the best saving opportunity for poultry growers. Even though productivity generally increases with farm renovation and settlement are generally higher as a result, cost of production was significantly increased by the high fuel prices.

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