MINIMIZING ENERGY REQUIREMENTS FOR BROILER GROWOUT OPERATIONS

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ABSTRACT

A simulation of on-farm broiler production is outlined. The simulation determines the cost of building and owning a broiler house plus the cost of the Liquified Petroleum Gas (LPG) required to maintain the desired house temperature and humidity. The model uses the daily high and low ambient temperatures to determine the amount of supplemental heat required. Grower management and construction practices have been evaluated in terms of fuel conservation potential and determine the optimum level of insulation. Limited area brooding can reduce fuel consumption by 56 percent. Increasing the width of the house could reduce fuel costs by 25 cents per broiler and construction costs by 15 cents per broiler. It has been found that the optimum level of insulation is a function of grower management practice and the rate of inflation associated with fuel cost. The economics associated with the solar heating of broiler houses is also discussed.

In 1976, the Delmarva Poultry Industry (DPI) produced 380 million broilers. According to a study by the DPI Energy Committee (17), brooding or heating of broiler houses was the largest consumer of energy in the production system. Agricultural Engineers at the University of Delaware have been working with DPI to develop a simulation of on-farm broiler production. The simulation has required the development of mathematical descriptions of the broiler, the broiler house and the grower management practice. The model is being used to evaluate proposed house construction and grower management strategies in terms of cost and energy conservation potential.

The model is continually revised and expanded as new questions are posed by DPI. At present, the portion of the supplemental heat load derived from ventilation is computed assuming continuous power ventilation. The amount of power ventilation required is determined by the amount of moisture produced in the house. Consideration of ammonia dilution, intermittent power ventilation and infiltration could alter the results. When reliable mathematical descriptions of these factors are developed they can be added to the simulation.

Outline of the Simulation

In Illustration 1, a simplified flow chart of the main program is provided. The main program reads the simulation variables and calls the Building and Ventilation subroutines which perform the simulation. The simulation variables have been divided into eight categories. Within the first category or read statement are variables used to select or limit the output during a given simulation. The second group of variables, building data, describes the house to be considered and includes such items as capacity, building width, door and window sizes, and brooding area. In the third read sequence, the construction details are specified. This group of data includes size and spacing of framing members, R values and material and labor costs. The building and construction data are used in the building subroutine to compute the building cost and heat loss characteristics.

The remaining read statements are required to specify the variables needed for the ventilation subroutine. The ventilation subroutine not only determines the optimum ventilation rates but also computes energy requirements and projects costs based on inflation and other factors. In the fourth read statement, economic data, such as length of growout, useful life of the house, fuel cost, inflation rate and the cost of ownership are accounted for. With the fifth and sixth read statements, the heating system and brooding practice are

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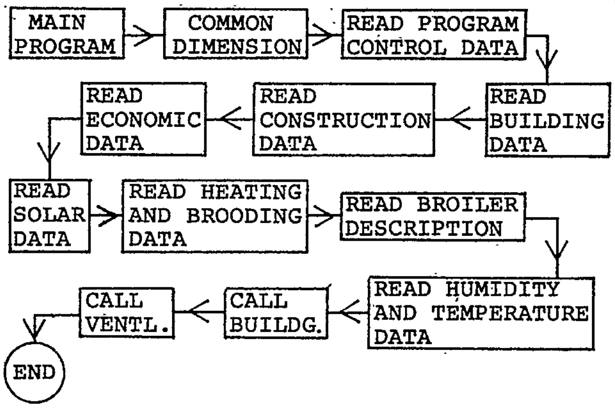
ILLUSTRATION 1

Simplified Flow Chart for Main Program



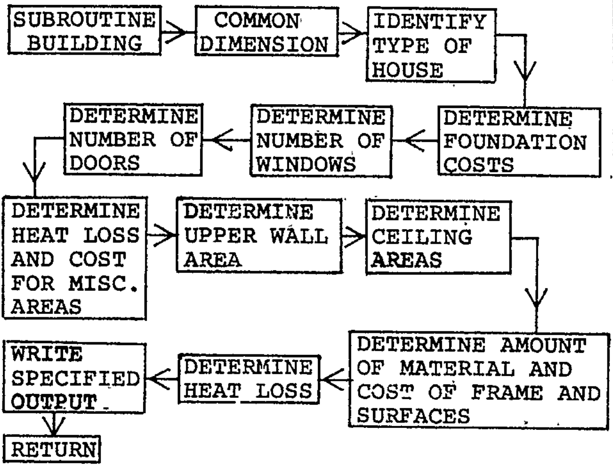
specified. Next, the growth rate, feed conversion, moisture production, broiler heat production, etc., are read to describe broiler performance. Finally, the house temperatures and humidities, as well as the physical properties of air, are provided.

Four important features are incorporated in the building subroutine so that various grower management and construction details may be considered. First, the building can be divided into three sections. This feature permits the consideration of many limited area brooding programs. Second, member sizes and insulation thickness can be varied from section to section. Third, the wall is divided into two parts. The lower wall, whose height may be zero, accounts for any block or foundation that extends above the floor line. The upper wall is then defined as the framed and insulated wall above the block. The fourth feature is that varying levels of insulation can be considered in a section of the building. That is, insulation thickness from zero to a specified upper limit can be considered during a given simulation.

The building subroutine is outlined in Illustration 2. Before any computations are made, the type of house must be identified in terms of ceiling configuration (flat, gable or trapezoidal), type of windows (curtain, glass or windowless) and degree of winterization (storm windows or inserts). These factors influence the size of the ceiling and wall areas as well as the heat loss from the structure. After classifying the structure, the cost of the foundation is determined. Because of variations from site to site, no site preparation costs are included.

ILLUSTRATION 2

Simplified Flow Chart For Building Program



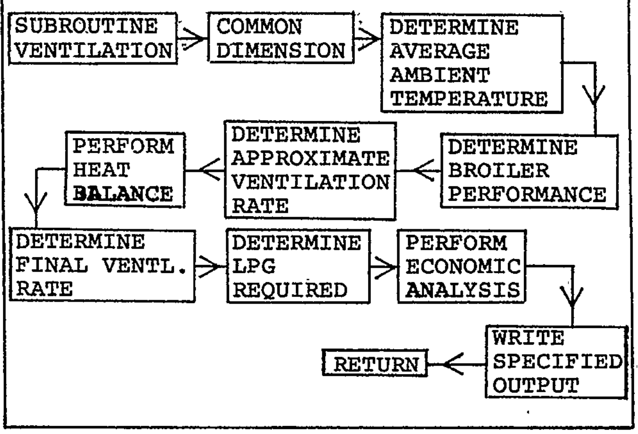
After determining the number of doors and windows in the building, the cost and heat loss for the miscellaneous areas are determined. The miscellaneous areas include windows, doors, lower wall and perimeter. These items remain fixed and do not vary during the rest of the analysis. Next, the upper wall area, which is a function of the number of windows and doors and the height of the lower wall is determined. After calculating the ceiling areas based on the type of structure, the amount of material, and its cost are computed for the framing members and covering surfaces.

The final sequence of calculations in the building subroutine determines the cost of insulation and the heat loss from the insulated areas of the structure. As indicated above, the simulation can be carried out for different levels of insulation. After computing the cost of insulation and the heat loss from the walls and ceilings, the costs and heat losses are totaled. The specified output is printed and the needed computations are carried into the ventilation subroutine.

The ventilation subroutine is outlined in Illustration 3. The first sequence of calculations determines average ambient and dew point temperatures for use in the heat balance and in determining the moisture holding capability of the air. At the present time, weather data for eight heating seasons (September 6 to April 17)

ILLUSTRATION 3

Simplified Flow Chart For Ventilation Program



is in the data deck. To reduce the amount of weather data required and to account for the diurnal fluctuations in temperature, the weather data has been treated in the following manner.

The sine series suggested by Jordan et al (90 to describe ambient temperature fluctuations was reduced to a simple sine series limited by the daily high and low temperatures. In previous work (4), it was found that after integrating the sine function, the average temperature for the warm twelve hours and the cold twelve hours could be described by:

$$SOT = .5(HT+LT) \pm A$$

$$A = .325\ (HT - LT)$$

where SOT = average ambient temperature for 12 hours
HT = daily high temperature
LT = daily low temperature
A = amplitude derived from integration of sine function

The dew point temperatures that occur with the daily high and low are used in the simulation and treated in the same manner.

No attempt is made to specify the time of day when the high or low occurs. The warm period is taken as the twelve hours around the high temperature while the remaining twelve hours constitute the cold period. On Delmarva, the high normally occurs in the late afternoon while the low occurs about sunrise.

The next segment of the program generates information concerning broiler growth. Since the simulation has been used for winter time condidions, it has been assumed that the house temperature and humidity remain relatively constant throughout the day. This assumption also permits the use of previously published data. Since the brooding temperatures normally considered in the simulations are similar to those rpported by Ota (13), Ota's data for latent and sensible heat are used in the model. In addition, broiler evaluations (2, 3, 11) conducted at the University of Delaware Substation use similar brooding temperatures. Therefore, these data have been used to determine the empirical constants used in describing broiler weight and feed conversion, ie,

$$BW(XND) = \sum_{N=1}^{7} BGC(N) \text{ X } XND^{(N-1)}$$

$$CFE(XND) = \frac{(CFEC(1)+CFEC(2) \text{ x } BW(XND)}{CFEC(3)*BW(XND)+CFEC(4)}$$

where BW(XND) = broiler weight, lbs.
BGC(N) = empirical constants

Using the above relationships and their derivatives, the daily feed consumption can be determined.

To relate daily feed consumption to fecal production, the following assumptions were made. First, broiler body moisture content is 75 percent at day one and declines to about 60 percent by the end of 9 weeks (1, 16, 18). Second, the moisture content of the feces (7, 10, 14) is 75 percent while the broilers are on the starter ration and declines to 73 percent when the finishing ration is fed. In addition, the feces moisture content (12) increased by one, two and four percent when the house temperature exceeds 76, 82 and 88°F, respectively. Third, it was assumed that the digestion process (10, 15) converted 54 percent of the starter ration and 51 percent of the finishing ration to water. The amount of feces (5) and the water removed from the feces (5) is computed by

$$FECES(XND) = ((1-XMC(XND)XDFC(XND) - (1-BMC(XND)*DG(XND))/(1-FMC)$$

$$FMR(XND)=(FECES(XND)XFMC-DFMC)/(1-DFMC)$$

where FECES(XND) = fecal material excreted, lbs.
XMC(XND) = fecal moisture content
DFC(XND) = derivative of cumulative feed conversion
BMC(XND) = body moisture content
DG(XND) = daily gain
FMC = feed moisture conversion
FMR(XND) = fecal moisture removed
DFMC = moisture content of dried feces

The total amount of moisture derived from the broiler is found by adding the fecal moisture removed to the respired moisture as measured by the latent heat.

Energy Requirements (Continued)

The next sequence of calculations computes the ventilation rate required to remove the broiler-derived water. This is only an approximation of the final ventilation since other sources of water have not been considered. The simulation uses the averaged dew point temperatures along with the averaged ambient and house temperatures to compute the volume of air required. Because of the variability in the moisture content of ambient air, the amount of air required is computed on a weekly basis. Thus, the computed ventilation rate is an average for the week. Also to be noted is the fact that weeks with ventilation rates in excess of a specified maximum (3 cfm) are excluded from the analysis. This was done to restrict fuel use when proper ventilation for moisture control is difficult.

The next phase is to determine the amount of energy required to maintain house temperature. This is outlined in more detail in Illustration 4. Depending on the portion of the house in use the heat from lights and the building heat loss is determined. Then, the amount of heat available from the solar heating system is determined based on the time of year. After determining the temperature differential, a heat balance is performed to calculate the amount of supplemental heat required. If LPG fuel is required, this is adjusted later in the simulation. If a solar heater is in use, the amount of energy required from the LPG brooders is reduced. The process is repeated for each 12 hour interval.

Returning to Illustration 3, the next step is to adjust the ventilation rate in order to remove the moisture produced by the combustion process. The iterative process used has been described in previous work (5). An additional amount of full is also required. When the final amount of heat energy supplied by the brooders has been determined, this can be converted to gallons of LPG.

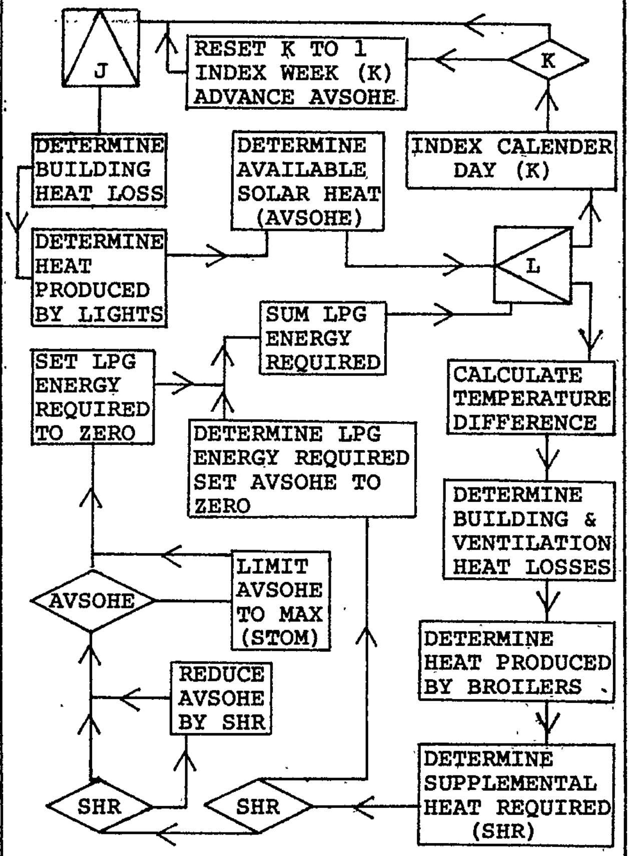
The final computations deal with the economic question of fuel cost. These calculations are based on asseries of inflation rates. The inflated fuel cost is then added to the building cost times an ownership factor to determine the combined cost. (A copy of the program can be obtained by writing the author).

Results and Discussion

The model's usefulness as an evaluative tool is dependent on its ability to accurately predict the energy requirements for brooding. At the start of the "1973 energy crisis," DPI was using conventional brooding as the grower management practice for raising broilers. With conventional brooding, the baby chicks and the LPG brooder stoves are placed uniformly throughout the house. At the time,,it was standard practice to operate the brooder stoves in such a manner as to provide a hover temperature of 90°F the first week and to reduce the temperature by 5°F per week until the fifth week. The corresponding average house temperatures for this period are 82, 79, 76, 73 and 70. After the fifth week hover and house temperature are both maintained at 70°F. The hover temperature is important for broiler comfort while the average house temperature determines the heating and ventilation requirements.

ILLUSTRATION 4

Simplified Flow Chart for Energy Balance



A comparison of the predicted and actual LPG consumption by a DPI company is shown in Table 1. The simulation is based on a 32' x 200' broiler house with two inches of fiberglass insulation (R= 3.2/in.) and a capacity of 8000 broilers. Over the ten week period, the model overestimated LPG consumption by about three percent. Within a given week and for a given broiler age, noticeable deviations occurred. These deviations are attributed to events that occur in the field but are not included in the model. For example, the actual ventilation rate may vary from that used in the model. At other times, growers may turn off the brooder stoves and allow the house temperature to fluctuate.

The effect of modifying the brooding and house temperatures used for conventional brooding is demonstrated in Illustration 5. In all cases, the house temperature starts at 82°F and is lowered 3°F per week until the final growout temperature is reached. The model indicates that increasing the growout temperature above 70°F will reduce LPG consumption. The optimum growout temperature, in terms of fuel usage, appears to be about 76°F. In a recent article, Day (6) reported that feed conversion also improved when the growout temperature is increased from 60°F to 70°F. At the present time, the model does not relate bird growth to house temperature. Therefore, the optimization of the fuel, feed and growout temperature cannot be achieved. This work is currently underway.

The potential for reducing LPG consumption by lowering the house temperature at night is shown in Table 2. For this simulation, it was assumed that the broiler had to be five weeks old before the temperature could be reduced at night and the growout temperature was 70°F. The maximum energy savings occurs when the difference between the day and night temperature is 4°F. Over a ten year period, 868 gallons of LPG would be saved. On a per flock basis, the grower would reduce fuel consumption by 2.2 gallons of LPG per thousand. The adverse effect on feed conversion may offset the fuel savings.

Also shown in Table 2 are the ventilation

TABLE 1

A Comparison of the Average Fuel Useage Computed by the Model and the Fuel Useage Reported by a Delmarva Company in 1973-1974.

Age, Weeks		1		2		3		4		5	
Rel. Humidity		.40		.43		.46		.49		.52	
		Gallons of LPG/1000 Broilers									
Week Starts	Amb. Temp. °F	C*	M**	C	M	C	M	C	M	C	M
12/12	40	20.4	20	12.5	16.7	4.9	8.4	2.5	5.1	.7	3.1
12/19	33	21.6	22.9	19.5	18.9	12.3	10.1	3.8	5.7	1.6	3.1
12/26	41	19.1	19.0	16.3	15.2	8.8	7.3	8.1	4.3	2.5	2.8
1/2	44	20.0	17.3	8.7	13.3	9.1	5.9	3.4	3.1	2.8	2.0
1/9	36	17.3	21.9	10.0	18.3	6.3	9.7	3.1	5.8	3.9	3.4
1/16	37	22.7	20.7	17.9	16.6	6.9	8.1	9.5	4.2	2.5	2.2
1/23	46	22.7	17.4	11.9	14.4	5.6	7.4	4.7	5.1	.9	4.1
1/30	48	16.5	16.1	11.5	13.0	7.3	6.7	5.2	4.8	2.1	3.9
2/6	36	17.6	21.9	10.4	18.3	7.2	9.7	3.4	5.8	1.2	3.4
2/13	32	23.6	23.1	21.1	19.0	16.3	9.8	10.2	5.3	8.8	2.8
Average		20.2	20.0	14.7	16.4	8.5	8.3	5.3	4.9	2.7	3.1
Total of Average Values				51.4	52.7						

* Company Data
** Model Prediction

rates required for moisture removal as a function of the day-night temperature difference. Notice that as the night temperature drops, a higher ventilation rate is required. The higher ventilation rates will require more electricity to operate the power ventilation system. This added electrical cost will offset some of the fuel savings.

The effect of building width and capacity on housing and fuel costs is shown in Table 3. In this simulation, it was assumed that the building would be used for 10 years, the current price of LPG was 45 cents per gallon and the fuel cost would increase 15 percent annually. For an 8000 bird house, which was representative in 1973, increasing the width reduced both the construction and the fuel costs. Most

ILLUSTRATION 5

The Effect of Growout Temperature on LPG Usage in Ten Years for Conventional Brooding

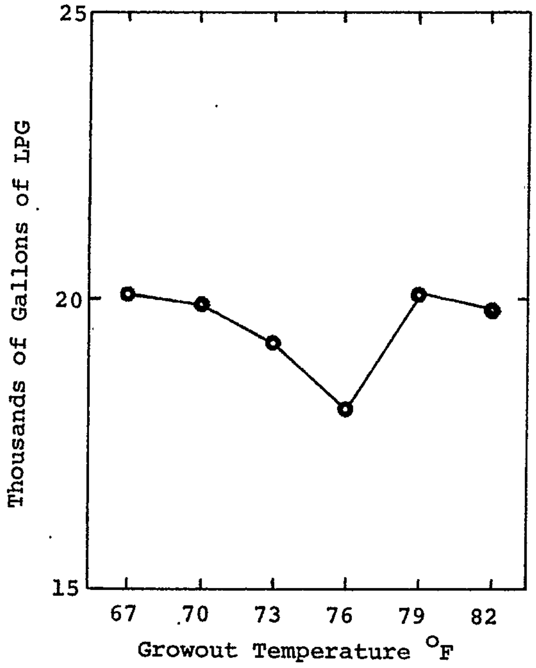


TABLE 2

The Effect of Reducing House Temperature at Night on Fuel Consumption and Ventilation Rate.

Day-Night Temperature Difference	Gallons of LPG Required	Ventilation Rate at 5 wks. CFM/bird
0	18663	.521
2	18028	.557
4	17795	.598
6	17929	.641
8	17955	.685
10	18017	.735

TABLE 3

The Effect of Building Width and Capacity on Construction and Fuel Costs.

Capacity (Broilers)	Building Width (ft)	Building Length (ft)	Construction Cost ($/Broiler)	LPG Cost ($/Broiler)
8,000	32	200	2.21	2.29
8,000	36	178	2.13	2.12
8,000	40	160	2.14	2.09
8,000	42	152	2.08	2.04
12,000	42	230	2.01	1.98
16,000	42	304	1.98	1.95
20,000	42	380	1.95	1.92
24,000	42	456	1.94	1.91
28,000	42	534	1.93	1.90

of this savings was attributed to a reduction in the number of windows used in the wider houses.

As the capacity of the house is increased from 8000 to 28000 broilers, the construction and fuel costs continued to decline. The cost reduction appears to be minimal at capacities over 20,000 broilers. A factor which is not included and may become important with the longer houses is the cost of site preparation. In 1977, houses under construction are predominantly 40 to 42 feet wide with a capacity of about 20,000 broilers.

In Table 4, the combined building ownership and fuel costs are shown for three grower management practices as a function of ceiling insulation thickness. The combined costs were computed assuming the building would be used for ten years. To account for taxes, interest, etc., the cost of construction was multiplied by 1.9 to obtain the cost of owning the house. The fuel costs were calculated assuming the current price of LPG was 45 cents per gallon and that the price of fuel would increase at 15 percent per year.

The grower management practices considered in Table 4 are whole, half and third house brooding. Whole house refers to the conventional brooding described earlier. With half house brooding, partitions are placed at the half and three-quarter points in the house. During the first three weeks the broilers are limited to half the house. For the next three weeks three-quarters of the house is used and finally the entire house is used for the last three weeks. Third house differs from half house in that the partitions are placed at the one-third and two-third points. In all the cases, hover and house temperatures were the same.

TABLE 4

The Effect of Ceiling Insulation Thickness and Type of Brooding on the Cost of Fuel and Owning the Building.

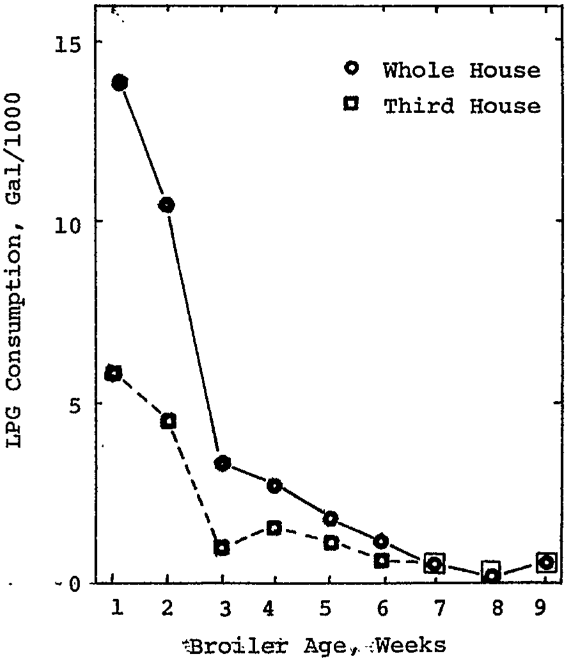
Thickness of Ceiling Insulation (in)	Cost of Fuel and Owning the Building, $/Broiler		
	Type of Brooding		
	Whole House	Half House	Third House
2	5.67	4.96	4.76
3	5.42	4.88	4.73
4	5.34	4.88	4.75
5	5.31	4.90	4.79
6	5.33	4.95	4.84
7	5.37	5.01	4.91
8	5.42	5.08	4.99
9	5.49	5.16	5.06

The reduction in the cost of fuel and owning the building is due to the fuel savings realized by using a limited portion of the house. In Illustration 6, the fuel consumption for whole and third house brooding is compared. The data was generated for a house with three inches of insulation and an average ambient temperature of 45°F. According to the model, the adoption of third house brooding will reduce LPG usage in broiler houses by 56 percent. In the field, growers are achieving a savings of about 40 percent. Some DPI companies will have converted almost 50 percent of their growers to limited area brooding by the fall of 1977.

There are two other factors that influence the thickness of insulation required to minimize the cost of fuel and the building. Both of these factors are difficult if not impossible to predict. First, what is the useful life of the structure and/or its components. Table 5 indicates the effect the assumed useful life has on the selection of the optimum level of insulation. For the 15 year life, the cost of ownership was taken as 2.4 times the first cost. As the useful life is increased from 10 to

ILLUSTRATION 6

The Effect of Grower Management Practice on LPG Consumption During Brooding



Energy Requirements (Continued)

15 years, the optimum level of insulation increases between three and four inches to five inches.

The other factor that is impossible to predict, but is of paramount importance, is the inflation rate. The effect of inflation rate on the combined cost is shown in Table 6. The calculations are based on a ten year useful life and half house brooding. At LPG price inflation rate of 10 percent per year, three inches of insulation would be the optimum while four inches would be the optimum for a 20 percent year increase in LPG price.

The feasibility of using a solar heating system to supply part of the supplemental heat is examined in Table 7. The analysis is based on a 10 year period with the 45 cent LPG increasing at 15 percent per year. The solar radiation values shown in Table 8 were used in the simulation. If only a collector is used, the projected savings or reduction in expenditures for LPG would be only $3,690. In terms of collector construction, the maximum economic construction cost per square foot would be 77 cents. If the collector is subject to ownership costs, such as taxes, interest, etc., the allowable construction cost would be reduced to 40 cents per square foot.

Brooding in a house with a 4800 square foot collector and a million BTU storage capacity would reduce expenditures for LPG by $11,761. This translates into a construction cost of $2.45 per square foot of collector if there are no ownership costs or $1.29 if ownership costs are considered. Recently, Forbes and McClendon (8) modified the wall of a pre-engineered metal building to form a solar collector. The cost of material was about one dollar per square foot. No estimate of labor or storage costs were provided.

Conclusions

1. The model provides a reasonable estimate of the amount of LPG required to brood broilers.
2. Third house brooding uses 56 percent less LPG than whole house brooding.
3. The economically justifiable level of insulation depends on the brooding management practice to be used.

TABLE 5

The Effect of the Useful Life on the Combined Cost of Fuel and Building Ownership.

Thickness of Ceiling Insulation (in)	Combined Cost $/Broiler 10 Year Life	Combined Cost $/Broiler 15 Year Life
2	4.96	7.52
3	4.88	7.24
4	4.88	7.16
5	4.90	7.15
6	4.95	7.18
7	5.01	7.23
8	5.08	7.30
9	5.16	7.39

TABLE 6

The Effect of LPG Price Inflation on the Optimum Level of Ceiling Insulation.

Thickness of Ceiling Insulation (in)	Combined Cost, $/Broiler Inflation Rate, Percent 0	10	15	20
2	4.38	4.71	4.96	5.28
3	4.37	4.66	4.88	5.15
4	4.41	4.68	4.88	5.13
5	4.46	4.72	4.90	5.15
6	4.52	4.77	4.95	5.19
7	4.59	4.83	5.01	5.24
8	4.67	4.91	5.08	5.31
9	4.75	4.99	5.16	5.38

TABLE 7

The Effect of Solar Heating Systems on LPG Consumption in Broiler Production.

Coll. Size (ft^2)	Storage (BTU)	System Eff.	LPG Used (gal)	LPG Cost ($)	Savings ($)
0	0	0	1	17617	-
4800	0	.50	15243	13927	3690
4800	100000	.45	14042	12830	4787
4800	1000000	.45	6409	5856	11761

TABLE 8

Daily Total Radiation (19)

	BTU/ft^2		BTU/ft^2
Sept.	1446*	Jan.	667
Oct.	1446	Feb.	1301
Nov.	1170	Mar.	1255
Dec.	736	Apr.	1255*

* Assumed values.

4. The rate of inflation and the useful life of the building are important considerations in the economic analysis.
5. To extend the usefulness of model, broiler growth must be sensitive to temperature.

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REFERENCES

1. Biddle, G. H. and E. M. Mergenson, Approved Practices in Poultry Production, Interstate Printers and Publishers, Danville, Ill. 1963.

2. Chaloupka, G. W. "Report on Weekly Growth and Feed Conversion, Substation Flock S376," University of Delaware Experiment Station, Substation Division, 1973.

3. Chaloupka, G. W. and S. Klopp, "Broiler Research Progress Report, Performance of Broilers as Influenced by Breed and Strain," University of Delaware Agricultural Experiment Station, Substation Division. 1974.

4. Collins, N. E. and E. W. Walpole. "Computer Simulation of Fuel Requirements for Growing Broilers," Transactions of ASAE, Vol. 19, No. 3, p 545. 1976.

5. Collins, N. E. and E. W. Walpole. "Computer Simulation of Winter Ventilation Rates for Broiler Houses," ASAE Paper No. 75-4519, ASAE, St. Joseph, Mi. 1975.

6. Day, E. J. "More Ways to Minimize Broiler Feed Costs." Broiler Business, p 22. February, 1976.

7. Eley, C. P. and E. Hoffman, "Feed Particle Size as a Factor in Water Consumption and Elimination," Poultry Science, Vol. 28, p 215. 1949.

8. Forbes, R. E. and R. W. McClendon, "The Heating of a Poultry Broiler House Using Solar Energy." ASAE Paper No. 77-3005. St. Joseph, Mi. 1977.

9. Jordan, K. A., T. Takakura, L. L. Boyd, R. L. Tibbits and M. L. Hellickson, "Predicting Diurnal Environmental Conditions Within Buildings," ASAE Paper No. 72-556, ASAE, St. Joseph, Mi. 49085. 1972.

10. Longhouse, A. D., H. Ota and W. Ashby, "Heat and Moisture Design Data for Poultry Housing." Agricultural Engineering, 1960.

11. Malone, G. W., G. W. Chaloupka, L. H. Littlefield and J. W. Merkley, "1976 Broiler Cross Evaluation Test, Growth and Feed Standards," University of Delaware Agricultural Experiment Station, Substation Division. June, 1977.

12. North, M. O. Commercial Chicken Production Manual, AVI Publishing Co., Inc. Westport, Conn. 1972.

13. Ota, H. "The Effect of Heat and Moisture on Growing Broilers." Proceedings of 1972 Broiler Housing Seminar." University of Delaware, Substation Division, Georgetown, Delaware. 1972.

14. Patrick, H. and A. Ferrise. "The Water Requirements of Broilers." Poultry Science, Vol. 41. pp 1363. 1962.

15. Runnels, T. Personal Communication. Poultry Nutritionist, Department of Animal Science and Agricultural Biochemistry, University of Delaware, 1976.

16. Scott, M. L., M. C. Nesheim and R. J. Young. Nutrition of the Chicken. M. L. Scott and Associates, Ithaca, N.Y. 1969.

17. Shelton, T. Sixteen Major Areas of Energy Use in an Integrated Broiler Operation. DPI Energy Committee Summary. 1976.

18. Sturkie, P. D. Avian Physiology, 2nd Edition, Comstock Associates, Cornell University Press, Ithaca, N.Y. 1965.

19. Telkes, M. "Storage of Solar Heating/Cooling Institute of Energy Conversion." University of Delaware, Newark, Del. ASHRAE Meeting, June, 1974.