Simulation of Weight Gain and Feed Consumption of Turkeys

by

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Agricultural Engineering

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May, 1989

Blacksburg, Virginia

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(ABSTRACT)

Like most agricultural production systems, effective decision making in turkey production systems requires the prediction of future status of the system and evaluation of alternative management policies. A simulation model of a turkey production system was developed to predict values of flock performance indicators of significant economic importance, namely body weight and feed consumption. Existing weather simulation models were combined and modified in order to develop a model that predicted daily dry-bulb temperature and humidity ratio outside the turkey house. The weather simulation model was validated using twenty years of daily observed weather data from Roanoke, Virginia. Thermal environment inside the turkey house was predicted from simulated outdoor weather using energy and mass balance equations. House environment prediction part of the model was validated using observed inside and outside temperature data collected at a turkey farm in Virginia. A discrete event simulation model was developed to simulate the effects of house thermal environment, feed energy, sex, and age on weight gain and feed consumption of growing turkeys. The model was validated using temperature, body weight, and feed consumption data collected at a turkey farm in Virginia. The observed average bird weights at marketing age were within 95% confidence intervals of the predicted values. However, the model underpredicted energy consumption values.

The sensitivity of the model to variations in R-value, ventilation rate, and feed energy concentration was evaluated. The model was more sensitive to feed energy concentration.

Acknowledgements

The author would like to thank the Virginia Poultry Federation for providing financial support for this research. Their patience and understanding is appreciated. Thanks are due to the Spitzer Farms for collecting and providing data needed for this research.

Special thanks are extended to Dr. Alvah T. Leighton, Jr. for providing data needed for this research.

Many thanks are extended to Dr. Kenneth C. Diehl, co-Major professor, for his guidance, encouragement and concern throughout this research. His patience, understanding, friendliness, and constructive criticism made this research a smooth project.

Appreciation is extended to Dr. Eldridge R. Collins, Jr., co-Major professor, for making financial and administrative arrangements that made the author's studies possible at Virginia Tech.

Special thanks are due to Dr. Ralph M. Hulet, for providing invaluable information needed to complete this research. His friendliness made this research a pleasant adventure.

Thanks are extended to Dr. J. Philip Mason for serving on the graduate committee, and helping to locate the needed information.

Thanks are extended to Dr. Conrad D. Heatwole for serving on the graduate committee. His friendliness, understanding and patience helped a great deal in completing this research.

Many thanks are due to the author's colleagues in the Agricultural Engineering Department of Virginia Tech for providing encouragement and a friendly environment throughout this research. Thanks are extended to , , , , , , and for making the author's stay in Blacksburg a pleasant experience.

The author extends his appreciation and gratitude to his family in India for being so patient, loving, and understanding throughout his stay in the United States.

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Introduction

Increasing awareness of adverse effects of animal fats in consumption of red meat by humans has resulted in a rapid increase in poultry meat consumption. Per capita consumption of turkey meat in the United States has more than doubled since 1960. This trend has closely followed total turkey meat production, which has quadrupled since 1960 as shown in Figure 1. However, turkey producers are still operating within narrow profit margins. Profit margins need to be improved in order to keep producers in business. One way to increase profit margin is through improved management strategies resulting from informed decision making. In the turkey industry, a production simulation model would be a valuable tool.

As in any complex biological system, many factors influence turkey production. Age, sex, breed, diet, light intensity, noxious gas concentrations, population density, and thermal environment have been shown to be important. Performance can be measured in terms of body weight gain, feed intake, feed efficiency, mortality, disease, water intake, carcass composition, and heat production. Of these, weight gain and feed intake are of greatest economic significance.

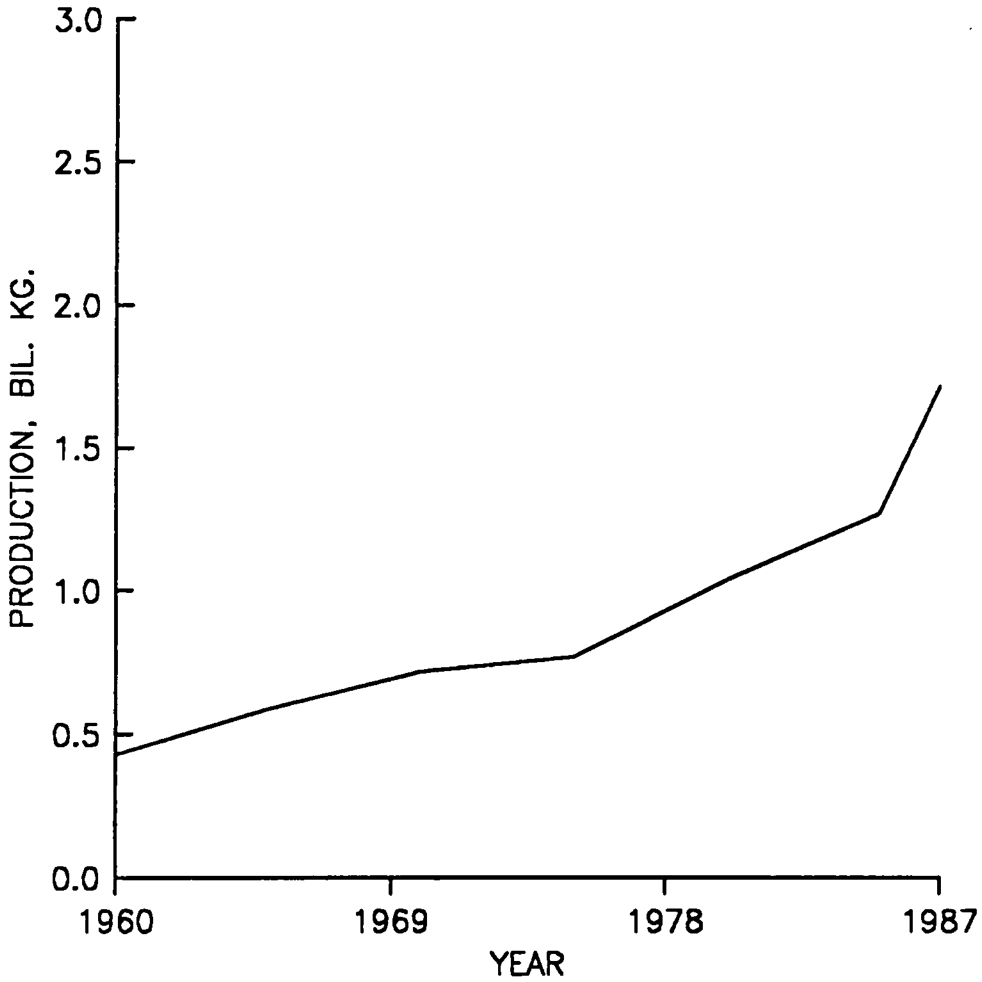

Figure 1. U.S. turkey meat production since 1960 (source: Sell, 1988)

Strain, sex, population density, marketing age, and feed formulation need to be selected carefully in order to maximize profits. Generally, optimization programs are used by company nutritionists to formulate least cost rations. The objective of such programs is to minimize cost under the constraints of satisfying nutrient requirements recommended by the National Research Council. The turkey farm manager has direct control over the environment of the birds. In order to control the environment, the manager needs to decide on the extent of ventilation, lighting, and heating or cooling.

Response of turkeys to a set of growing conditions varies from one bird to another, making turkey production a stochastic system. Also, since management decisions are made to plan a future course of action, prediction of future conditions introduces probability into the decision making process.

Like any other livestock production system, management strategies based on accurate predictions of future conditions are desirable to make turkey production as economical as possible. In a complex system like turkey production where a large number of components interact in a stochastic or probabilistic fashion, the future status of the system (market weight, marketing age, feed consumption, etc.) can be predicted using a stochastic simulation model.

The goal of this research was to develop a simulation model of a turkey production system to predict body weight and feed consumption of turkeys. Development of such a model required data on the interaction of various components of the turkey production system. Most of the information needed to construct the model was available in the literature in one form or another. However, integration of this information into a more useful form was necessary.

Specifically, the objectives of this study were three fold.

1. To simulate outdoor dry-bulb temperature and humidity ratio.

2. To predict dry-bulb temperature and humidity ratio inside the turkey house from simulated outdoor weather.

3. To simulate body weight gain and energy consumption of turkeys.

Literature Review

Until recently, turkey production was not a significant part of U. S. Agriculture. Information from experiments performed on chickens and broilers was used to make management decisions in turkey production. Increases in turkey meat consumption have been accompanied by a great deal of research in turkey production during the last decade. Research in the area of weather prediction has also been significant during the last decade due to its impact on agricultural production. Literature topics will be reviewed as they relate to the research objectives.

Weather Simulation

A number of weather simulation models have been developed during the last 15 years. The number of weather parameters generated varies from one model to another. Some of these models predict hourly weather while others predict daily or weekly weather. Similarly, model inputs vary from one model to another. Some of the models require only the normal weather of the location while others need probabilities of occurrence of various events.

Koon et al. (1987) reported that the daily mean dew-point temperature can be predicted with reasonable accuracy from early morning dry-bulb temperature in humid regions. They used two methods of comparing early morning dry-bulb temperatures with daily mean dew-point temperature. In the first method, they compared observed hourly dry-bulb temperatures at 0400, 0500, 0600, 0700, and 0800h to the observed daily mean dew-point temperature. In the second method, they used the following equation developed by Hill (1983) to predict hourly dry-bulb temperature.

$$T = \frac{(T_{high} + T_{low})}{2} + \frac{(T_{high} - T_{low})}{2}$$
$$\times [\ \sin(0.26179(Hour + 13)) + \sin(0.26179(Hour + 13) \times 2)/3]$$

where, T = hourly dry-bulb temperature, [°C]

T_{high} = daily high dry-bulb temperature, [°C]

T_{low} = daily low dry-bulb temperature, [°C]

$Hour$ = hour of day

The equation above was found to predict early morning hour temperatures accurately when the weather pattern followed the typical pattern of low morning dry-bulb temperatures followed by a warming trend during the day and cooler temperatures at night.

Kline et al. (1985) developed a simulation model for hourly dry-bulb and wet-bulb temperatures. Periodic variations over the year were modeled using spectral analysis and least-square regression. The deterministic component of the model was determined using a Fourier series as

$$
\begin{aligned}
T(t) = \bar{T} &+ A_1 \sin(2\pi t/N) + B_1 \cos(2\pi t/N) \\
&+ A_{365} \sin(2\pi(365t)/N) + B_{365} \cos(2\pi(365t)/N) \\
&+ A_{730} \sin(2\pi(730t)/N) + B_{730} \cos(2\pi(730t)/N) \\
&+ A_{1095} \sin(2\pi(1095t)/N) + B_{1095} \cos(2\pi(1095t)/N)
\end{aligned}
$$

where $\bar{T}$ is the mean of the sample and N is the number of discrete intervals in one year which in this case was 8760. A_n and B_n where n represents the appropriate harmonic, are the coefficients of the Fourier series.

The stochastic part of the model was simulated using a multisite Markov model. Residual dry-bulb temperature and log humidity ratio were generated by the following equation,

$$X_{i+1} = AX_i + B\varepsilon_{i+1}$$

where X_i is a (2×1) matrix whose elements are residual dry-bulb temperature and log humidity ratio at time i. A and B are (2×2) matrices whose elements are defined in such a way that the synthetic sequences generated by the above stochastic model resemble the observed historic sequences. ε_{i+1} is a (2×1) matrix whose elements are mutually independent random variables from a standard normal distribution, and are independent of the elements of of X_i. A and B are defined as follows:

$$
\begin{aligned}
A &= M_1 M_0^{-1} \\
BB^t &= M_0 - M_1 M_0^{-1} M_1^t
\end{aligned}
$$

where M_1 and M_0 were the lag-one and lag-zero covariance matrices, respectively. The periodic and random components were combined to obtain pairs of dry-bulb temperature and humidity ratio. These pairs were then transformed into dry-bulb and wet-bulb temperature pairs.

The model was able to generate pairs of dry-bulb and wet-bulb temperatures with statistics that closely resembled the observed pairs of data used in the developmental sample. The model can be applied to any location with a minimum of one year of location-specific hourly dry-bulb temperature and relative humidity data.

Richardson (1981) developed a model for the simulation of daily precipitation, temperature, and solar radiation. Precipitation was considered to be the primary variable that affects other variables. A first-order Markov chain with two states, wet or dry, was used to determine if the current day was wet or dry. A day with a total rainfall of 0.2mm or more was considered a wet day. The transition probabilities were completely defined by the probabilities of a wet day following a wet day, a wet day following a dry day, and wet or dry state on the previous day, and are described as follows:

$$P(D/W) = 1 - P(W/W)$$

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where,

$P(D/W)$ = probability of a dry day following a wet day

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$P(W/D)$ = probability of a wet day following a dry day

An exponential distribution was used to simulate the amount of rainfall on wet days.

Maximum temperature, minimum temperature, and solar radiation were simulated using a multivariate stochastic process with the daily means and standard deviations conditioned on the wet or dry state of the day. The time series of each variable was reduced to a time series of residual elements using the following equations:

$$R_{p,i}(j) = \frac{X_{p,i}(j) - \overline{X}_i^0(j)}{\sigma_i^0(j)} \qquad \textit{for dry days}$$

$$R_{p,i}(j) = \frac{X_{p,i}(j) - \overline{X}_i^1(j)}{\sigma_i^0(j)} \qquad \textit{for wet days}$$

where,

$\overline{X}_i^0(j)$ = mean of variable j on day i

$\overline{X}_i^1(j)$ = mean of variable j on wet day i

$\sigma_i^0(j)$ = standard deviation of variable j on dry day i

$\sigma_i^1(j)$ = standard deviation of variable j on wet day i

$R_{p,i}(j)$ = residual component of variable j on day i of year p

Using this technique resulted in a residual series for each variable that was stationary in the mean and standard deviation with a mean of zero and standard deviation of unity. The serial correlation coefficients and the cross-correlation coefficients of the series were used to describe the dependence and interdependence of the variables. Residuals of maximum temperature, minimum temperature, and solar radiation were generated by a multivariate generation model of Kline et al. (1985) discussed above.

Richardson and Wright (1984) developed a weather simulation model called WGEN. The model development was based primarily on the method described in Richardson (1981) discussed above. The model generated daily values for precipitation, maximum temperature, minimum temperature, and solar radiation. The authors of this model determined values of model parameters that were required to generate new sequences of the weather variables for locations in the 48 contiguous states of the United States. Values of the model parameters for any location in the continental United States can be interpolated from the maps and tables of model parameter values prepared by the authors, or can be generated using parameter generation model, WGEN PAR. About 20 years of precipitation and 10 years of temperature and relative humidity data are required as inputs to the WGEN PAR model, which is capable of using any available historical weather data to improve the accuracy.

The temperature simulation portion of the model was tested using the observed temperature records at five locations: Columbia, MO; Boise, ID; Miami, FL; Phoenix , AZ; and Boston, MA. Mean daily maximum and mean daily minimum temperature by month were significantly different in 20 of the 130 cases. The results improved when local average temperature corrections were applied. The model did not accurately simulate the extreme temperatures.

Larsen and Pense (1982) used a first order, two state Markov chain to simulate the occurrence of wet and dry days. Amount of rainfall on a wet day was simulated using a two-parameter gamma distribution. Parameter estimates were made for each month conditioned by the previous day's status. Two bivariate normal distributions conditioned by the precipitation status on the current day were used to simulate current temperature deviations from long term average temperature curves obtained from the actual data. Solar radiation deviations from the calculated maximum clear day radiation on dry days were simulated by a two-parameter gamma distribution. On wet days, the solar deviations were simulated by a two-parameter beta distribution.

The model was developed with data from Columbia, MO and validated with data from Albuquerque, NM; Caribou, ME; Medford, OR; and Miami, FL. Generally, results from the model did not significantly differ from observed data.

Pickering (1982) developed two models for daily temperature simulation. The first was a first-order Markov model conditioned by the occurrence of precipitation:

$$T_i = \mu_m(k) + \rho_1(jk)\frac{\sigma_m(k)}{\sigma_m(j)}[T_{i-1} - \mu_m(j)] + 1 - \rho_1^2(jk)\sigma_m(k)V_i$$

where,

T_i = temperature on day i

T_{i-1} = temperature on day (i-1)

μ_m = mean temperature for period m

σ_m = standard deviation of the temperature in period m

ρ_1 = lag-one autocorrelation

V_i = random standard normal variate

j = precipitation status (D or W) on day (i-1)

k = precipitation status (D or W) on day i

This model uses a biweekly period and requires a total of 108 parameter values: 26X2 (W or D) values for both μ_m and σ_m and 4 values of ρ_1.

The second version was a simpler model that requires 12 parameter values, and is a first-order Markov independent of precipitation:

$$T_i = \mu_m + \rho_1[T_{i-1} - \mu_m] + \sqrt{1 - \rho_1^2}\,\sigma_m V_i$$

where the parameters have the same meaning as in the first model but differ in that they are not conditioned on the occurrence of precipitation. Historic temperature data for Ames, IA; Aurora, NY; and Watkinsville, GA were used to develop the following regression equations:

$$\sigma_m^2 = 33.4 - 1.17\mu_m\,, \quad \mu_m \leq 28.6°C$$

$$\sigma_m = 5.72 - 0.122\mu_m\,, \quad \mu_m \leq 46.9°C$$

The correlation coefficients for these equations were 0.94 and 0.92, respectively. ρ_1 was calculated to be 0.664, 0.632, and 0.652 for Aurora, Ames, and Watkinsville, respectively. The author chose a value of $\rho_1 = 0.65$ to be the appropriate constant to use.

Bruhn and Fry (1980) used Monte Carlo techniques to simulate daily values of precipitation, maximum temperature, minimum temperature, minimum relative humidity, and total solar radiation. Each weather variable was represented by a theoretical probability distribution, but values of the parameters describing each distribution were determined dependent upon the occurrence of rainfall. The occurrence of rainfall was described by a first order Markov chain, and the amount of rainfall was determined by a random number generated from a gamma probability distribution. The temperature was simulated using a trivariate normal distribution. Maximum temperature was correlated with maximum temperature on the previous day, and minimum temperature was correlated with the current day's maximum temperature.

Occurrence of rainfall on the previous day determined parameter values for the temperature distributions. Normal distributions were used to simulate minimum relative humidity and solar radiation. Occurrence of rainfall on the current day determined parameter values for solar radiation distribution while occurrence of rainfall on both the current day and previous day determined parameter values for minimum relative humidity distribution.

The model was validated by comparing cumulative frequency distributions of simulated weather data with those of actual weather data from Geneva, NY and Fort Collins, CO. Mean response variability and autocorrelation characteristics were found to be adequately simulated by the model.

Nicks and Harp (1980) simulated daily temperature by four equations which corresponded to four rain day conditions which could exist: (1) a dry day after a dry day, (2) a wet day after a dry day, (3) a dry day after a wet day, (4) a wet day after a wet day. Transition between seasons was simulated by developing models for each month of the year. The models can be used to generate both maximum and minimum temperatures:

$$T_i(K,M,N) = \bar{T}(K,M,N) + r_T(K,M,N)[T_{i-1}(K,M,N) - \bar{T}(K,M,N)] + t\sigma_T(K,M,N)[1 - r_T^2(K,M,N)]^{1/2}$$

where,

T_i = current day temperature, [°C]

T_{i-1} = previous day temperature, [°C]

$\bar{T}$ = mean daily temperature, [°C]

r_T = lag-1 correlation coefficient

σ_T = standard deviation of daily temperature

t = a standard, random, normal, and independent distributed variable

$K = 1, 2, 3, 4,$ the four possible rain state conditions

$M = 1, 2,..., 12,$ the number of months or seasons

$N = 1, 2,$ the maximum or minimum temperature, respectively

Solar radiation was modeled the same way:

$$S_i(K,M) = \bar{S}(K,M) + r_S(K,M)[S_{i-1}(K,M) - \bar{S}(K,M)] + t\sigma_S(K,M)[1 - r_S^2(K,M)]^{1/2}$$

where,

S_i = solar radiation on current day, [*langleys*]

S_{i-1} = solar radiation on previous day, [*langleys*]

$\bar{S}$ = mean solar radiation, [*langleys*]

r_S = lag-1 correlation coefficient

σ_S = standard deviation of daily solar radiation

t = standard normal, random variate

$K = 1, 2, 3, 4,$ the four possible rain state conditions

$M = 1, 2,..., 12,$ the number of months or seasons

Hansen and Driscoll (1977) developed a mathematical model of hourly temperature for Big Spring, TX. Annual and diurnal variables were represented by harmonics. A first-order Markov chain was used to incorporate adjustments for the seasonal variations of the serial correlation coefficient, and for the seasonal and diurnal variations of the variability and non-normality of frequency distributions of hourly temperatures. The model underestimated the variability of mean monthly temperature and the frequency of occurrence of low diurnal ranges. The model gave good estimates of the periods below $0°C$ and above $18.3°C$.

The sequences of rain days required by the above model were generated by a two-state Markov chain model. The necessary statistical parameters, mean, standard deviation and lag-1 correlation coefficients were calculated using actual data.

Dunmont and Boyce (1974) developed a method of simulating five weather variables for any location for which historical weather data are available. Rainfall was simulated in two steps. The first step determined whether the day was wet or dry on the basis of four probabilities calculated from actual data. These were probabilities of a wet day following two wet days, PWWW(J); a wet day following a dry day, PDWW(J); a dry day following a wet day, PWDW(J); two dry days, PDDW(J). Probabilities were found for each two week period, J, using the formula,

$$PWWW(J) = \frac{\#\ of\ wet\ days\ following\ 2\ wet\ days\ in\ period\ J}{\#\ of\ days\ following\ 2\ wet\ days\ in\ period\ J}$$

and similarly for the other sequences. A random number, Ru_i was generated. If $Ru_i \leq PWDW(J)$, the day was designated wet. Otherwise the day was designated dry. To simulate amount of rainfall, the year was divided into four 13-week periods and Gamma distributions were used to simulate the amount on days following wet days and days following dry days, separately.

Temperature for day i was simulated using the following equation,

$$T_i = a\, T_{i-1} + (1-a)\, \overline{T}_i + e_i$$

where a is the first order correlation coefficient, e_i is a random term, and $\overline{T}_i$ is the actual average temperature for day i calculated from the historical data of the location.

Jones et al. (1972) developed the following equations to simulate probabilities of wet and dry days for College Station, MS.

$$P_n(i) = 0.194 + 0.042W - (6.89)(10^{-3})W^2 + (4.43)(10^{-4})W^3 - (1.35)(10^{-5})W^4 + (1.94)(10^{-7})W^5 - (1.03)(10^{-9})W^6$$

$$P_m(i) = 0.419 + 0.042W - (8.32)(10^{-3})W^2 + (6.07)(10^{-4})W^3 - (2.02)(10^{-5})W^4 + (3.13)(10^{-7})W^5 + (1.84)(10^{-9})W^6$$

where $i = W =$ week number of the year; $P_m(i)$ is the conditional probability that any day during the i th week will be wet, given that the previous day was wet; $P_n(i)$ is the conditional probability that any day during the i th week will be wet, given that the previous day was dry.

An incomplete gamma function was used to describe daily rainfall amount:

$$G(y) = (1 - P) + P.\int_0^y \frac{y^{\gamma-1}.e^{-y/\beta}}{\beta^{\gamma}.\Gamma_{(\gamma)}} dy$$

where,

$P =$ probability of receiving rain; either $P_m(i)$ *or* $P_n(i)$ depending on the previous day

$y =$ rainfall, inches

$G(y) =$ probability of receiving y inches or less of rainfall

The parameters γ and β were determined by rainfall data, and were calculated by

$$\gamma = \frac{1 + \sqrt{1 + \frac{4}{3}[\ln(\bar{y}) - (\frac{1}{n})\sum_{j-1}^{n} \ln(y_j)]}}{4[\ln(\bar{y}) - \frac{1}{n}\sum_{j-1}^{n} \ln(y_j)]}$$

$$\beta = \frac{\bar{y}}{\gamma}$$

where,

n = number of days of rainfall, and

y_i = rainfall amount in inches for the jth day of the ith week

Daily temperature was simulated by computing averages and standard deviations for each day of the year as follows:

$$T_d(i) = 49 - 2.31W + 0.342W^2 - (1.009)10^{-2}W^3 + (8.31)10^{-5}W^4$$
$$T_w(i) = 52 - 1.77W + 0.267W^2 - (7.775)10^{-3}W^3 + (6.19)10^{-5}W^4$$
$$S_d(i) = 8.91 + 0.903W - (0.1006)W^2 + (2.90)10^{-3}W^3 - (2.49)10^{-5}W^4$$
$$S_w(i) = 9.08 + 0.497W - 0.0713W^2 + (2.15)10^{-3}W^3 - (1.86)10 -5W^4$$

where,

$i = W$ = week number of the year

$T_d(i)$ = average daily temperature for dry days of the ith week

$T_w(i)$ = average daily temperature for wet days of the ith week

$S_d(i)$ = standard deviation of temperature for dry days of the ith week

$S_w(i)$ = standard deviation of temperature for wet days of the ith week

Models that predict weather on a daily basis are appropriate in developing a simulation model of turkey production because turkey production data are, generally, available on a daily basis as discussed later in this chapter. Also, models for which values of input variables are easily available are preferred. Two weather simulation models that satisfied the above two criteria were Richardson and Wright (1984) and Pickering (1982).

Turkey House Thermal Environment

Many attempts have been made to predict the turkey house environment. Some of the approaches are based on sound heat transfer principles while others have used statistical relationships between outside and inside thermal environment.

Timmons and Gates (1987) proposed the following criteria to estimate the temperature inside a turkey house during cold weather:

1) minimum possible inside temperature was the greater of
    a) outside temperature plus 1.7°C or
    b) 10°C
2) maximum possible inside to outside temperature difference of 6.7°C
3) target inside temperature of 15.6°C

The minimum temperature difference criteria were based upon a previous study conducted by Timmons et al. (1986) in which a value of 1.7°C was found to be the average difference between inside and outside air temperature for summer conditions in the Southeastern United States in a naturally ventilated broiler house. The other criteria were based on the authors' experience with commercial operations.

Hurwitz and Talpaz (1985) used a statistical relationship between outside and inside temperature in developing a simulation model of a turkey production system. They predicted dry-bulb temperature inside the turkey houses by regressing the outside temperature with the temperature inside the turkey house. Inside and outside temperature data used to develop the regression equation were collected at five farms in Israel. The regression analysis yielded the following equation:

$$T_{in} = 2.6 + 0.86T_{out}, \quad (S_{yx} = 1.7,\ R = .946)\,, \quad 5°C < T_{out} < 30°C$$

where T_{in} is the average temperature inside the house, T_{out} is the average temperature outside the house, and S_{yx} is the standard error.

Validation of the simulation model by comparing the model results with Minnesota feeding trials (Waibel et al., 1976) indicated that the model underestimated body weights by about 4% while energy intake was underestimated by about 12%. Use of the above regression equation to predict the dry-bulb temperature inside the house may have been partially responsible for the underestimation because the equation was developed using environmental data from Israel, and environmental conditions of Minnesota may have been outside the range of validity of the equation.

Reece and Lott (1982) used energy balance principles to predict inside thermal environment from outside thermal environment. The ventilation rate V_t, to control temperature, was calculated by the following general equation:

$$V_t = \frac{Q_s - Q_b}{1.005(t_i - t_o)}$$

where,

Q_b = total heat loss or gain given by a building, $\left[\frac{kJ}{hr}\right]$

Q_s = total sensible heat produced by birds in a building, $\left[\frac{kJ}{hr}\right]$

t_i = inside temperature, $[°K]$

t_o = outside temperature, $[°K]$

V_t = ventilation rate to control temperature in a building heated only with bird heat, $\left[\frac{kg}{hr}\right]$

The equation is valid only if $Q_b < Q_s$ and $t_i < t_o$. The ventilation rate to control the humidity was generated by the following general equation,

$$V_h = \frac{Q_l}{2428(w_i - w_o)}$$

where,

Q_l = total latent heat produced in the building, $\left[\frac{kJ}{hr}\right]$

V_h = ventilation rate to control humidity in a building containing birds, $\left[\frac{kg}{hr}\right]$

w_i = humidity ratio in house for temperature and relative humidity specified, $\left[\frac{kg\ of\ moisture}{kg\ of\ dry\ air}\right]$

w_o = humidity ratio outside for climatic conditions specified, $\left[\frac{kg\ of\ moisture}{kg\ of\ dry\ air}\right]$

If $V_h > V_t$ for the conditions specified, the house temperature and relative humidity specified cannot be maintained without the addition of heat to supplement that provided by the birds. In this case, amount of supplemental heat required to maintain the specified house temperature and relative humidity at V_h is given by the following equation:

$$Q_f = 1.005(V_h - V_t)(t_i - t_o)$$

where Q_f is the supplemental heat required to maintain temperature and humidity when $V_h > V_t$.

Operating the house at V_h when $V_h > V_t$ results in lower (than desired) inside temperature and higher humidity ratio. In this case, inside temperature and humidity ratio are given by the following equations:

$$t_i = \frac{Q_s}{1.005V_h + U_c A_t} + t_o$$

$$w_i = \frac{Q_l}{2428V_t} + w_o$$

where,

U_c = composite coefficient of heat transmission for the building, $\left[\frac{kJ}{hr \cdot m^2 \cdot {}^\circ K} \right]$

A_t = total area of walls, roof, and openings for a building, $[m^2]$

These equations are valid for steady state conditions. Because of continuous change in outdoor weather, turkey houses are always subjected to transient heat and mass transfer conditions. Also, these equations are valid only for buildings that are mechanically ventilated. Models that predict environment inside the building from outdoor environment using transient heat and mass transfer principles need to be developed.

Effect of thermal environment on heat production of turkeys

Turkeys, being homeotherms, essentially maintain a constant body temperature through regulation of body heat production and heat dissipation. Heat is produced in the body by oxidation of food stuffs in the body. Heat is lost from the body of turkeys in the form of sensible and latent heat by three channels: the skin, lungs and excretions. The major portion of heat is lost through skin and lungs. Sensible heat is lost through conduction, convection and radiation. Heat loss through conduction in birds is very small compared to heat loss through convection and radiation. Heat loss through convection is governed by Newton's law of cooling (Warren, 1957),

$$Q_c = hA(t_s - t_e)$$

where,

Q_c = heat transferred by convection, $\left[\frac{kJ}{hr} \right]$

h = heat transfer coefficient, $\left[\frac{kJ}{hr \cdot m^2 \cdot {}^{\circ}K} \right]$

A = area, $[m^2]$

t_s = skin temperature, $[{}^{\circ}K]$

t_e = environmental temperature, $[{}^{\circ}K]$

Radiation heat loss between two bodies is governed by the Stefan-Boltzman law,

$$Q_r = \sigma \varepsilon_1 F_1 A_1 (T_s^4 - T_e^4)$$

where,

Q_r = heat transferred by radiation, $[\frac{kJ}{hr}]$

σ = Stefan-Boltzman constant

F_1 = configuration factor

ε_1 = emissivity of the surface

A_1 = surface area, $[m^2]$

T_s = surface temperature, $[°K]$

T_e = environmental temperature, $[°K]$

Since rate of sensible heat loss is a function of temperature difference between the environment and the body, environmental temperature affects the rate of sensible heat loss. To make up for reduced sensible heat loss because of narrow temperature differences, animals make certain physiological changes like increasing the blood flow to the outer skin layer and dilation of peripheral blood vessels resulting in higher latent heat loss. Latent heat loss is increased by increasing respiration rate and sweating. Latent heat loss is the result of evaporation of body moisture. Since evaporation is a function of temperature and relative humidity of inspired air, moisture in the air affects the rate of latent heat loss from the body.

DeShazer et al. (1974) measured the sensible and latent heat losses of large white male turkeys 6 to 36 days of age maintained at environmental temperatures recommended by the University of Nebraska (Table 1) and at 5.56°C above and 5.56°C below the recommended temperatures. Sensible heat loss per unit body weight for the recommended temperatures and 5.56°C below the recommended temperatures remained fairly constant with increasing age. But the sensible heat loss per unit body weight at 5.56°C above the recommended temperatures increased with increasing age. The evaporative heat loss per unit body weight decreased with increasing age. However, the evaporative heat loss per turkey remained fairly constant with increasing age.

Buffington (1971) determined heat production of growing turkeys as a function of age and body weight. Heat production was measured from seven to twelve weeks of age using indirect calorimetry. The following equations were developed to predict heat production for day and night:

$$Q_s = 11.35 - 0.065t \qquad \text{for daytime}$$

$$Q_s = 7.64 - 0.036t \qquad \text{for nighttime}$$

where,

Q_s = specific heat production, $\left[\frac{kcal}{hr \cdot kg} \right]$

t = turkey age, $[days]$

Total heat production of turkeys was calculated by multiplying specific heat production and weight of the bird where weight of turkey was determined from the Gompertz equation:

$$Q_T = (11.35 - 0.065t)(A\, exp(-B \ \exp(-C\, t)))$$

where,

Q_T = total heat production, $\left[\frac{kcal}{hr} \right]$

Table 1. Temperatures recommended at 5.08 cm above the litter at the edge of the turkey brooder

age (days)	recommended temperature °C
0 to 7	35.0
8 to 14	32.2
15 to 21	29.4
22 to 28	26.7
29 to 35	23.9

(Source: Sullivan et al., 1968)

$A, B,$ *and* C = Gompertz growth equation parameters

t = turkey age, [*days*]

Malhotra (1967) measured the partitional heat losses of mature Broad Breasted Bronze turkeys at 5°C intervals for environmental temperatures ranging from 10° to 35°C. The least square method was used to develop equations for sensible, latent and total heat loss from male and female turkeys,

$$Q_s = -2.786 + 0.328t + 1.414w + 3.033(S) - 0.021t^2$$
$$Q_l = 3.084 + 0.286t + 0.329w - 1.162(S)$$
$$Q_T = 4.845 + 0.458t + 1.763w + 2.005(S) - 0.017t^2$$

where,

Q_r = radiation heat loss, $\left[\frac{kcal}{hr}\right]$

Q_s = sensible heat loss, $\left[\frac{kcal}{hr}\right]$

Q_l = latent heat loss, $\left[\frac{kcal}{hr}\right]$

Q_T = total heat loss, $\left[\frac{kcal}{hr}\right]$

t = environmental temperature, [°C]

w = weight of the bird, [*kg*]

S = sex of the bird:

= 1 for male birds

= 2 for female birds

Ota and McNally (1961) conducted a series of short time tests with five hens and four toms to determine heat production of turkeys. Average weight was 8.8 kg for toms and 4.4 kg for hens. Temperatures were controlled at 18.3°C and 26.6°C. Average heat production ranged from 10.93 to 13.49 kJ/hr/kg of which 3.72 to 4.0 kJ/hr/kg was sensible heat.

Models that predict partitional heat loss of turkeys are appropriate in simulation of turkey production because sensible and latent heat produced by birds is needed separately to develop house environment simulation models which involve developing heat and mass transfer equations. Also, the heat production models that take bird weight into account are preferred because the change in strain of birds which results in change of bird weight can be handled by such models. The model that met the above criteria is Malhotra(1967).

Body Weight Gain and Feed Consumption of Turkeys

Many studies have been conducted to determine the parameters that affect the body weight gain and feed consumption of turkeys. Effect of thermal environment, and temperature in particular, has been the subject of most such studies. Other factors studied include feed energy, protein, and amino acid levels as well as sex of birds.

Hellickson et al. (1967) conducted one of the early studies of effect of temperature on performance of growing turkeys. Performance factors included were body weight gain, feed consumption, and fat deposition. Average weight gain of turkeys was found to be dependent on environmental temperature. Performance of growing turkeys was found to be optimum from 15.5°C to 21.1°C . The following equations were developed for turkeys 12 to 24 weeks old:

$$Y_{fc} = 12.365 - 0.157X + 0.00106X^2 \qquad (S.E. = 1.722)$$

$$Y_{fdm} = -22.146 + 1.005X - 0.00837X^2 \qquad (S.E. = 3.72)$$

$$Y_{fdf} = -24.861 + 1.105X - 0.00868X^2 \qquad (S.E. = 3.15)$$

$$Y_{wgm} = -9.321 + 0.597X - 0.00475X^2 \qquad (S.E. = 1.59)$$

$$Y_{wgf} = 3.606 + 0.1029X - 0.00106X^2 \qquad (S.E. = 0.606)$$

where,

Y_{fc} = feed conversion (males and females), $\left[\frac{lb\ feed}{lb\ gain} \right]$

Y_{fdm} = fat deposition in male, $[lb]$

Y_{fdf} = fat deposition in females, $[lb]$

Y_{wgm} = average weight gain for males, $[lb]$

Y_{wgf} = average weight gain for females, $[lb]$

X = environmental temperature, $[°F]$

$S.E.$ = standard error

Magruder and Nelson (1967) conducted a 24-week long experiment involving 1200 Large White turkeys divided into two groups of 300 toms and 300 hens in replicate pens housed in a heated and in a "normal" ambient temperature environment. Mean temperature for the 24-week period was 37°C during the day and 30°C during the night in the heated environment. Turkeys housed in the "normal" environment were exposed to a high mean temperature of 25°C and low mean of 16°C. The results of the experiment are tabulated in Table 2. The heated environment was obviously detrimental to growth performance of the birds.

Table 2. Performance of Large White turkeys housed in a "normal" and in a heated environment.

environment	sex	marketing age (weeks)	avg. body weight (kg)	kg feed per kg gain	mortality %
normal	male	24	12.04	1.59	18.0
	female	14	4.95	1.20	3.3
heated	male	24	10.38	1.56	39.7
	female	14	4.36	1.19	4.3

(Source: Magruder and Nelson, 1967)

Hurwitz et al. (1980) studied the effects of sex, diet and environmental temperature on the performance of Large White growing turkeys during a 4 to 5 week period after brooding. They reported significant effects of sex and environmental temperature on body weight gain which increased between 12 and 18°C, followed by a graded decrease up to 32°C. Reduction in body weight gain at high temperatures was not recovered by feeding a high protein diet.

Energy requirements of the individual turkey were partitioned into energy needed for maintenance and energy needed for weight gain. It was assumed that the maintenance energy requirements depend upon environmental temperature while energy needed for weight gain is not a function of the environment. The following model was developed:

$$\frac{TEC}{G} = M\,\frac{\overline{BW}^{2/3}}{G} + D$$

where, TEC is the daily energy intake (kcal/day); G is the daily weight gain (g); $\overline{BW}$ is the average body weight (g); and M and D are the energy requirements for maintenance (kcal/ $g^{2/3}$) and weight gain (kacl/g), respectively.

Significant effects of sex, diet and environmental temperature on feed intake were also reported. Feed intake showed a linear reduction with increasing temperature between 12 and 32°C. Males showed higher feed intake compared to females. Birds consumed more feed when a low-energy, high protein diet was used. Feed efficiency was significantly influenced by sex, diet and environmental temperature. Feed efficiency increased with increasing temperature, reached a peak between 24 and 28°C, and then declined at 32°C. Males showed higher feed efficiency compared to females. Feed efficiency was greater for high-energy diet compared to low-energy diet.

Hurwitz et al. [1983(a)] conducted an experiment to study the effects of environmental temperature on performance of 20-week old male British United Turkeys. Differences between weight gains at 10 and 20°C were insignificant. At 27°C, weight gain declined by 30 percent compared to weight gain at 20°C. At 35°C, weight gain was only 20 percent of that of turkeys maintained at 20°C. Difference between feed intake at 10 and 20°C was insignificant. Feed intake was depressed by 15 percent and 33 percent at 27 and 35°C , respectively, when compared to intake of turkeys at 20°C. Feed efficiency was not significantly influenced by temperature up to 27°C . However, at 35°C, feed efficiency was only 17 percent of the feed efficiency at 20°C.

Albuquerque et al. (1978) studied the effects of environmental temperature, sex, and dietary fat levels on the performance of Large White turkeys. Birds were subjected to constant environmental temperatures of 10 , 18.3 , 26.7 , and 35°C. Two types of diets, low-fat (0%) and high-fat (8%), were used. Growth period for birds in each treatment was 8 to 24 weeks of age.

Environmental temperature did not affect body weight gain from 10 to 18.3°C . Body weights at 24 weeks of age were depressed by 6 and 13% at 26.7 and 35°C , respectively. The trend of body weight gain was quadratic from 8 to 18 weeks, and linear from 18 to 24 weeks.

Feed efficiency increased with rising environmental temperature. Between 10 and 26.7°C, the rate of feed efficiency increase was about 1.2% per degree increase in environmental temperature. Difference between feed efficiencies at 26.7 and 35°C was not significant. Also, males showed higher feed efficiency compared to females. Addition of 8% fat to the diet did not significantly affect body weight gains for males or females. However, addition of 8% fat to the diet increased feed efficiency from 4.7 to 6.5%.

Rose and Michie (1987) studied the effects of environmental temperature over a five week period on the performance of 10-week-old female British United Turkeys reared on different protein concentration diets. For each 1°C increase in temperature, feed intake of the turkeys decreased by 1.2% and the feed conversion ratio decreased by 0.6%. Weight gain was not significantly affected by temperature. However, weight gain at higher environmental temperature tended to be lower. Regression analysis of the experimental data yielded following equations:

$$Y_{WT} = 3.07 - 0.0154T \quad \text{S.E.} = 0.00972, \ R = 0.544$$

$$Y_{FI} = 11.4 - 0.111T \quad \text{S.E.} = 0.185, \ R = 0.926$$

$$Y_{CR} = 3.76 - 0.0214T \quad \text{S.E.} = 0.0214, \ R = 0.801$$

$$Y_{BR} = 26.5 - 0.174T \quad \text{S.E.} = 0.0614, \ R = 0.756$$

$$Y_{DR} = 21.8 + 0.147T \quad \text{S.E.} = 0.0450, \ R = 0.801$$

where,

Y_{WT} = body weight gain, $\left[\frac{kg}{5\ weeks} \right]$

Y_{FI} = feed intake, $\left[\frac{kg}{5\ weeks} \right]$

Y_{CR} = feed conversion ratio, $\left[\frac{kg\ feed}{kg\ gain} \right]$

Y_{BR} = breast meat yield, [% *of weight*]

Y_{DR} = dark meat yield, [% *of weight*]

T = environmental temperature, [°C]

Models that simulate weight gain and feed consumption as a function of sex, environment, feed formula, and age are needed in simulation of turkey production. Two studies that can be used in the development of such models are Hurwitz et al. (1980) and Albuquerque (1978).

Dietary Factors Affecting Turkey Performance

Researchers have studied the effects of dietary energy, fat, and protein levels on the weight gain, feed consumption, feed efficiency, and carcass composition of turkeys in efforts to maximize growth performance. Maximizing weight gain and feed efficiency while minimizing feed consumption has been the primary goal.

Salmon and O'Neil (1971) studied the effects of level and source of dietary fat on the weight gain, feed conversion and carcass composition of male turkeys 46 days to 24 weeks of age. Dietary fat level was found not to influence body weight gain. At 2% added dietary fat level, source of added fat had no significant effect on body weight gain. However, at 11.4% added dietary fat level, rapeseed oil depressed body weight gain whereas palm oil increased body weight gain when compared to 2% added fat level. Added dietary fat increased the feed efficiency of birds during all periods except 16 to 24 weeks of age. Higher added fat level (11.4% of diet) gave higher feed efficiency than lower fat level (2% of diet). A linear relationship existed between levels of added fat and feed efficiency:

$$Y = 3.39 - 0.0387X \pm 0.116$$

$$r = 0.862, \quad p < 0.01$$

where,

Y = feed consumption per unit of weight gain

$= \dfrac{1}{\text{feed efficiency}}$

X = percent fat in diet

The increase in feed conversion at low added fat levels in diet was reported to have been the result of an increase in energy content of the diet contributed by added fat. Source of added fat did not have a significant effect on feed conversion. Added fat significantly increased fat scores of breasts and backs. However, the difference between fat scores at 2% and 11.4% added fat levels in the diet was insignificant. Palm oil gave significantly higher fat scores than rapeseed oil. Standard breast and back skin sample weights increased with increasing dietary fat levels. However, fat source had no significant effect on skin sample weight.

Feed energy requirement of turkeys can be divided into two parts: energy requirements for maintenance and energy requirements for growth. Hurwitz et al. (1980) developed an energy intake model for Large White turkeys based on the assumptions that only maintenance energy depends upon environmental temperature, and energy for growth is not a function of environment. The same assumption was used by other researchers (Balnave, 1978; Byerly, 1978) for laying hens. Male and female turkeys were maintained at 12, 18, 24, 28, and 32°C and fed two different diets. Relative humidity was not controlled, and ranged between 50 and 70%. The energy conversion model was:

$$\frac{TEC}{G} = M(t)\frac{\overline{BW}^{2/3}}{G} + D$$

where,

TEC = daily energy intake, $\left[\frac{kcal}{day}\right]$

G = daily weight gain, $\left[\frac{g}{day}\right]$

$\overline{BW}$ = average body weight, $[g]$

$M(T)$ = energy requirement for maintenance, $\left[\frac{kcal}{g^{2/3} \cdot day}\right]$

D = energy requirement for weight gain, $[\frac{kcal}{g}]$

Energy concentration was 3000 kcal/kg for the high-energy diet and 2850 kcal/kg for the high-protein diet. Protein content was 28.20% for the high-energy diet and 26.90% for the high-protein diet. Linear regression was performed between $\frac{TEC}{G}$ *and* $\frac{\overline{BW}^{2/3}}{G}$ to determine M(T) and D. The slope of the regression equation represents the maintenance energy requirement and the intercept represents the energy requirement for growth. Coefficients of the regression equation are represented in Table 3 and Table 4.

Table 3. Coefficients of regression of [1] (TEC / G) and (metabolic weight / G) for turkeys fed high energy diet.

Temperature °C	Sex	Slope	Intercept	R
12	M	2.60	1.25	.971
	F	2.55	1.10	.961
18	M	2.47	1.08	.986
	F	2.42	0.94	.992
24	M	2.01	1.53	.970
	F	2.09	1.08	.954
28	M	2.25	0.67	.990
	F	2.31	0.50	.972
32	M	2.43	0.04	.971
	F	2.55	0	.980

(Source: Hurwitz et al., 1980)

[1] TEC = daily energy intake, kcal/day
G = daily weight gain, g

Table 4. Coefficients of regression of [1] (TEC / G) and (metabolic weight/ G) for turkeys fed high protein diet.

Temperature °C	Sex	Slope	Intercept	R
12	M	2.64	1.63	.954
	F	2.46	1.29	.983
18	M	2.73	0.90	.939
	F	2.55	0.55	.984
24	M	2.61	0.24	.985
	F	2.65	0	.982
28	M	2.36	0.57	.942
	F	1.97	0.99	.990
32	M	2.51	0.05	.974
	F	2.31	0.18	.980

(Source: Hurwitz et al., 1980)

[1] TEC = daily energy intake, kcal/day
G = daily weight gain, g

Hurwitz et al. [1983(a)] studied the effects of dietary energy density on the performance male British United Turkeys. They conducted four experiments of two weeks each using birds of different age groups. In experiment 1, one-week-old birds were used. Seven diets with dietary energy concentration ranging from 2200 to 3000 kcal/kg were used. Fat content in all diets was maintained at 8.8% and protein content varied from 22% to 30%. Weight gain increased linearly at an accelerated rate up to an energy concentration of 2736 ± 108 kcal/kg and then increased linearly at a slower rate up to 3000 kcal/kg. Feed intake increased linearly with increase in energy concentration, peaking at 2400 kcal/kg, and then decreased linearly with further increase in dietary energy concentration. Feed efficiency increased with increase in dietary energy concentration at a decreasing rate between 2500 and 3000 kcal/kg.

In experiment 2, five-day-old birds were used. Six diets with energy concentrations ranging from 2600 to 3000 kcal/kg were used. Fat content for all diets was fixed at 9% and protein content varied from 26% to 30%. Body weight gain increased linearly at the rate of 1.6% per 100 kcal/kg increase in dietary energy density. Feed intake decreased linearly and feed efficiency increased linearly with increase in dietary energy concentration. Linear regression yielded the following equations:

$$Y_{WT} = 224 + .071X$$

$$Y_{FI} = 709 - .041X$$

$$Y_{FE} = .241 + .00017X$$

where,

Y_{WT} = weight gain, $\left[\frac{g}{2\ weeks}\right]$

Y_{FI} = feed intake, $\left[\frac{g}{2\ weeks}\right]$

Y_{FE} = feed efficiency

X = dietary energy concentration, $\left[\frac{kcal}{kg}\right]$

In experiment 3, seven-week-old birds were used. Energy concentration of six diets used varied from 2600 to 3050 kcal/kg. Protein content varied from 24 to 27.3% and fat content was fixed at 9%. Regression analysis of this experiment yielded the following equations:

$$Y_{WT} = 899 + .19X$$

$$Y_{FI} = 3751 - .40X$$

$$Y_{FE} = .0544 + .00018X$$

Experiment 4 was conducted with fourteen-week-old birds. Dietary energy concentration of the five diets used varied from 2600 to 3100 kcal/kg, while dietary fat content was fixed at 8.5% and protein content varied from 18.9 to 23%. Weight gain increased at an accelerated rate up to dietary concentrations of 2900 $\pm$ 83 kcal/kg, and then remained constant up to 3100 kcal/kg. Feed intake did not change between 2600 and 2900 kcal/kg and then decreased with further increase in energy concentration. Feed efficiency increased with rising dietary energy concentration over the entire range of the experiment.

Hurwitz et al. (1987) conducted four sets of experiments of three weeks each to study the effects of dietary carbohydrates and fats on the performance of male British United Turkeys maintained at 10 and 27°C . In the first set of experiments, fats were substituted for dietary carbohydrates by replacing corn with soybean oil and soybean oil meal, keeping the fiber level constant. The birds used were 6 and 9 weeks old. A linear increase in body weight gain and feed efficiency was observed when dietary fat levels were increased up to 7% of the diet. Weight gain of the birds kept at 10°C was significantly higher compared to birds kept at 27°C. However, differences between feed efficiencies of birds maintained at 10°C and 27°C was insignificant. Energy intake was greater for birds fed higher dietary fat energy concentrations. Carcass fat concentration was significantly higher for birds fed greater dietary fat diets.

In the second set of experiments, fiber was replaced by dietary fat, keeping the carbohydrate level constant. Birds used were 9 weeks old. Weight gain and feed efficiency increased with increasing dietary fat energy. Weight gain at 10°C was significantly higher compared with 27°C. Feed efficiency was significantly higher at higher temperatures. Energy intake increased with an increase in dietary fat energy concentration. Carcass fat levels also increased with increases in dietary fat energy concentration.

In the third set of experiments, fat was added to the diet by replacing corn, wheat bran, and glucose with soybean oil, keeping the dietary energy concentration constant at 2900 kcal/kg level. They observed an energy-independent response to dietary fat only at 27°C. Weight gain increased linearly and feed efficiency decreased quadratically with increase in dietary fat supplementation at 27°C. Significant increase in carcass fat was observed at higher dietary fat energy concentrations.

In the fourth set of experiments, dietary energy concentration was varied by varying the carbohydrates, keeping protein and amino acids to energy ratio constant. Birds used in this set of experiments were 9 weeks old. Increased growth and decreased feed efficiency were observed at 10°C compared with 27°C. Weight gain and feed efficiency increased with an increase in dietary energy provided by carbohydrates.

Higher feed intake was observed at lower levels of dietary energy provided by supplemental carbohydrates. Carcass fat was significantly greater at higher carbohydrate levels at 10°C .

Studies that deal with effects of diets on performance over the entire rage of bird's life are needed in simulation of turkey production. The study conducted by Hurwitz et al. (1980) meets this criterion.

Model Development

A simulation model of a turkey production system was developed by Hurwitz and Talpaz (1985). They used average (normal) outdoor temperature values for predicting temperature inside the turkey house. The temperature inside the turkey house was predicted using a regression equation relating outside and inside temperatures. Because the regression equation was developed using outside and inside temperature data for specific houses at a particular location, the portability of the model may be limited. Also, the model is deterministic because the interrelationships between the system components have been expressed as deterministic. The deterministic nature of the model limits the risk analysis of the results of the model.

The model developed in this study differs from the model developed by Hurwitz and Talpaz (1985) in five main respects:

1. Outdoor temperature is simulated using a stochastic weather simulation model so that risk analysis could be performed on the results.

2. The temperature inside the turkey house is predicted from the outdoor temperature using heat and mass balance equations in order to make the model portable.

3. Interrelationships between turkey production system components are expressed stochastically so that risk analysis could be performed on the results of the model.

4. Effects of humidity on weight gain and feed consumption are included in the model.

5. Effects of turkey strain improvement on weight gain and feed consumption were included in the model in order to make the model applicable for future applications.

The model was developed in three parts: the weather simulation submodel, the house environment prediction submodel, and the flock performance simulation submodel. The schematic diagram of the model is shown in Figure 2.

The model was developed as a discrete event model. Because most of the information regarding growth of turkeys available in the literature is in terms of daily performance, day was chosen as the time step for the model. The weather simulation submodel simulates hourly mean dry-bulb temperature and humidity ratio outside the turkey house. User supplied values of location-specific weather variables were used as input to the weather simulation submodel. The simulated values of dry-bulb temperature and humidity ratio from the weather simulation submodel, along with the house dimensions, house insulation values, number of birds in the house, and weight

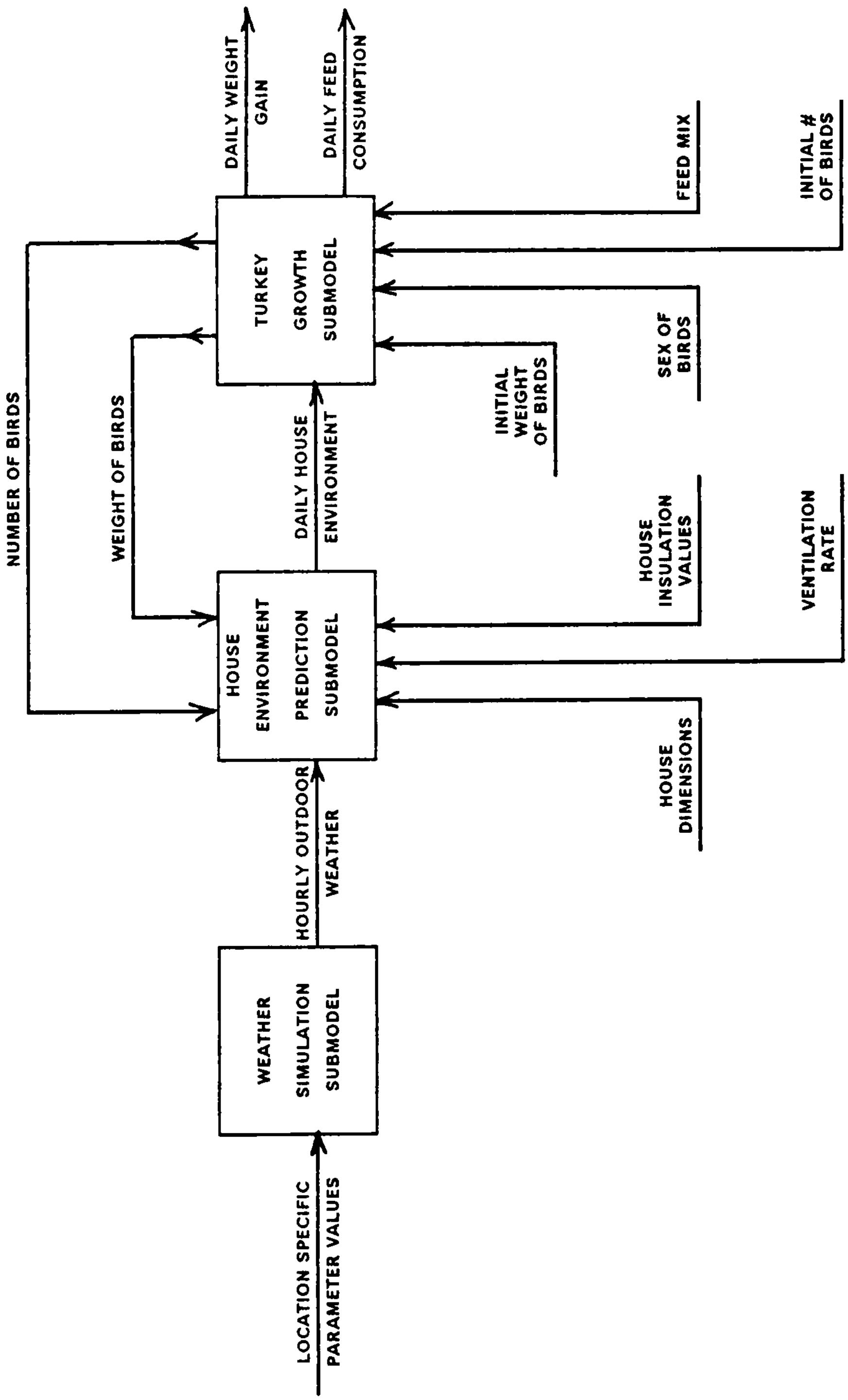

Figure 3. Schematic diagram of the model

of the birds, serve as inputs to the house environment prediction submodel. House dimensions and insulation values needed to be supplied by the user while number of birds in the house and weight of birds were simulated and supplied by the turkey performance simulation submodel. The number and weight of birds from the previous day were used as the inputs to the house environment prediction submodel. The house environment prediction submodel predicts hourly dry-bulb temperature and humidity ratio inside the turkey house using heat and mass balance equations. Daily mean temperature and humidity ratio values inside the house are computed by taking the average of hourly values. Predicted daily values of the inside daily dry-bulb temperature and humidity ratio, along with the sex of birds, and the feed formula used, serve as inputs to the turkey growth simulation submodel. The turkey growth simulation submodel simulates daily weight gain, feed consumption, and energy consumption of the birds for each day of the flock's cycle.

Weather Simulation Submodel

As discussed in the previous chapter, there are many weather simulation models available in literature. The objective of this part of the research was to select a weather simulation model from the literature that simulates outdoor temperature and humidity ratio. There was no suitable weather simulation model available that could directly simulate outdoor humidity ratio. However, simulated daily maximum and minimum temperatures can be used to estimate humidity ratio by incorporating reasonable assumptions and/or by combining with other weather prediction models such as Koon et al. (1987) discussed in the previous chapter. The selection criteria for the weather simulation models were:

Portability The model needed to be portable in the sense that location specific input values should be easily available.

Adaptability The model needed to provide output that could either on its own, or when coupled with other techniques, generate the required inputs for the other submodels.

Accuracy The model needed to be accurate in simulating average as well as the variation from average weather.

Portability:

Weather simulation models developed by Richardson and Wright (1984), and Pickering (1982) met the criterion of portability. The only location-specific input needed for the model developed by Pickering (1982) is monthly average temperature values. Monthly average temperature values for all locations in the United States are available in 'Climate Normals for United States' compiled by the National Climatic Center for Environmental Data and Information Service.

Values of the following location-specific inputs are needed for the model developed by Richardson and Wright (1984):

1. Latitude

2. Probability of a wet day following a wet day

3. Probability of a wet day following a dry day

4. Gamma distribution shape factor

5. Gamma distribution scale factor

6. Fourier coefficients of maximum temperature on dry days

7. Fourier coefficients of maximum temperature on wet days

8. Fourier coefficients of minimum temperature

9. Fourier coefficients of radiation on dry days

10. Fourier coefficients of radiation on wet days

11. Monthly values of actual mean temperature (optional)

12. Monthly values of actual mean maximum temperature (optional)

13. Monthly values of actual mean minimum temperature (optional)

14. Monthly values of actual mean rainfall (optional)

15. Measured rainfall values (optional)

Latitude for any location can be found from geographical maps. Input values for the above mentioned location-specific parameters, except parameters followed by (optional) for 48-contiguous states of the United States, were compiled by the authors of the model in the form of tables and charts. Input values for locations not listed in these tables and charts can be interpolated from the locations listed. The accuracy can be increased by providing optional inputs.

Adaptability:

Both models that met the criterion of portability did not directly simulate the humidity ratio. Hence, it was essential to incorporate assumptions in these models in order to simulate the humidity ratio from other weather parameters. Researchers have predicted dew-point temperature from daily minimum temperature (Reece and Lott, 1982; Berry and Miller, 1988). For this submodel, it was assumed that daily average dew-point temperature is equal to the daily minimum temperature. This assumption was tested using 20 years of weather records from Roanoke, Virginia.

Accuracy:

The models that met the adaptability and portability criteria were run to simulate 20 years of weather at Roanoke, Virginia. Simulated daily mean temperatures were compared with the 20 years of observed daily mean temperatures. Results of the comparison tests will be discussed in the next chapter.

Hourly Weather:

To increase accuracy of the house environment submodel (discussed in this chapter under House Environment Submodel), hourly dry-bulb temperature and humidity ratio needed to be computed. Hourly temperature was computed from the daily temperature using the following equation reported in Koon et al. (1987):

$$T = \frac{T_{max} + T_{min}}{2} + \frac{T_{max} - T_{min}}{2} \times [\ \sin\{0.26179(hour + 13)\} + \sin\{0.26179(hour + 13)2\}/3]$$

$$T_{max} = 2T_{mean} - T_{min}$$

where,

T = hourly dry-bulb temperature, [°C]

T_{max} = daily maximum temperature, [°C]

T_{min} = daily minimum temperature, [°C]

T_{mean} = daily mean temperature, [°C]

$hour$ = hour of day

Except under unusual weather conditions, dew-point temperature does not vary considerably throughout the day. Therefore, outdoor humidity ratio was assumed to be constant throughout the day.

Summary of Weather Simulation Submodel:

The weather simulation submodel in its final form is as follows:

$$T_o(I,J) = \frac{T_{omax}(I) + T_{omin}(I)}{2} + \frac{T_{omax}(I) - T_{omin}(I)}{2} \times [\ \sin\{0.26179(J+13)\} + \sin\{0.26179(J+13)2\}/3] \qquad [1]$$

$$T_{omax}(I) = 2T_{omen}(I) - T_{omin}(I) \qquad [2]$$

$$T_{omen}(I) = \mu_{omen}(m) + \rho_1[T_{omen}(I-1) - \mu_{omen}(m)] + \sqrt{1-\rho_1^2}\,\sigma_{omen}(m)R(I) \qquad [3]$$

$$\sigma_{omen}(m) = 5.72 - 0.122\mu_{omen}(m) \qquad [4]$$

$$T_{omin}(I) = \mu_{omin}(m) + \rho_1[T_{omin}(I-1) - \mu_{omin}(m)] + \sqrt{1-\rho_1^2}\,\sigma_{omin}(m)R(I) \qquad [5]$$

$$\sigma_{omin}(m) = 5.72 - 0.122\mu_{omin}(m) \qquad [6]$$

$$W_o(I,J) = 0.62198\frac{pw_o(I)}{P - pw_o(I)} \qquad [7]$$

$$\ln\{pw_o(I)\} = 24.2779 - \frac{6238.64}{T_{dp}(I) + 273.16} - 0.344438\ln\{T_{dp}(I) + 273.16\} \qquad [8a]$$

$$-40.0°C \le T_{dp}(I) \le 0°C$$

$$\ln\{pw_o(I)\} = \frac{-7511.52}{T_{dp}(I) + 273.16} + 89.63121 + 0.0239998970\{T_{dp}(I) + 273.16\}$$
$$- 1.1654551 \times 10^{-5}\{T_{dp}(I) + 273.16\}^2$$
$$- 1.2810336 \times 10^{-8}\{T_{dp}(I) + 273.16\}^3 \qquad [8b]$$
$$+ 2.0998405 \times 10^{-11}\{T_{dp}(I) + 273.16\}^4$$
$$- 12.150799 \ \ln\{T_{dp}(I) + 273.16\}$$

$$0°\mathrm{C} \le T_{dp}(I) \le 120.0°\mathrm{C}$$

$$T_{dp}(I) = T_{omin}(I) \qquad \text{May through October}$$
$$= T_{omin}(I) - 2.0°\mathrm{C} \qquad \text{November through April}$$

where,

$T_o(I,J)$ = outdoor mean dry-bulb temperature at the end of hour J on day I, [°C]

$T_{omax}(I)$ = maximum outdoor temperature on day I, [°C]

$T_{omin}(I)$ = minimum outdoor temperature on day I, [°C]

$T_{omen}(I)$ = mean outdoor temperature on day I, [°C]

J = hour of day

= 1,2,.....,24

$\mu_{omen}(m)$ = mean monthly dry-bulb temperature during month m, [°C]

$\mu_{omin}(m)$ = mean minimum temperature during month m, [°C]

$\sigma_{omen}(m)$ = standard deviation of daily mean temperature during month m, [°C]

$\sigma_{omin}(m)$ = standard deviation of daily minimum temperature during month m, [°C]

m = month of year

= 1,2,..........,12

ρ_1 = lag-one autocorrelation

= 0.65

$W_o(I,J)$ = outdoor humidity ratio at the end of hour J on day I, $\left[\frac{kg\ of\ water}{kg\ of\ dry\ air}\right]$

$pw_o(I)$ = partial pressure of water vapor in outdoor air on day I, [kPa]

P = atmospheric pressure

= 101.325 kpa

$T_{dp}(I)$ = outdoor dew-point temperature on day I, [°C]

$R(I)$ = standard normal random variate

= N(0,1)

House Environment Simulation Submodel

Temperature and humidity ratio inside the turkey house were predicted using heat and mass balance equations. Heat is gained inside the turkey house from three sources: body heat of birds, supplemental heat provided, and heat from lights and operation of mechanical equipment. Heat is lost from the house through ventilation, and through walls and the ceiling of the building. In addition, conditions in the house are nonsteady. Therefore, a positive or negative accumulation of heat will occur over the time interval used as the time step in the model.

Birds maintain a nearly constant body temperature through heat production and dissipation. Body heat is produced by burning the consumed food and body reserves, and is dissipated in the form of sensible and latent heat. Heat dissipation is a function of body weight and thermal environment.

Due to a temperature differential between the inside and the outside of the turkey house, heat flows through the walls and ceiling of the building. The rate of heat flow is a function of the temperature differential and the thermal resistance of the building envelope. Ventilation is necessary in order to modulate temperature, humidity, odors, and to provide air movement inside the house. The design ventilation rates are based on the need to control temperature or humidity inside the house. During cold weather, the inside temperature can drop below a desired value even when the house is ventilated at some prescribed minimum rate. In such cases, supplemental heating is necessary in order to maintain the desired inside temperature.

Under nonsteady state conditions the principle of conservation of energy applied to an open system yields,

$$Q_s + Q_{supp} + Q_{mech} = Q_v + Q_b + \Delta Q_{accum} \qquad [10]$$

where,

Q_s = rate of sensible heat production of birds, $[\frac{kcal}{hr}]$

Q_{supp} = rate of supplementary heat supply, $[\frac{kcal}{hr}]$

Q_{mech} = rate of heat production of lights, mechanical equipment etc. $[\frac{kcal}{hr}]$

Q_v = rate of heat loss through ventilation, $[\frac{kcal}{hr}]$

Q_b = rate of heat loss through walls and ceiling, $[\frac{kcal}{hr}]$

ΔQ_{accum} = rate of accumulation of heat inside the building, $[\frac{kcal}{hr}]$

The heat loss due to ventilation is

$$Q_v = \frac{V}{v_o} C_p[T_{ia}(I,J) - T_{oa}(I,J)] \qquad [11]$$

where,

V = ventilation rate, $\left[\frac{m^3}{hr} \right]$

v_o = specific volume of ventilation air, $\left[\frac{m^3}{kg\ dry\ air} \right]$

C_p = specific heat of air, $\left[\frac{kcal}{kg \cdot {}^\circ C} \right]$

$T_{ia}(I,J)$ = average inside temperature during hour J of day I, [°C]

$$= \frac{T_i(I,J) + T_i(I,J-1)}{2}$$

$T_i(I.J)$ = inside temperature at the end of hour J on day I, [°C]

$T_o(I,J)$ = average outdoor temperature during hour J of day I, [°C]

$$= \frac{T_o(I,J) + T_o(I,J-1)}{2}$$

$T_o(I,J)$ = outdoor temperature at the end of hour J on day I, [°C]

The heat loss from the building is found from

$$Q_b = U_c A_t [T_{ia}(I,J) - T_{oa}(I,J)] \quad [12]$$

where,

$$U_c = \frac{\sum_{k=1}^{\infty} U_k A_k}{A_t} \quad [13]$$

where,

k = number of building surfaces through which heat is transferred,

U_k = overall heat transfer coefficient of surface k through which heat ,

is lost, $\left[\frac{kcal}{hr \cdot m^2 \cdot {}^\circ C} \right]$

A_k = area of surface k through which heat is lost, [m^2]

A_t = total surface area of the building, [m^2]

The heat which accumulates in the house is

$$\Delta Q_{accum} = \frac{V_I}{v_i} C_p[T_i(I,J) - T_i(I,J-1)] \qquad [14]$$

where,

V_I = volume of house, $[m^3]$

v_i = specific volume of inside air, $\left[\frac{m^3}{kg \cdot dry \cdot air} \right]$

Assuming Q_{mech} = 0 and substituting [11], [12] and [14] into [10] and solving for $T_i(I,J)$,

$$T_i(I,J) = \frac{T_i(I,J-1)(2C_1 - C_2) + 2H_a + C_2\{T_o(I,J) + T_o(I,J-1)\}}{2C_1 + C_2} \qquad [15]$$

$$C_1 = C_p \frac{V_I}{v_i} \qquad [16]$$

$$C_2 = U_c A_t + \frac{V}{v_o} C_p \qquad [17]$$

$$H_a = Q_s + Q_{supp}$$

For simplicity, v_i was calculated by the equation reported in Wilhelm (1976) using inside conditions at $(I,J-1)$ as follows:

$$v_i = \frac{R_a T_i(I,J-1)}{P} [1 + 1.607 W_i(I,J-1)] \qquad [18]$$

$$v_o = \frac{R_a T_o(I,J)}{P} [1 + 1.607 W_o(I)] \qquad [19]$$

where,

R_a = universal gas constant of air, $\left[\frac{N \cdot m}{kg \cdot {}^\circ C} \right]$

P = atmospheric pressure, $[kPa]$

$W_o(I)$ = outdoor humidity ratio on day I, $\left[\frac{kg\ water}{kg\ dry\ air} \right]$

$W_i(I,J)$ = inside humidity ratio at end of hour J on day I, $\left[\frac{kg\ water}{kg\ dry\ air} \right]$

Again, for simplicity, Q_s was calculated by the equation reported by Malhotra (1967) at $T_i(I,J-1)$

$$Q_s = [-2.786 + 0.328T_i(I,J-1) + 1.414w(I-1) + 3.033(S) - 0.021T_i^2(I,J-1)]N(I) \quad [20]$$

where,

$w(I-1)$ = weight of bird at the end of day I-1, $[kg]$

S = sex of bird

= 1 for male

= 2 for female

Daily mean temperature was computed from the hourly temperature values as follows:

$$T_i(I) = \frac{\sum_{j=1}^{24} T_i(I,J)}{24} \quad [21]$$

A nonsteady moisture balance on the house yields,

$$\frac{Q_l}{q_l} + \frac{V}{v_o} W_o(I) = \frac{V}{v_i} W_i(I,J) + \Delta M_{accum} \quad [22]$$

where,

Q_l = rate of latent heat production, $[\frac{kcal}{hr}]$

q_l = heat of vaporization of water, $\left[\frac{kcal}{kg\ of\ water} \right]$

ΔM_{accum} = rate of moisture accumulation inside the house, $\left[\frac{kg\ of\ moisture}{hr}\right]$

Moisture accumulation was calculated as,

$$\Delta M_{accum} = \frac{V_I}{v_i}\left[W_i(I,J) - W_i(I,J-1)\right] \qquad [23]$$

Substituting [23] in [22],

$$W_i(I,J) = W_i(I,J-1)\frac{C_3 - C_4}{C_3 + C_4} + 2C_4\left[\frac{W_o(I)}{2(C_3 + C_4)}\right] + \frac{Q_l}{q_l(C_3 + C_4)} \qquad [24]$$

$$C_3 = \frac{V_I}{v_o} \qquad [25]$$

$$C_4 = \frac{V}{2v_o} \qquad [26]$$

Q_l was calculated using the equation developed by Malhotra (1967)

$$Q_l = \left[3.084 + 0.286T_{ia}(I,J) + 0.329w(I) - 1.162(S)\right]N(I) \qquad [27]$$

Q_l in the above equation does not include spillage which can be neglected because the amount of moisture from spillage is very small compared to that produced by birds.

Inside relative humidity was calculated from the humidity ratio as follows:

$$\phi_i(I,J) = \frac{pw_i(I,J)}{pws_i(I,J)} \quad [28]$$

where,

$\phi_i(I,J)$ = relative humidity inside the house on hour J day I, [*dimensionlessfraction*]

$pw_i(I,J)$ = partial pressure of water vapors inside the house on hour J day I, [kPa]

$pws_i(I,J)$ = water vapor pressure of saturated air inside the house on hour J day I, [kPa]

Daily average relative humidity was computed from the hourly relative humidity values as follows,

$$\phi_i(I) = \frac{\sum_{j=1}^{24} \phi_i(I,J)}{24} \quad [29]$$

where,

$\phi_i(I)$ = average relative humidity inside the house on day I, dimensionless fraction

Flock Performance Simulation Submodel

Performance of the flock was simulated in terms of two parameters of significant economic importance: body weight and feed consumption. A discrete event simulation model using a time step of one day was developed in order to predict average and standard deviation of daily bird weight as well as energy consumption per bird.

The flock was represented by 30 birds. Each representative bird was simulated as an individual entity in order to take bird to bird variation into account. The model simulates growth of each bird 25 times in order to calculate average and standard deviations of the daily weight and energy consumption.

Weight Gain

Weight gain is dependent on bird's age, strain, sex, environmental temperature and humidity, and feed formula. Because most of the turkeys grown in the United States are white turkeys, the model was developed based on data collected from white turkeys.

Year to year improvement in turkey strains was included in the model in order to make the model applicable for future applications. The model is applicable to both male and female birds. The model was developed for simulating weight gain for birds of minimum 6 weeks starting age. The effects of environmental temperature and humidity were included in the model. Effect of feed formula on weight gain was quantified in terms of effect of feed energy concentration on weight gain.

Daily weight gain of the bird was simulated using the following model:

$$TOTWT(I) = WT(I)*[1 + INCENG(I)] \quad [30]$$

$$WT(I) = WT(I-1) + G(I) + INCBRD(I)*G(I) - DECHUM(I)*G(I) \quad [31]$$

$$G(I) = N(\ AVG(I)\ ,\ SD\ ) \quad [32]$$

where,

TOTWT(I) = weight of the bird when I days old, [*kg*]

WT(I) = weight of the bird without feed energy concentration correction when bird is I days old, [*kg*]

WT(I-1) = weight of the bird without feed energy concentration correction when I-1 days old, [*kg*]

AVG(I) = mean standard daily weight gain for day I of the bird's life, [*kg*]

SD = standard deviation of standard daily weight gain, [*kg*]

G(I) = standard daily weight gain on day I of the bird's life, [*kg*]

INCBRD(I) = strain correction factor, [*dimensionless*]

DECHUM(I) = environmental humidity correction factor, [*dimensionless*]

INCENG(I) = feed energy concentration correction factor, [*dimensionless*]

An extensive experiment to study the effects of temperature, sex, and feed was conducted at Virginia Tech in 1969-70 (Albuquerque, 1970; Leighton, 1970). Data from this experiment were used for developing the weight gain model. The data from this experiment includes the effects of environmental temperature, age and sex of the bird on the weight gain of turkeys. Each component of equations [30], [31], and [32] will be discussed in more detail.

Values of the mean daily weight gain, AVG(I), as a function of age, environmental temperature and sex are shown in Table 5 and Table 6. These tables show weight gain values at biweekly intervals at four different environmental temperatures. Linear interpolations in vertical as well as horizontal directions were used in Table 5 and Table 6 in order to approximate AVG(I) at given age and temperature values. Extrapolations were also used to approximate values of AVG(I) at temperatures lower than 10°C (down to 1.7°C) and higher than 35°C (up to 43.3°C). Daily inside temperature needed for table lookup of Table 5 and Table 6 was calculated using equation [21].

Standard deviations of weight gains, SD, of turkeys was not available in the literature. However, standard deviations of heat production of male and female turkeys at various temperatures are available (Malhotra, 1967). Because heat production is an indicator of the discomfort of birds, it was assumed that the coefficient of variation of body weight gains is the same as the coefficient of variation of heat production. Leighton (1988) indicated that coefficient of variation values for heat production are similar to those of weight gain. Coefficients of variation for heat production at different environmental temperatures for male and female turkeys calculated from data reported by Malhotra (1967) are shown in Table 7. Linear interpolations and extrapolations were used to approximate SD at temperatures not listed in Table 7. Daily inside temperature needed for table lookup of Table 5 and Table 6 was calculated using equation [21].

Because animal body weights are normally distributed, standard daily weight gain, G(I), was calculated by generating a random variate from a normal distribution whose mean was AVG(I) and standard deviation was SD.

The data of Albuquerque (1970) were used to calculate AVG(I). To account for breed improvement since 1970, a strain correction factor, INCBRD(I), was introduced in the model. INCBRD(I) was calculated by comparing turkey weight standards for the year in which the model is being used to those of 1970. Turkey weight standards are reported in the January issue of 'Turkey World' magazine each year. Turkey weight

Table 5. Mean weight gain of male turkeys at different environmental temperatures.

Age (weeks)		Weight gain (kg) at			
Starting	**Ending**	**10.0 °C**	**18.3 °C**	**26.7 °C**	**35.0 °C**
6	8	0.974	0.947	0.998	0.983
8	10	1.244	1.272	1.185	1.124
10	12	1.193	1.241	1.073	0.908
12	14	1.347	1.379	1.193	1.215
14	16	1.179	1.143	1.123	1.009
16	18	1.016	1.143	1.091	0.909
18	20	1.103	0.863	0.940	0.895
20	22	0.847	0.778	0.830	0.892
22	24	0.776	0.931	0.787	0.644
Total gain since 6 weeks of age		9.670	9.697	9.220	8.580

(Data source: Leighton, 1970)

Table 6. Mean weight gain of female turkeys at different environmental temperatures.

Age (weeks)		Weight gain (kg) at			
Starting	**Ending**	**10.0 °C**	**18.3 °C**	**26.7 °C**	**35.0 °C**
6	8	0.790	0.736	0.818	0.805
8	10	0.861	0.934	0.916	0.868
10	12	0.860	0.833	0.753	0.672
12	14	0.948	0.880	0.834	0.803
14	16	0.803	0.789	0.774	0.673
16	18	0.734	0.648	0.613	0.533
18	20	0.585	0.462	0.445	0.509
20	22	0.435	0.350	0.471	0.433
Total gain since 6 weeks of age		6.028	5.634	5.628	5.298

(Data source: Leighton, 1970)

Table 7. Mean and standard deviation of heat production of turkeys at various temperatures, kcal/hr-kg

sex		heat production at					
		10°C	15°C	20°C	25°C	30°C	35°C
male	mean	1.783	1.723	1.744	1.802	1.305	1.213
	st dev	0.148	0.154	0.188	0.267	0.246	0.176
	c.o.v.	0.083	0.089	0.108	0.148	0.188	0.145
female	mean	1.939	2.009	1.730	1.769	1.395	1.256
	st dev	0.263	0.189	0.226	0.258	0.186	0.120
	c.o.v.	0.135	0.944	0.130	0.146	0.134	0.096

(Data source: Malhotra, 1967)

standards for the year for which the model is being run need to be supplied by the user. INCBRD(I) for year n is calculated as follows:

$$INCBRD(I) = \frac{WEIGHT(I)_n - WEIGHT(I)_{1970}}{WEIGHT(I)_{1970}} \quad [33]$$

where n is the current year.

Table 8 and Table 9 show weight standards for 1970 through 1987. Turkey weight standards reported in the magazine 'Turkey World' are on a weekly basis. Weight standards on a daily basis were calculated by using linear interpolation.

High humidity levels at high dry-bulb temperatures have been shown to suppress weight gains in broilers (Winn and Godfry, 1967). Effect of humidity on weight gain of broilers reared at temperatures below 26.6°C were negligible. Increase in humidity at temperatures above 26.6°C resulted in significant decreases in body weight gain. For this model, the loss in weight gain per unit body weight due to high humidity levels was assumed to be the same in turkeys and broilers. Effects of humidity on weight gain of broilers reported by Winn and Godfry (1967) were used to quantify loss in weight gain for turkeys and are shown in Table 10. Relative humidity calculated in equation [28] was used for table lookup of data in Table 10. DECHUM(I) at environmental temperature $T_i(I)$ and relative humdity $\phi_i(I)$ was calculated as follows:

$$DECHUM(I) = 0 \qquad \text{if } T_i(I) < 26.7°C \quad [34a]$$

$$DECHUM(I) = 0 \qquad \text{if } \phi_i(I) < 40\% \quad [34b]$$

Table 8. Live weight standards of large type turkey toms.

age (weeks)	live weight in kg during 1970	1975	1980	1985	1986	1987	% increase from 1970 to 1987
6	1.587	1.724	1.814	1.796	1.796	1.855	16.88
8	2.585	2.903	3.084	2.894	2.894	2.998	15.98
10	3.946	4.309	4.536	4.200	4.205	4.368	10.69
12	5.262	5.670	5.942	5.967	5.715	5.937	12.83
14	6.622	6.985	7.348	7.316	7.362	7.647	15.48
16	8.028	8.300	8.709	9.010	9.058	9.403	17.13
18	9.480	9.662	10.161	10.714	10.786	11.176	17.89
20	10.886	11.022	11.567	12.442	12.533	12.968	19.12
22	12.247	12.338	12.973	14.106	14.220	14.746	20.40
24	13.653	13.653	14.333	15.608	15.595	16.406	20.16

(Data source: Jensen, 1971; Jensen, 1976; Jensen, 1981; Sell, 1986; Sell, 1987; Sell, 1988)

Table 9. Live weight standards of large type turkey hens.

age (weeks)	live weight in kg during						% increase from 1970 to 1987
	1970	1975	1980	1985	1986	1987	
6	1.542	1.542	1.588	1.560	1.560	1.560	1.17
8	2.449	2.449	2.586	2.517	2.517	2.531	3.35
10	3.402	3.402	3.583	3.620	3.619	3.661	7.61
12	4.400	4.400	4.627	4.731	4.731	4.811	9.38
14	5.398	5.307	5.534	5.738	5.738	5.838	8.15
16	6.350	5.942	6.260	6.586	6.586	6.686	5.29
18	6.895	6.577	6.8951	7.303	7.303	7.403	7.37
20	7.257	7.167	7.530	7.893	7.893	7.992	10.13

(Data source: Jensen, 1971; Jensen, 1976; Jensen, 1981; Sell, 1986; Sell, 1987; Sell, 1988)

$$\mathrm{DECHUM(I)} = \frac{DEC(\phi_i(i))_{35.0} - DEC(\phi_i(I))_{26.7}}{8.3} \times (T_i(I) - 26.7) + DEC(\phi_i(I))_{26.7} \quad [34c]$$

$$\text{if } 26.7°C \le T_i(I) \le 35.0°C \quad \text{and} \quad 40\% \le \phi_i(I) \le 90\%$$

$$DEC(\phi_i(I))_{26.7} = \frac{\phi_i(I) - 40}{50} \quad [34d]$$

$$DEC(\phi_i(I))_{35.0} = \frac{18(\phi_i(I) - 40)}{50} \quad [34e]$$

where,

$DEC(\phi_i(I))_{26.7}$ = percent decrease in weight gain due to humidity at relative humidity $\phi_i(I)$ and temperature 26.7°C

$DEC(\phi_i(I))_{35.0}$ = percent decrease in weight gain due to humidity at relative humidity $\phi_i(I)$ and temperature 35.0°C

The weight gain of turkeys is affected by the feed formula. Effect of feed formula on weight gain was quantified in terms of effect of feed energy concentration on weight gain. A feed energy correction factor, INCENG(I), was used to include the effect of feed formula on weight gain. Data collected from 205 producers at the time of marketing was used to run regression between weight gain (from birth to marketing age) and average feed energy concentration (calculated by dividing total energy consumed throughout bird's life by total feed consumed throughout bird's life) at each of the observed marketing ages. Marketing age varied from 91 to 105 days for hens, and 110 to 132 days for toms. Feed energy concentration varied from 3016.57 kcal/kg to 3302.2 kcal/kg. The data are shown in Appendix E. The slope of the regression equations did not vary considerably from one marketing age to another, and was approximately 0.0025.

Table 10. Percent decrease in body weight gain due to relative humidity.

Temperature °C	Percent decrease in weight gain at 40% Rh	90% Rh
<26.7	0	0
26.7	0	1
35.0	0	18

(Source: Winn and Godfry, 1967)

Change in weight gain due to change in feed energy concentration was calculated as follows:

$$WG_1 = 0.0025 FDEN_1$$

$$WG_2 = 0.0025 FDEN_2$$

From these two equation,

$$\frac{WG_1 - WG_2}{WG_1} = \frac{FDEN_1 - FDEN_2}{FDEN_1}$$

where WG_1 and WG_2 are weight gains when a bird is fed feed containing energy concentration of $FDEN_1$ and $FDEN_2$, respectively.

INCENG(I) was defined as:

$$\text{INCENG(I)} = \frac{FDEN_{a/c}(I) - FDEN_{na}(I)}{FDEN_{na}(I)}$$

where,

$FDEN_{a/c}(I)$ = energy concentration of feed being fed when birds are I days old, $\left[\frac{kacl}{kg\ feed} \right]$

$FDEN_{na}(I)$ = national average of energy concentration of feed when birds are I days old, $\left[\frac{kcal}{kg\ feed} \right]$

It was assumed that the above formula for INCENG(I) was applicable for younger birds. The youngest age at which data were available was 91 days for hens, and 110 days for toms.

Total weight for each of the representative birds was simulated using equation [30] for each day of the bird's life. This was repeated 25 times. Because of the random variables in equations [3], [5], and [32], sample paths observed in each of the 25 cases were different. The average weight for a day was calculated by taking the average of 30 observations (one for each of 30 birds) for that day. Mean average body weight for a day was calculated by taking the average of 25 observations (one from each of the 25 repetitions) for that day. Standard deviation of average body weight for a day was calculated from the 25 observations (one from each of the 25 repetitions) for that day. By the central limit theorem average body weight for each day follows a normal distribution.

Feed Consumption

Feed consumption was calculated from the energy requirement of the birds which was split into two parts: energy required for body maintenance and energy required for weight gain. On the basis of experiments conducted by Hurwitz et al. (1980), it was assumed that maintenance energy requirement is a function of environmental temperature while energy required for weight gain is independent of the environmental temperature. The following model developed by Hurwitz et al. (1980) was used to calculate the energy requirements of the bird:

$$TEC(I) = TEC(I-1) + EC(I) \qquad [36]$$

$$\frac{EC(I)}{G_n(I)} = M(T_i(I))\ \frac{\{TOTWT(I)\}^{2/3}}{G_n(I)} + D \qquad [37]$$

$$G_n(I) = TOTWT(I) - TOTWT(I-1) \qquad [38]$$

where,

$G_n(I)$ = daily weight gain for I days old bird, $[g]$

$TEC(I)$ = cumulative energy intake by bird till day I of its age, $[kcal]$

$EC(I)$ = energy intake by bird on day I of its life, $[kcal]$

$M(T_i(I))$ = energy required for maintenance on day I, $\left[\frac{kcal}{g^{2/3}}\right]$

$T_i(I)$ = temperature inside the house on day I, [°C]

$TOTWT(I)^{2/3}$ = metabolic body weight of bird on day I, $[g^{2/3}]$

D = energy required for weight gain, $\left[\frac{kcal}{g}\right]$

A number of experiments were performed by the authors of the above equation and data were used to perform regression analysis between $\frac{EC(I)}{G_n(I)}$ and $\frac{TOTWT(I)^{2/3}}{G_n(I)}$. $M(T_i(I))$ was the slope and D was the intercept of the regression equation. Value of D was 0.7 kcal/kg and values of $M[T_i(I)]$ at various values of $T_i(I)$ and feed formula are shown in Table 3 and Table 4 in the previous chapter. Linear interpolation was used to compute maintenance energy requirements at temperatures other than those listed in Table 3 and Table 4.

Total energy consumption for each of the representative birds was simulated 25 times using equation [35] for each day of the bird's life. Because of the random variables in equations [3], [5], and [32], sample path observed in each of the 25 cases was different. The average weight for a day was calculated by taking the average of 30 observations (one for each of 30 birds) for that day. Mean average energy consumption for a day was calculated by taking the average of 25 observations (one from each of the 25 repetitions) for that day. Standard deviation of average energy consumption

Table 11. Feed consumption standards of large type turkey toms.

age (weeks)	kg of feed required per kg of turkey 1970	1975	1980	1985	1986	1987	% change from 1970 to 1987
6	0.816	0.726	0.726	0.694	0.694	0.694	-14.95
8	0.907	0.771	0.771	0.789	0.789	0.789	-13.01
10	0.953	0.816	0.816	0.884	0.884	0.884	-7.24
12	0.998	0.907	0.907	0.975	0.975	0.975	-2.30
14	1.043	1.043	0.998	1.075	1.075	1.075	3.07
16	1.134	1.134	1.134	1.179	1.179	1.179	3.97
18	1.179	1.225	1.225	1.283	1.283	1.283	8.82
20	1.225	1.361	1.315	1.388	1.388	1.388	13.30
22	1.315	1.406	1.361	1.488	1.488	1.488	13.15
24	1.406	1.497	1.451	1.596	1.596	1.596	13.51

(Data source: Jensen, 1971; Jensen, 1976; Jensen, 1981; Sell, 1986; Sell, 1987; Sell, 1988)

Table 12. Feed consumption standards of large type turkey hens.

age (weeks)	kg of feed required per kg of turkey 1970	1975	1980	1985	1986	1987	% change from 1970 to 1987
6	0.726	0.726	0.726	0.726	0.726	0.726	0
8	0.816	0.816	0.816	0.826	0.826	0.826	1.22
10	0.862	0.907	0.907	0.925	0.925	0.925	7.30
12	0.953	0.998	0.953	1.030	1.030	1.030	8.80
14	1.043	1.089	1.043	1.139	1.139	1.134	8.72
16	1.134	1.225	1.179	1.247	1.247	1.234	8.82
18	1.270	1.315	1.315	1.365	1.365	1.347	6.06
20	1.406	1.452	1.452	1.488	1.488	1.488	5.83

(Data source: Jensen, 1971; Jensen, 1976; Jensen, 1981; Sell, 1986; Sell, 1987; Sell, 1988)

for a day was calculated from the 25 observations (one from each of the 25 repetitions) for that day. By the central limit theorem, average energy consumption for each day follows a normal distribution.

Computer Program

A computer program was written to combine all three submodels. The model was programmed using FORTRAN-77 and is shown in Appendix B. The program requires a minimum of four input files. Input file 1 must be provided by the user, and must include the following information:

1. Age of birds at the start of simulation

2. Date at the start of the simulation

3. Sex of birds

4. Number of birds at the start of simulation

5. Average weight of birds at the start of simulation

6. Type of feed formula intended to use: high energy or high protein

7. Area of building surfaces involved in heat transfer

8. Volume of house

9. Overall R-value of house

10. Ventilation rate

Input file 2 requires information regarding the energy concentration of the feed. The user needs to provide the following information:

1. National average energy concentration values for the year for which the simulation is being performed: available in January issue of "Turkey World' magazine for that year.

2. Energy concentration of the feeds.

Input file 3 and 4 require information regarding the national weight standards for the year for which the model is being used. File 3 is for males and file 4 is for females. Only one of these files is needed to run the model, depending upon the sex of birds. The user must provide the following information for input file 3 or 4:

1. National standards of bird weight for the year for which the model is being used: available in 'Turkey World' magazine, January issue of that year.

Input file 5 requires data concerning the normal weather at or near the location of the building in which the birds are housed. User needs to input the following information:

1. Normal monthly temperature: available in 'Climate Normals For the U.S.', published by NOAA

2. Normal monthly minimum temperature: available in "Climate Normals for the U.S.', published by NOAA

Internal documentation of the program guides the user to recognize the user supplied information and and indicates the location of sources of such information.

The program outputs means and standard deviations of average bird weight, average cumulative energy consumption per bird, and average feed consumption per bird from the starting date (supplied by user) until the birds are 24 weeks old (if males) and 22 weeks old, (if females). The program also provides distributions of average bird weight, average cumulative energy consumption per bird, and average daily feed consumption per bird for each day.

Model Validation

The three constituent submodels were validated separately. The separate validations were performed to facilitate the process of recognizing the model segments that contribute to the inaccuracies in the overall model output. Weather data observed at Roanoke, Virginia, and the turkey house environment and turkey performance data collected at a turkey farm near Harrisonburg, Virginia, were used to validate the submodels. After all submodels were validated, the composite model was then validated.

Weather Simulation Submodel

The weather simulation submodel adopted from Pickering (1982) was expanded by introducing the assumption that the daily average dew-point temperature is equal to the daily minimum temperature for the months of May through October, and equal to daily minimum temperature minus 2°C for the months of November through April. The candidate weather simulation models as well as the assumptions needed to make the adopted model functional were validated using 20 years of daily mean, minimum and dew-point temperature data recorded at Roanoke, Virginia. The models were run to simulate 20 years of weather at Roanoke, Virginia. Simulated daily temperatures were compared with the 20 years of observed daily mean temperature at Roanoke, Virginia.

The model developed by Pickering(1982) simulated the daily mean temperature directly whereas the daily mean temperature in the observed data and in the model developed by Richardson and Wright (1984) were computed as follows,

$$T_j = \frac{T_{\max j} + T_{\min j}}{2}$$

where,

T_j = Mean temperature on day j

$T_{\max j}$ = Maximum temperature on day j

$T_{\min j}$ = Minimum temperature on day j

Observed daily mean temperature for Roanoke, Virginia, is shown in Table 27 in Appendix A. Average daily mean temperature and standard deviation of daily mean temperature were calculated for the observed data as well as the simulated data as follows:

$$\bar{T}_j = \frac{\sum_{i=1}^{20} T_{ji}}{20}$$

$$S_j = \sqrt{\frac{(\sum_{i=1}^{20} T_{ji})^2 - \frac{(\bar{T}_j)^2}{20}}{19}}$$

where,

$\bar{T}_j$ = Average daily mean temperature on day j

T_{ji} = Daily mean temperature for day j in year i

WGEN (Richardson and Wright, 1984) Model:

The WGEN model was run (using monthly average temperature as input) to simulate 20 years of maximum and minimum temperature data for Roanoke, Virginia. T_j and S_j were calculated for each day of the year for the observed data, and the data simulated by the WGEN model. S_j^2 for observed data was compared with the corresponding S_j^2 for the simulated data using F-test. The assumption of normality that underlies the F-test has been demonstrated to be valid for mean temperature (Jones et al., 1972; Miller and Weaver, 1970; Thom, 1973).

The F-test rejected the null hypothesis of S_j^2 for the simulated data being equal to the S_j^2 for the observed data for 67 days out of 365 days of a year. 95% confidence bands for the observed data and the data simulated by WGEN are shown in Figure 3.

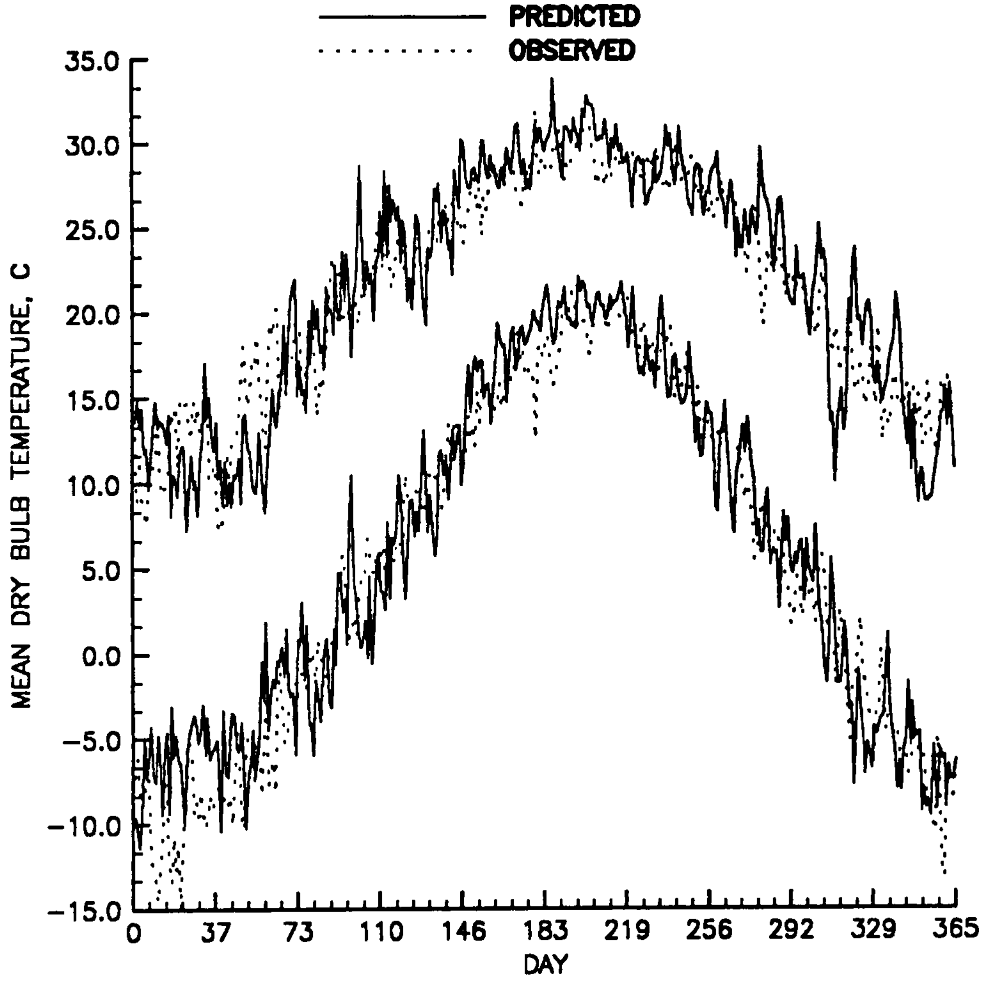

Figure 3. 95% confidence bands for observed and simulated (WGEN model) mean temperature data for Roanoke, Virginia.

Similarly, daily minimum temperature simulated by the model was compared with the observed daily minimum temperature. The F-test rejected the null hypothesis of S_j^2 for simulated data being equal to S^2_j for the observed data for 32 days out of 365 days. The 95% confidence bands for the observed and the simulated minimum temperature data are shown in Figure 4.

Pickering (1982) Model:

The model developed by Pickering (1982) was run to simulate 20 years of mean and minimum temperature data for Roanoke, Virginia. The same procedure as used for the WGEN model was followed to compare S_j^2 for the observed and simulated data for the Pickering model. For mean temperature, the F-test rejected the null hypothesis for 32 days out of 365 days of a year. The 95% confidence bands for the observed data and the data simulated by the Pickering model are shown in Figure 5.

For minimum temperature, F-test rejected the null hypothesis of S_j^2 for simulated data being equal to S_j^2 for the observed data for 9 days out of 365 days. The 95% confidence bands for the observed and the simulated minimum temperature data are shown in Figure 6.

Assumptions used by other researchers to relate dew-point temperature to daily minimum temperature were validated. Reece and Lott (1982) assumed that the dew-point temperature does not vary considerably, and is very nearly the same as the daily minimum temperature in the areas of the United States where dew or frost is a common phenomenon. The assumption seems reasonable because dew or frost is formed when dry-bulb temperature becomes equal to the dew-point temperature. To

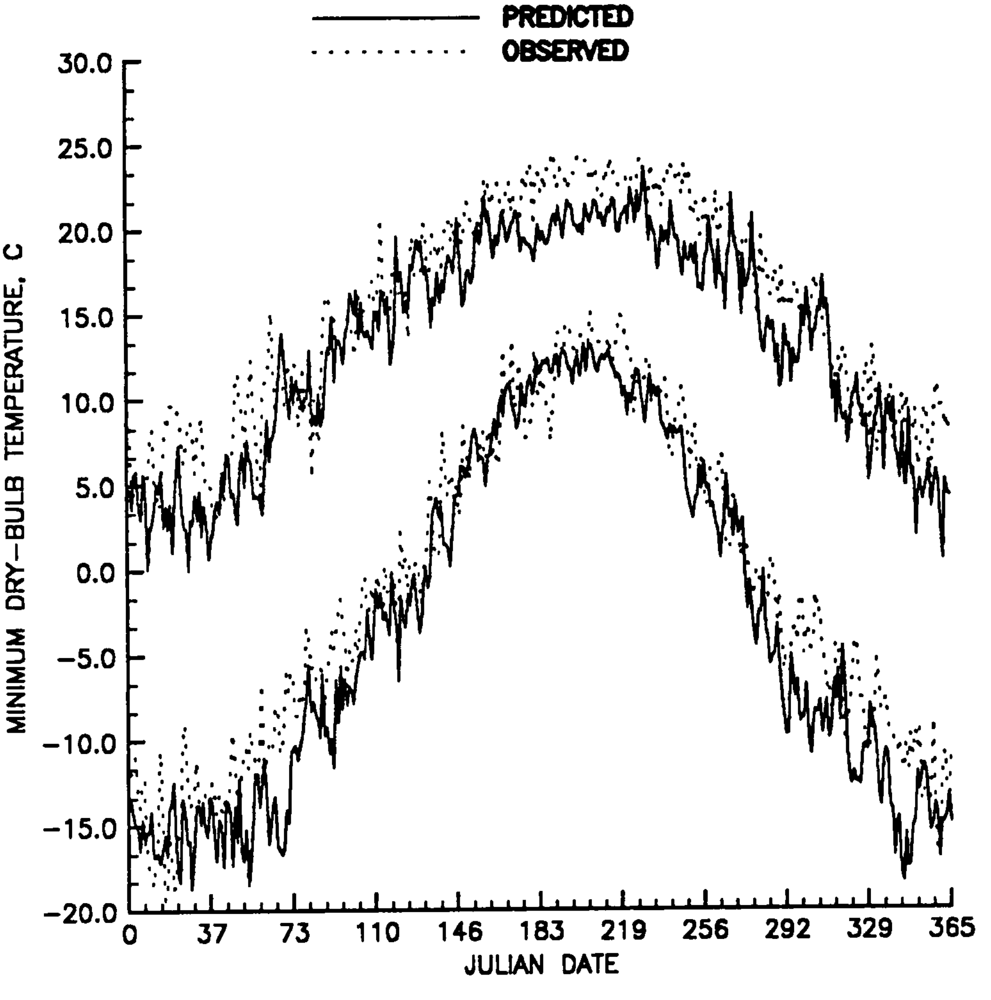

Figure 4. 95% confidence bands for observed and simulated (WGEN model) minimum temperature data for Roanoke, Virginia.

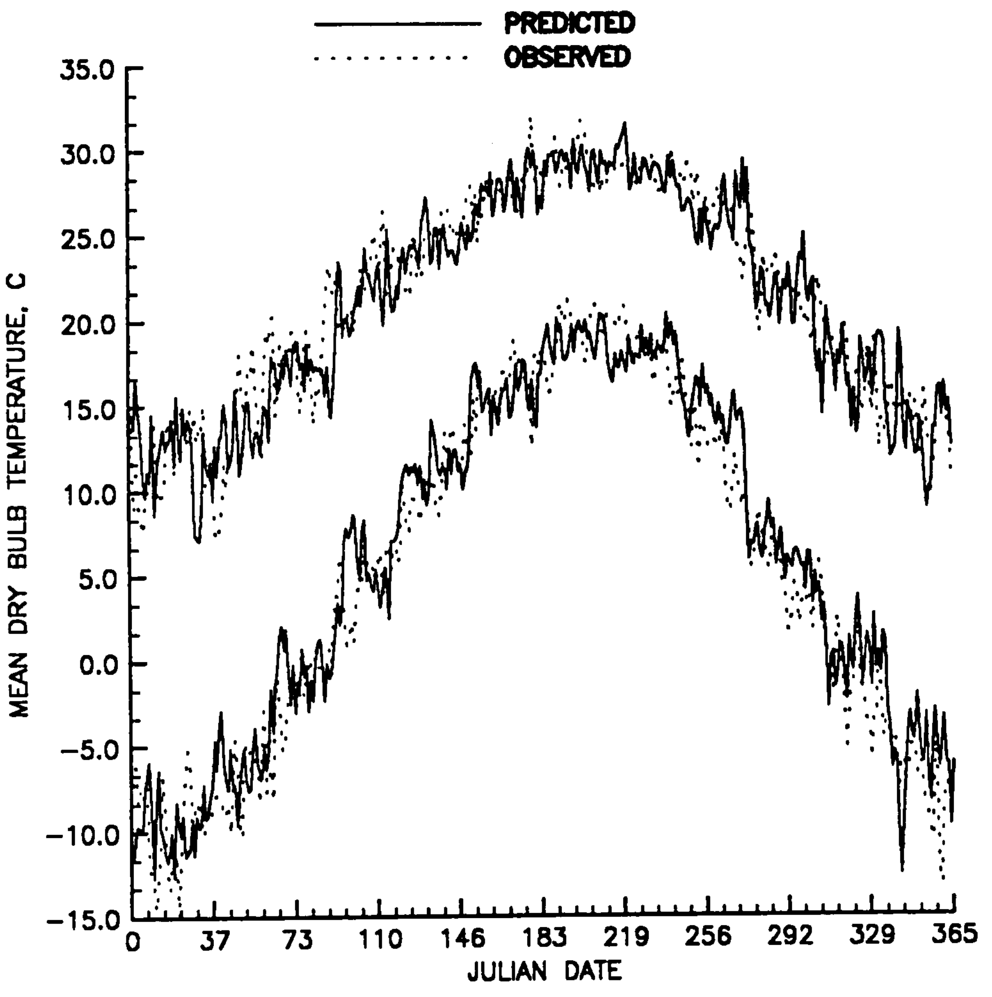

Figure 5. 95% confidence bands for observed and simulated (Pickering, 1982 model) mean temperature data for Roanoke, Virginia.

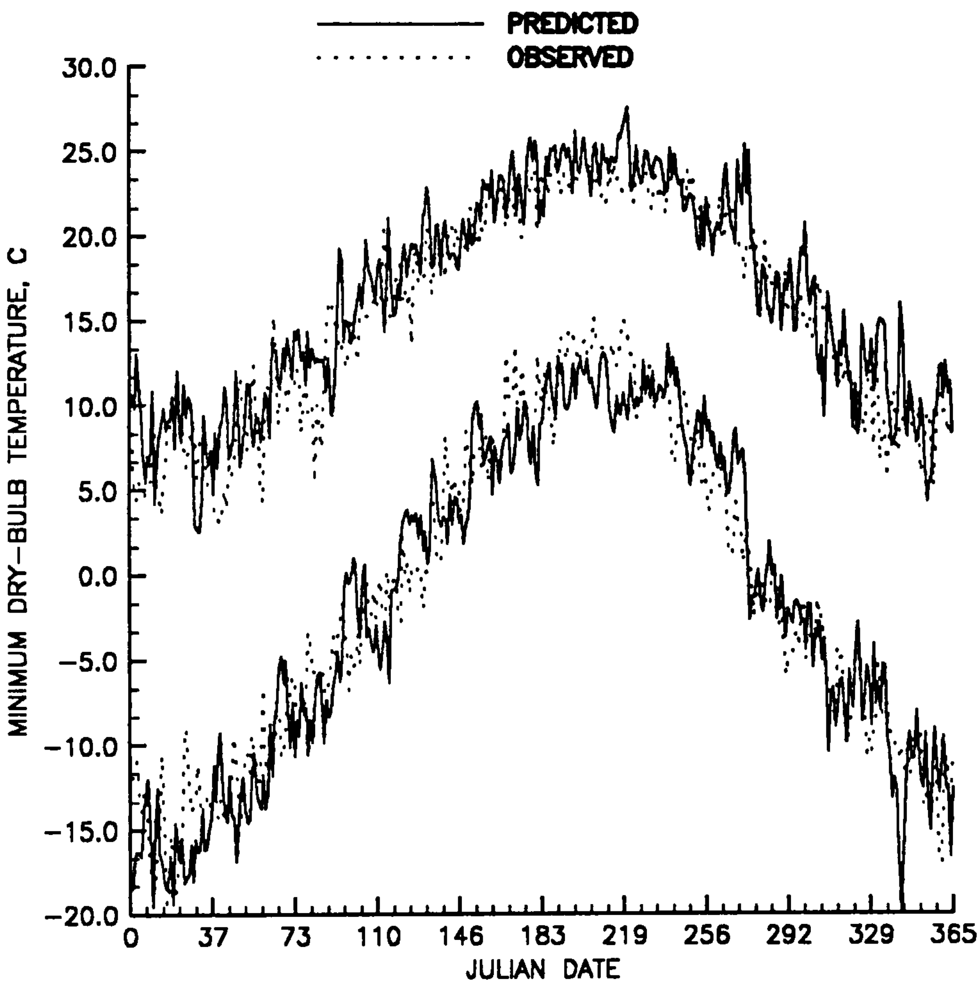

Figure 6. 95% confidence bands for observed and simulated (Pickering, 1982 model) minimum temperature data for Roanoke, Virginia.

validate this assumption, 18-years of observed monthly mean minimum temperature data were compared with the observed monthly mean dew-point temperature data for Roanoke, Virginia. The observed monthly mean minimum temperature and dew-point temperature data are shown in Table 13 and Table 14. The monthly mean temperatures were calculated as follows:

$$\text{Monthly mean min. temp. for month i} = \frac{\sum_{j=1}^{n_i} \text{daily minimum temp. on day j}}{n_i}$$

where,

where, $n_i =$ number of days in month i

Average and standard deviation of monthly mean minimum temperatures were calculated from the 18-years of observed data for each month (Table 13). Similarly, average and standard deviation of monthly mean dew-point temperature were calculated from the 18-years of observed data for each month (Table 14).

Average monthly dew-point temperature (Table 13) was compared with the average monthly minimum temperature (Table 14) of the corresponding month using t-test. Standard deviation of the mean monthly dew-point temperature was compared with the standard deviation of the mean monthly minimum temperature of the corresponding month using an F-test. Since monthly mean value (of minimum as well as dew-point temperatures) for each month was calculated from 28 to 31 values of daily values, the central limit theorem is applicable to the monthly mean value data. Thus, the assumption of normality that underlies the t-test and the F-test is valid for monthly

Table 13. Mean monthly minimum temperatures in °C for Roanoke Airport, Virginia

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	-4.33	-0.78	1.28	7.89	11.33	16.39	19.55	16.83	15.00	8.72	3.72	-1.39
1985	-5.33	-2.17	3.61	9.33	13.22	16.39	19.50	17.72	13.55	10.00	7.78	-3.61
1984	-4.00	0.50	0.94	6.94	10.89	16.83	17.39	17.83	11.67	12.44	1.39	2.72
1983	-2.39	-2.61	3.50	6.28	9.50	14.50	17.83	18.83	12.89	8.22	3.00	-3.17
1982	-6.83	-1.83	0.72	4.05	12.55	15.67	18.83	16.61	12.50	8.28	2.61	0.78
1981	-5.33		0.22	7.94	9.50	17.33	19.11	16.33	12.94	6.11	1.28	-3.72
1980			0.78	7.28	11.39	14.61	19.22	18.55	16.11	6.94	7.44	-1.78
1976	-4.94	1.11	3.39	5.22	10.11	14.83	16.72	15.11				
1975		-0.67	0.61		13.72	16.11	18.39	19.33		8.89	4.00	-1.83
1974		-2.17	4.28	6.89	11.55	14.17					2.17	-1.17
1973		-3.72	4.44	3.89	7.78		18.28	19.00	15.28	8.83	3.44	-0.94
1972	-1.55	-3.39	1.33	5.72	10.22	13.78	17.78	16.83	13.72	5.17	2.39	2.05
1971	-4.28	-2.17	0.22	4.50	9.94	16.55	17.50	16.67	16.05	11.89	1.78	1.72
1970	-6.67	-3.50	0.00	7.05	12.39	15.94	18.11	17.33	15.61	9.28	2.28	-1.17
1969	-4.44	-1.50	-1.44	7.33	11.17	16.78	18.61	16.72	13.11	6.61	0.78	-3.22
1968	-4.50	-5.00	3.67	7.17	10.55	15.05	18.33	18.22	12.28	8.39	4.11	-4.11
1967	-0.83	-4.11	1.94	7.89	8.83	14.72	17.44	16.94	10.17	6.05	0.61	0.05
1966	-5.11	-2.39	1.55	5.55	10.94	14.11	18.44	17.44	13.50	5.55	1.78	-1.05
Average	**-4.32**	**-2.15**	**1.72**	**6.53**	**10.86**	**15.51**	**18.30**	**17.43**	**13.62**	**8.21**	**2.97**	**-1.17**
St Dev.	**1.72**	**1.64**	**1.69**	**1.51**	**1.52**	**1.11**	**0.79**	**1.10**	**1.70**	**2.10**	**2.03**	**2.08**

(Source: NOAA)

Table 14. Mean monthly dew-point temperatures in °C for Roanoke Airport, Virginia

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1986	-7.4	-0.94	-2.50	3.94	10.83	15.44	18.44	17.17	16.11	8.83	4.11	-2.55
1985	-8.39	-5.72	-1.39	4.28	11.44	14.17	17.27	16.83	13.00	8.83	8.39	-5.94
1984	-6.05	-1.611	-1.05	4.78	9.44	16.72	17.55	18.39	12.78	13.39	-2.44	1.83
1983	-5.00	-3.89	0.55	3.33	9.44	15.55	17.22	17.78	12.22	8.33	2.22	-5.00
1982	-8.89	-3.33	-0.55	0.00	12.22	16.11	18.89	16.67	13.33	8.33	3.89	1.11
1981	-8.89		-4.44	6.11	9.44	16.67	17.78	15.00	12.22	5.00	-0.55	-5.00
1980			-0.55	5.55	10.55	13.89	18.89	18.33	16.11	6.11	-0.55	-4.44
1976	-7.78	-1.67	1.67	2.22	10.00	16.11	16.67	15.55				
1975		-2.78	-2.22		13.33	15.55	18.33	18.89		8.89	2.22	-3.33
1974		-4.44	1.11	4.44	11.11	14.44					-0.55	-2.78
1973		-7.22	4.44	3.89	7.78		18.89	19.44	16.11	8.89	2.22	-2.78
1972	-2.78	-6.11	-2.78	3.33	10.00	12.78	18.33	17.78	15.00	6.11	1.11	0.55
1971	-7.22	-5.55	-5.00	-1.11	9.44	17.78	18.33	17.22	16.67	12.78	0.55	1.11
1970	-8.89	-6.11	-2.22	3.89	11.11	15.55	17.78	18.33	16.67	9.44	2.22	-3.33
1969	-8.33	-6.67	-6.11	5.55	10.55	16.11	18.89	16.67	13.33	6.11	-1.11	-5.55
1968	-7.22	-13.33	-2.78	3.89	8.89	14.44	17.22	17.78	11.67	7.22	1.67	-7.22
1967	-3.33	-6.67	-0.55	3.33	7.78	15.00	16.11	16.11	10.00	5.55	-3.89	-2.22
1966	-7.78	-5.00	-3.33	3.89	8.89	13.33	15.55	17.22	12.22	5.55	0.55	-4.44
Average	**-7.00**	**-5.06**	**-1.54**	**3.60**	**10.12**	**15.27**	**17.77**	**17.36**	**13.83**	**8.08**	**1.18**	**-2.94**
St Dev.	**2.00**	**2.96**	**2.54**	**1.84**	**1.44**	**1.30**	**1.00**	**1.17**	**2.11**	**2.44**	**2.81**	**2.69**

(Source: NOAA)

mean minimum and dew-point temperature data. The assumption of equal variance that underlies the two-sample t-test was validated using the F-test. The following hypothesis was used to compare the variance of mean minimum temperature with the variance of mean dew-point temperature for each month of the year:

$$H_0: \quad \sigma^2_{\min} = \sigma^2_{dew}$$

$$H_a: \quad \sigma^2_{\min} \neq \sigma^2_{dew}$$

Test statistic $F_{ts} = \dfrac{S^2_{\min}}{S^2_{dew}}$

Rejection region : For Type I error α and $df_1 = n_{\min} - 1$ and $df_2 = n_{dew} - 1$, reject H_0 if $F_{ts} > F_{\alpha/2}$

where, σ^2_{dew} = population variance of monthly mean dew-point temperature

$\sigma^2_{\min}$ = population variance of monthly mean minimum temperature

S_{dew} = sample standard deviation of monthly mean dew-point temperature

$S_{\min}$ = sample standard deviation of monthly mean minimum temperature

n_{dew} = number of observations of monthly mean dew-point temperature

$n_{\min}$ = number of observations of monthly mean minimum temperature

The results of F-tests are shown in Table 15.

At the 5% level of significance the variance of monthly mean dew-point temperature is equal to the variance of monthly mean minimum temperature except for February. However, at the 10% level, variance of monthly mean dew-point temperature for the month of February is also equal to the variance of monthly mean minimum temperature.

Table 15. Results of F-test performed on monthly mean temperature data to validate the assumption "Daily average dew-point temp. is same as daily minimum temp."

Month	Average temp.		Standard deviation		No. of observations		F-test		
	dew point	min.	dew point	min.	dew point	min.	F_{ts}	$F_{.05}$	result
JAN	-7.00	-4.32	2.00	1.72	14	14	1.35	2.58	Fail to reject H_0
FEB	-5.06	-2.15	2.96	1.64	16	16	2.69	2.41	[2]Reject H_0
MAR	-1.54	1.72	2.54	1.69	18	18	2.25	2.28	Fail to reject H_0
APR	3.60	6.53	1.84	1.51	17	17	1.49	2.33	Fail to reject H_0
MAY	10.12	10.86	1.44	1.52	18	18	0.89	2.28	Fail to reject H_0
JUN	15.27	15.51	1.30	1.11	17	17	1.37	2.33	Fail to reject H_0
JUL	17.77	18.30	1.00	0.79	17	17	1.59	2.33	Fail to reject H_0
AUG	17.36	17.43	1.17	1.10	17	17	1.12	2.33	Fail to reject H_0
SEP	13.83	13.62	2.11	1.70	15	15	1.53	2.48	Fail to reject H_0
OCT	8.08	8.21	2.44	2.10	16	16	1.34	2.41	Fail to reject H_0
NOV	1.18	2.97	2.81	2.03	17	17	1.90	2.33	Fail to reject H_0
DEC	-2.94	-1.17	2.69	2.08	17	17	1.82	2.33	Fail to reject H_0

[2]Fail to reject at 10% level.

The following hypothesis was used to perform the t-test for comparing average monthly mean dew-point temperature with average monthly mean minimum temperature for each month of the year:

$$H_0: \quad \mu_{\min} = \mu_{dew}$$

$$H_a: \quad \mu_{\min} \neq \mu_{dew}$$

Test statistic $\quad t_{ts} = \dfrac{\bar{T}_{\min} - \bar{T}_{dew}}{S_p\sqrt{\dfrac{1}{n_{\min}} + \dfrac{1}{n_{dew}}}}$

Rejection region : For Type I error α and df $= n_{\min} + n_{dew} - 2$, reject H_0 if $|t_{ts}| > t_{\alpha/2}$

where,

$n_{\min}$ = number of observations of monthly minimum temperature

n_{dew} = number of observations of monthly mean dew-point temperature

$\bar{T}_{\min}$ = average monthly mean minimum temperature

$$= \frac{\sum_{1}^{n_{\min}} \text{monthly mean minimum temperature}}{n_{\min}}$$

$\bar{T}_{dew}$ = average monthly mean dew-point temperature

$$= \frac{\sum_{1}^{n_{dew}} \text{monthly mean dew-point temperature}}{n_{dew}}$$

S_p = pooled standard deviation

$$= \sqrt{\frac{(n_{min} - 1)S_{min}^2 + (n_{dew} - 1)S_{dew}^2}{n_{min} + n_{dew} - 2}}$$

S_{min} = standard deviation of monthly mean minimum temperature

S_{dew} = standard deviation of monthly mean dew-point temperature

Results of t-tests are shown in Table 16. The average monthly mean dew-point temperature is the same as average monthly mean minimum temperature for six months of the year (May through October). The average monthly mean dew-point temperature is significantly different from the average monthly mean minimum temperature for the colder months of the year (November through April). Hence, the assumption that the daily average dew-point temperature is the same as the daily minimum temperature is valid only for May through October at Roanoke, Virginia.

Berry and Miller (1988) assumed that the daily dew-point temperature is equal to 1.0°C less than the daily minimum temperature. This assumption was validated using the same procedure as used to validate the assumption that the daily average dew-point temperature is the same as the daily minimum temperature, except that 1.0°C

Table 16. Results of t-test performed on monthly mean temperature data to validate the assumption "Daily average dew-point temp. is same as daily minimum temp."

Month	Average temp.		Standard deviation		No. of observations		t-test		
	dew point	min.	dew point	min.	dew point	min.	$\lvert t_{ts} \rvert$	$t_{.05/2}$	result
JAN	-7.00	-4.32	2.00	1.72	14	14	3.79	2.16	Reject H_0
FEB	-5.06	-2.15	2.96	1.64	16	16	3.70	2.13	[2]Reject H_0
MAR	-1.54	1.72	2.54	1.69	18	18	4.53	2.11	Reject H_0
APR	3.60	6.53	1.84	1.51	17	17	5.06	2.12	Reject H_0
MAY	10.12	10.86	1.44	1.52	18	18	1.50	2.11	Fail to reject H_0
JUN	15.27	15.51	1.30	1.11	17	17	0.58	2.12	Fail to reject H_0
JUL	17.77	18.30	1.00	0.79	17	17	1.68	2.12	Fail to reject H_0
AUG	17.36	17.43	1.17	1.10	17	17	0.17	2.12	Fail to reject H_0
SEP	13.83	13.62	2.11	1.70	15	15	0.29	2.14	Fail to reject H_0
OCT	8.08	8.21	2.44	2.10	16	16	0.15	2.13	Fail to reject H_0
NOV	1.18	2.97	2.81	2.03	17	17	2.13	2.12	Reject H_0
DEC	-2.94	-1.17	2.69	2.08	17	17	2.76	2.12	Reject H_0

[2]Equal variance assumption valid at 10% level.

was subtracted from each observation in Table 13. Results of F-tests and t-tests are are shown in Table 17 and Table 18.

As shown in Table 17, the assumption of equal variance is valid for all months at the 5% level of significance except for the month of February where it is valid at the 10% level. The daily average dew-point temperature is equal to the daily minimum temperature less 1°C for six months in a year as shown in Table 18. Hence, the assumption that the daily average dew-point temperature is equal to the daily minimum temperature less 1.0°C, is valid only for six months at Roanoke, Virginia.

A close examination of Table 15 and Table 16 indicates that average dew-point temperature is equal to the minimum temperature for May through October. However, from further examination of Table 15 and Table 16, the average dew-point temperature appears to be equal to about 2°C less than the minimum temperature for November through April. Thus, it was assumed that daily average dew-point temperature is equal to the daily minimum temperature for May through October, and equal to 2°C less than the daily minimum temperature for November through April. This assumption was validated the same way as the other two assumptions discussed previously.

The results of F-tests and t-tests performed to validate the assumption are shown in Table 19 and Table 20. As shown in Table 20, average monthly dew-point temperature is equal to the average monthly minimum temperature for May through October. For the months of November through April, average monthly dew-point temperature is 2.0°C less than the average monthly minimum temperature. The variation in average monthly dew-point temperature is the same as the variation in average monthly

Table 17. Results of F-test performed to validate the assumption "Daily average dew-point temp. is same as daily minimum temp. less 1.0 °C."

Month	Average temp.		Standard deviation		No. of observations		F-test		
	dew point	[1]min.	dew point	[1]min	dew point	[1]min	F_{ts}	$F_{.05}$	result
JAN	-7.00	-5.32	2.00	1.72	14	14	1.35	2.58	Fail to reject H_0
FEB	-5.06	-3.15	2.96	1.64	16	16	2.69	2.41	[2]Reject H_0
MAR	-1.54	0.72	2.54	1.69	18	18	2.25	2.28	Fail to reject H_0
APR	3.60	5.53	1.84	1.51	17	17	1.49	2.33	Fail to reject H_0
MAY	10.12	9.86	1.44	1.52	18	18	0.89	2.28	Fail to reject H_0
JUN	15.27	14.51	1.30	1.11	17	17	1.37	2.33	Fail to reject H_0
JUL	17.77	17.30	1.00	0.79	17	17	1.59	2.33	Fail to reject H_0
AUG	17.36	16.43	1.17	1.10	17	17	1.12	2.33	Fail to reject H_0
SEP	13.83	12.62	2.11	1.70	15	15	1.53	2.48	Fail to reject H_0
OCT	8.08	7.21	2.44	2.10	16	16	1.34	2.41	Fail to reject H_0
NOV	1.18	1.97	2.81	2.03	17	17	1.90	2.33	Fail to reject H_0
DEC	-2.94	-2.17	2.69	2.08	17	17	1.82	2.33	Fail to reject H_0

[1] min. = minimum temperature – 1°C

[2]Fail to reject at 10% level.

Table 18. Results of t-test performed to validate the assumption "Daily average dew-point temp. is same as daily minimum temp. less 1.0 °C."

Month	Average temp.		Standard deviation		No. of observations		t-test		
	dew point	[1]min.	dew point	[1]min.	dew point	[1]min.	$\lvert t_{ts} \rvert$	$t_{.05/2}$	result
JAN	-7.00	-5.32	2.00	1.72	14	14	2.37	2.16	Reject H_0
FEB	-5.06	-3.15	2.96	1.64	16	16	2.43	2.13	[2]Reject H_0
MAR	-1.54	0.72	2.54	1.69	18	18	3.14	2.11	Reject H_0
APR	3.60	5.53	1.84	1.51	17	17	3.32	2.12	Reject H_0
MAY	10.12	9.86	1.44	1.52	18	18	0.52	2.11	Fail to reject H_0
JUN	15.27	14.51	1.30	1.11	17	17	1.82	2.12	Fail to reject H_0
JUL	17.77	17.30	1.00	0.79	17	17	1.53	2.12	Fail to reject H_0
AUG	17.36	16.43	1.17	1.10	17	17	2.39	2.12	Reject H_0
SEP	13.83	12.62	2.11	1.70	15	15	1.71	2.14	Fail to reject H_0
OCT	8.08	7.21	2.44	2.10	16	16	1.08	2.13	Fail to reject H_0
NOV	1.18	1.97	2.81	2.03	17	17	0.94	2.12	Fail to reject H_0
DEC	-2.94	-2.17	2.69	2.08	17	17	3.94	2.12	Reject H_0

[1] min. = minimum temperature – 1°C

[2]Equal variance assumption valid at 10% level.

minimum temperature (Table 19). Hence, the assumption that average daily dew-point temperature is equal to the daily minimum temperature for the months of May through October, and 2.0°C less than the daily minimum temperature for the months of November through April, is valid for Roanoke, Virginia.

Equation [9] from the previous chapter was modified as follows:

$$T_{dp}(I) = T_{omin}(I) \qquad \text{for May through October} \qquad [9b]$$

$$T_{dp}(I) = T_{omin}(I) - 2.0^{\circ}C \qquad \text{for November through April} \qquad [9a]$$

The following conclusions were drawn from the validation of this submodel:

Both WGEN and Pickering models are portable. Input values needed to run the Pickering model for any location are available from 'Climate Normals for United States', published by NOAA. Input parameter values required to run the WGEN model for all locations in 48 contiguous states of the United States are available in Richardson and Wright (1984). Both models simulate daily mean and minimum temperature and can easily be modified to simulate daily humidity ratio. The daily humidity ratio can be calculated from the daily minimum temperature by using the assumption that the daily average dew-point temperature does not vary considerably and is equal to daily minimum temperature for months of May through October and equal to minimum temperature minus 2°C for months of November through April. The assumption was shown to be valid for Roanoke, Virginia. The assumption of daily dew-point temperature being equal to the daily minimum temperature used by Reece and Lott (1982) is not valid for Roanoke, Virginia. The reason, perhaps, is that fog or

Table 19. Results of F-test performed to validate the assumption "Daily average dew-point temp. is same as daily min. temp. for May thru Oct. and 2°C less than daily min. temp. for Nov. thru Apr.

Month	Average temp.		Standard deviation		No. of observations		F-test		
	dew point	[1]min.	dew point	[1]min.	dew point	[1]min.	F_{ts}	$F_{.05}$	result
JAN	-6.00	-5.32	2.00	1.72	14	14	1.35	2.58	Fail to reject H_0
FEB	-5.06	-4.15	2.96	1.64	16	16	2.69	2.41	[2]Reject H_0
MAR	-1.54	-0.27	2.54	1.69	18	18	2.25	2.28	Fail to reject H_0
APR	3.60	4.53	1.84	1.51	17	17	1.49	2.33	Fail to reject H_0
MAY	10.12	10.86	1.44	1.52	18	18	0.89	2.28	Fail to reject H_0
JUN	15.27	15.51	1.30	1.11	17	17	1.37	2.33	Fail to reject H_0
JUL	17.77	18.30	1.00	0.79	17	17	1.59	2.33	Fail to reject H_0
AUG	17.36	17.43	1.17	1.10	17	17	1.12	2.33	Fail to reject H_0
SEP	13.83	13.62	2.11	1.70	15	15	1.53	2.48	Fail to reject H_0
OCT	8.08	8.21	2.44	2.10	16	16	1.34	2.41	Fail to reject H_0
NOV	1.18	0.97	2.81	2.03	17	17	1.90	2.33	Fail to reject H_0
DEC	-2.94	-3.17	2.69	2.08	17	17	1.82	2.33	Fail to reject H_0

[1]min. = minimum temperature for November through April
= minimum temperature − 2.0°C for May through October

[2]Fail to reject at 10% level.

Table 20. **Results of t-test performed to validate the assumption "Daily average dew-point temp. is same as daily min. temp for May thru Oct. and equal to 2 °C less than daily min. temp. for Nov.thru Apr."**

Month	Average temp.		Standard deviation		No. of observations		t-test		
	dew point	[1]min.	dew point	[1]min.	dew point	[1]min.	$\lvert t_{ts} \rvert$	$t_{.05/2}$	result
JAN	-7.00	-6.32	2.00	1.72	14	14	0.96	2.16	Fail to reject H_0
FEB	-5.06	-4.15	2.96	1.64	16	16	1.16	2.13	[2]Fail to reject H_0
MAR	-1.54	-0.27	2.54	1.69	18	18	1.76	2.11	Fail to reject H_0
APR	3.60	4.53	1.84	1.51	17	17	1.59	2.12	Fail to reject H_0
MAY	10.12	10.86	1.44	1.52	18	18	1.50	2.11	Fail to reject H_0
JUN	15.27	15.51	1.30	1.11	17	17	0.58	2.12	Fail to reject H_0
JUL	17.77	18.30	1.00	0.79	17	17	1.68	2.12	Fail to reject H_0
AUG	17.36	17.43	1.17	1.10	17	17	0.17	2.12	Fail to reject H_0
SEP	13.83	13.62	2.11	1.70	15	15	0.29	2.14	Fail to reject H_0
OCT	8.08	8.21	2.44	2.10	16	16	0.15	2.13	Fail to reject H_0
NOV	1.18	0.97	2.81	2.03	17	17	0.24	2.12	Fail to reject H_0
DEC	-2.94	-3.17	2.69	2.08	17	17	0.27	2.12	Fail to reject H_0

[1]min. = minimum temperature for November through April
= minimum temperature − 2.0°C for May through October

[2]Equal variance assumption valid at 10% level.

frost is not a common phenomenon at Roanoke, Virginia throughout the entire year. The assumption of dew-point temperature being equal to the daily minimum temperature minus 1°C was also not valid for Roanoke, Virginia. The humidity ratio can be calculated from the dew-point temperature using equations developed by Wilhelm (1976).

The model developed by Pickering (1982) was chosen for this application for the following two reasons:

1. The model simulated both the daily mean and daily minimum temperature more accurately compared to the WGEN model for Roanoke, Virginia.

2. The model can be represented with a very compact computer code compared to the WGEN model.

House Environment Simulation Submodel

The following data were collected for a flock of male turkeys at a turkey farm near Harrisonburg, Virginia, during the winter of 1987-88:

1. Hourly outdoor temperature

2. Hourly temperature inside the house

3. Weekly weight of the birds

4. Amount of feed consumed at the time of refilling of feed tanks

5. Feed energy concentration values for all the feed mixes used

6. Protein contents of all the feed mixes used

Other pertinent data recorded were as follows:

- Sex of birds = male
- Starting age = 7 weeks
- Starting date = December 22, 1987
- Marketing age = 16 weeks
- Number of birds at week 7 = 4858
- Total mortality (week 7 through week 16) = 232
- Average starting weight = 2.3 kg
- Standard deviation of starting weights = 0.668 kg
- Type of ventilation system = Positive pressure
- Approximate ventilation rate = 7475.6 m^3 / hour

- Length of the building = 152.2 m

- Width of the building = 12.2 m

- Height of curtains = 1.5 m

- Height of walls = 2.31 m

- Slope of roof = 1/3

- Overall R-value of the building = 4.7 hr • ft^2 • °*F*/btu

The house was equipped with an automatic heating system that provided heat to the incoming ventilation air whenever the outdoor temperature dropped below 10°C. The ventilation air was heated to 10°C. However, on very cold days, ventilation air was heated to an unknown higher temperature. The farm manager used his personal judgement in making a decision about increasing the energy flow rate from the heater. Data regarding the amount of energy used on such days was not available. Because of the small frequency of very cold days throughout the growth period of the flock, the effect on the validation was considered to be small.

Thermocouples connected to a Data Electronics Datataker DT-100 datalogger (Zitech Corp., Palo Alto, CA) were used to measure temperatures. The datalogger recorded temperatures hourly. Outdoor temperature was measured at a point under the overhang of the house. Inside temperature was measured at a location 1 meter above the floor of the house, approximately 3 meters from one side of the house, and 20 meters from the end. Each week 20 birds were weighed by the farm manager to determine the average weight of the flock.

A FORTRAN program to validate this submodel was written. The observed outdoor hourly temperature values along with the other observed data mentioned above, were used as input to this program. Observed bird weights and mortality rates (rather than those predicted by the Flock Performance Simulation Submodel) were used as input to the program. Since the outdoor weather was not predicted by the Weather Simulation Submodel, and the bird weights were not predicted by the Flock Performance Simulation Submodel, there were no random terms involved in this program. Daily observed and simulated inside temperatures are shown in Figure 7. The predicted temperature was close to the observed temperature except on very cold days (days with average outside temperature of 2.0°C or less). This was likely because the model did not supply extra supplementary heat to the ventilation air on colder days as was done in the real system by the farm manager. Also, on colder days the predicted temperature was closer to the observed temperature when birds were older compared to when the they were younger. Because older birds produced more sensible heat compared to younger birds as shown in Figure 8. The other probable sources of error were as follows:

1. Exact number of birds present inside the house on each day was not known. Mortality rates were recorded on a weekly basis and daily mortality rates were linearly interpolated from the weekly rates.

2. Exact amounts of supplementary heat provided were not known. The manufacturer's criteria to provide supplementary heat were used in the model. The cri-

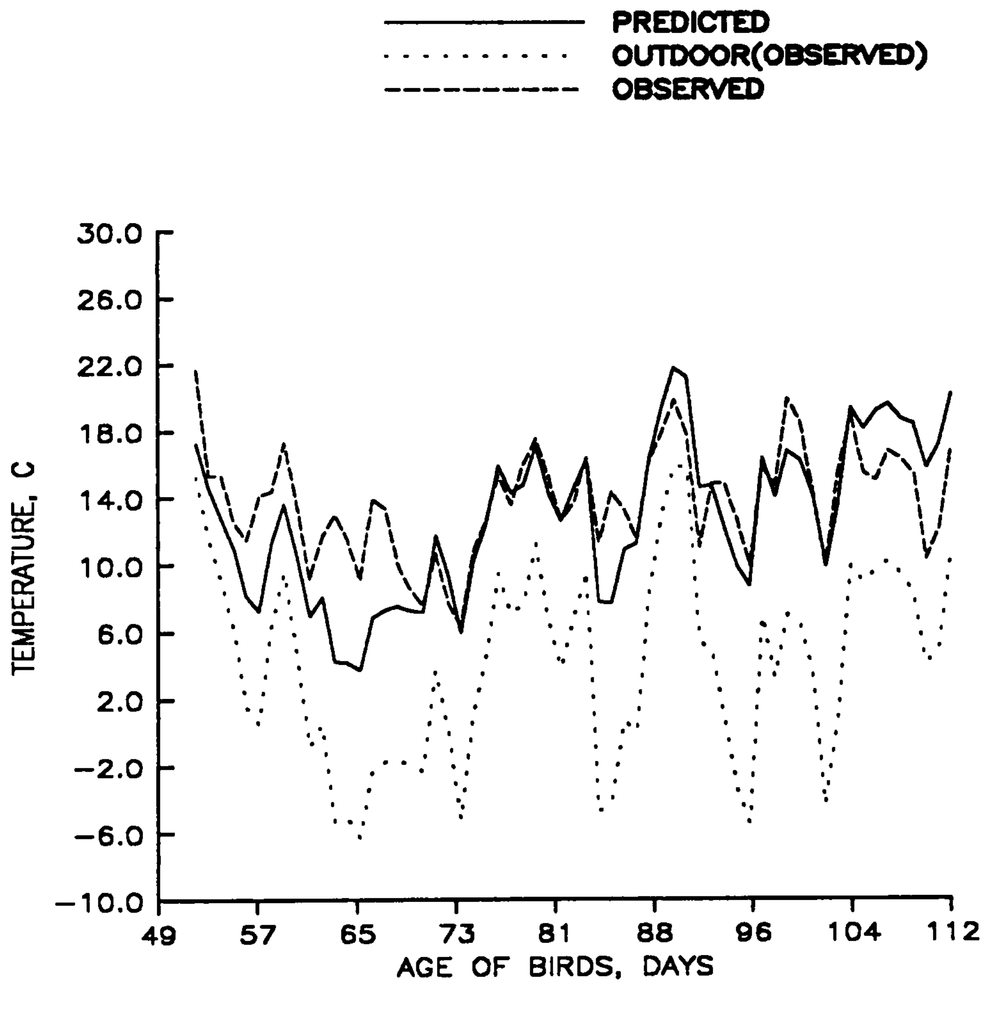

Figure 7. Observed and predicted daily inside temperature

teria were based on a continuous time basis. However, for modeling purposes, hourly temperature values were used.

3. Any errors in the bird heat production model would also be reflected in this submodel.

4. Variation of C_p of air with temperature was not considered in the submodel.

5. The dew-point temperature values used in calculating the specific volume of air were not observed. The dew-point temperature values were predicted using the assumption that the daily dew-point temperature is the same as the daily minimum temperature for the months of May through October, and 2.0°C less than daily minimum temperature for the months of November through April.

6. Outdoor dew-point temperature was assumed to be constant throughout the day.

7. Any errors in the data logging system would also be reflected in Figure 7.

8. Daily bird weights were linearly interpolated from the weekly values.

Flock Performance Submodel

The flock performance submodel was validated in two parts:

1. Weight gain

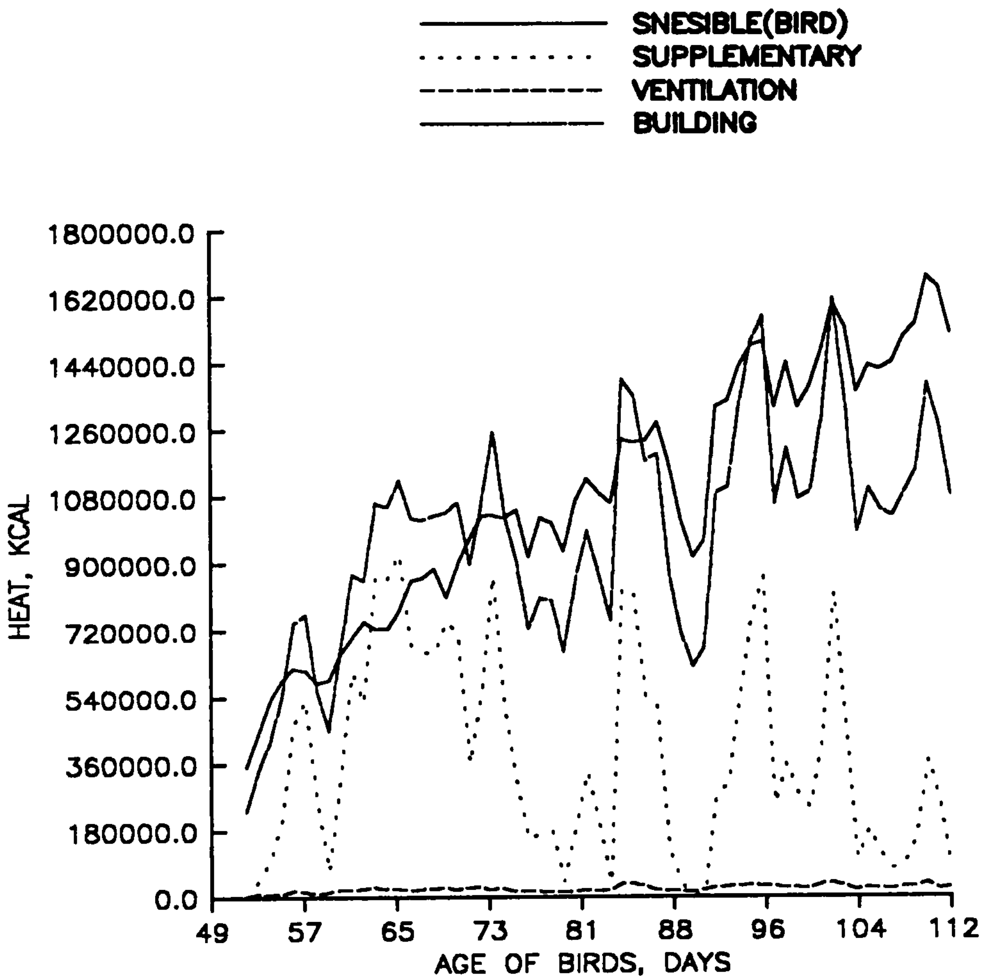

Figure 8. Components of heat generated in the building and heat lost from the building.

2. Energy consumption

A FORTRAN program was written for this submodel. The program was run with the observed daily mean temperature (computed from the hourly temperature observations) inside the house, and the average and standard deviation of the observed starting weights of the birds as the input to the program. The model also used the observed feed energy concentration values, shown in Table 21, as input. The daily mean temperature inside the house never exceeded 26.7°C . Thus, DECHUM(I) = 0 for all I.

The model predicted daily mean average weight and 95% confidence limits for the daily average weight. For the weight gain part, the submodel was validated by comparing the observed weekly weights with the corresponding simulated weights. The results are shown in Table 22.

The percent error of weight prediction decreased as the birds grew older. This may be due to the fact that the data used in developing the model regarding the effects of feed energy concentration on weight gain was from birds of market age (110 to 132 days old). The procedure to calculate INCENG(I) might not be applicable to birds younger than 110 days old. The other factor that may have contributed to the error could be the fact that feed energy concentration calculations in the observed data were only approximate. It was not possible to determine the exact day of feed formula change because feed tanks were not cleared before refilling with new feed formula.

Table 21. Observed feed energy concentrations

Age (weeks)	Feed Energy concentration kcal/kg
06	3009.3
07	3009.3
08	3009.3
09	3141.6
10	3141.6
11	3141.6
12	3373.1
13	3373.1
14	3472.3
15	3472.3
16	3472.3

Table 22. Observed and predicted weights of male turkeys

Age (weeks)	Average weight in kg. Predicted	Observed	[1] % Error
8	3.247	2.908	10.4
9	4.272	4.009	6.1
10	5.089	5.045	0.86
11	6.014	6.197	-3.0
12	7.125	7.019	1.4
13	7.948	8.284	-4.2
14	9.115	8.852	2.8
15	10.312	10.227	0.08
16	11.414	11.488	-0.06

[1] $\% \text{ Error} = \frac{\text{Predicted - Observed}}{\text{Predicted}} \times 100$

For energy consumption, the predicted and observed cumulative energy consumptions were compared and are shown in Table 23. The error in cumulative energy consumption prediction at 16 weeks of age is 25%. The percent error becomes larger as the birds grow older. This is because of comparing the cumulative energy consumption values which also makes the error cumulate as age of the bird increases. Also, the error is always negative indicating that the predicted energy consumption is always larger than the observed values. This could be due to the following reasons:

1. The data used to develop the energy consumption model developed by Hurwitz et al.(1980) was collected from turkeys confined in cages. Thus the model does not include the energy consumed by turkeys in moving around. The data used to validate this submodel was collected from turkeys reared on litter floors and thus includes the energy spent by birds in moving about on the floor.

2. The observed feed consumed was calculated at the time of refilling the feed tanks. Six different feed mixes were used throughout the growth period of the birds. Whenever the new feed mix was put into the tank, it was put on top of the left-overs from the previous feed mix. It was not possible to observe the exact day on which the birds started eating the new feed mix. Hence, the cumulative energy consumption values as shown in Table 23 are only approximate values.

3. Feed spilled on the floor by the birds during feeding is not accounted for

Table 23. Predicted and observed cumulative energy consumptions of male turkeys

Age (weeks)	Cumulative energy consumed, kcal/bird Predicted	Observed	% Error
8	4818.8	5054.6	-4.9
9	9827.4	10659.6	-8.4
10	15168.1	18363.2	-21.0
11	22147.4	26388.2	-19.1
12	28645.9	35318.7	-23.3
13	36594.0	44847.4	-22.5
14	43450.0	55990.3	-28.8
15	52183.0	66766.1	-27.9
16	62494.3	78143.9	-25.0

[1] $\% \text{ Error} = \frac{\text{Predicted - Observed}}{\text{Predicted}} \times 100$

Composite Model

A computer program, shown in Appendix B, was written in FORTRAN-77 for the composite model that combines the three submodels. The composite model was evaluated using the data from the same farm used in validation of the house environment and flock performance simulation submodels. Normal temperature values at Staunton, Virginia, were supplied to the model, and are shown in INPUT FILE 5 in Appendix C. Values of other inputs that must be supplied by the user were taken from the data listed in 'House Environment Simulation Submodel' and 'Flock Performance Simulation' sections of this chapter. The input files prepared from this data are shown in Appendix C.

The output of the model is shown in Appendix D. The model output shows mean and standard deviation of average bird weight, mean and standard deviation of cumulative average energy consumption per bird, and mean and standard deviation of average feed consumption per bird for each day of the flock's cycle. Since male birds were simulated in this sample run, the flock performance was simulated up to 24 weeks of age. For female birds, the simulation would be performed up to 22 weeks of age.

The sample output also indicates the distributions of the simulated flock performance parameters and warns about the deficiency in the energy consumption simulation part of the model.

Since the simulation can be started from any age of birds (minimum 6 weeks old), the model can be run to simulate a future flock or the expected performance of an ongoing flock. The simulation output would indicate the performance of birds from the user specified starting age up to 24 weeks for male and 22 weeks for female turkeys.

Since the distributions of the simulated flock performance parameters are completely known, probability of achieving a particular value of the performance parameter can be calculated. For example, the probability of achieving average bird weight of more than 12.4 kg on day 112th day of flock's life is 50%.

The simulated and the observed average bird weight and average energy consumption are shown in Figure 9 and Figure 10, respectively. The observed average bird weight was within the 95% confidence limits of the simulated average bird weight except when birds were about 14 weeks old. However, at marketing age (16 weeks), the observed average weight was within the predicted limits.

As shown in Figure 10, the observed cumulative energy consumption values are consistently above the predicted limits. Besides the probable reasons of error in weight and energy consumption prediction previously discussed in this chapter, additional probable reasons for error in the composite model are:

1. The error of outdoor weather prediction.

2. The error of house environment prediction.

3. Supplementary heat was not provided on very cold days as was done in the real system.

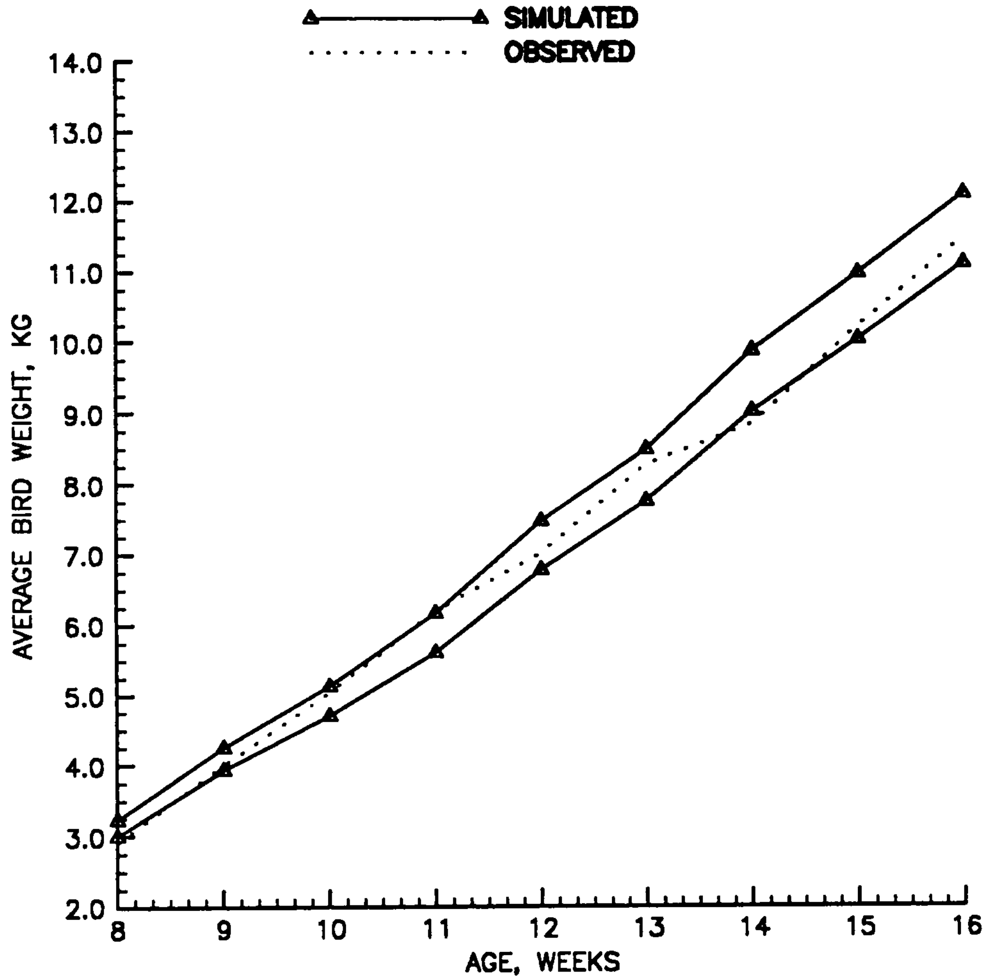

Figure 9. Observed and 95% confidence bands of simulated average bird weight.

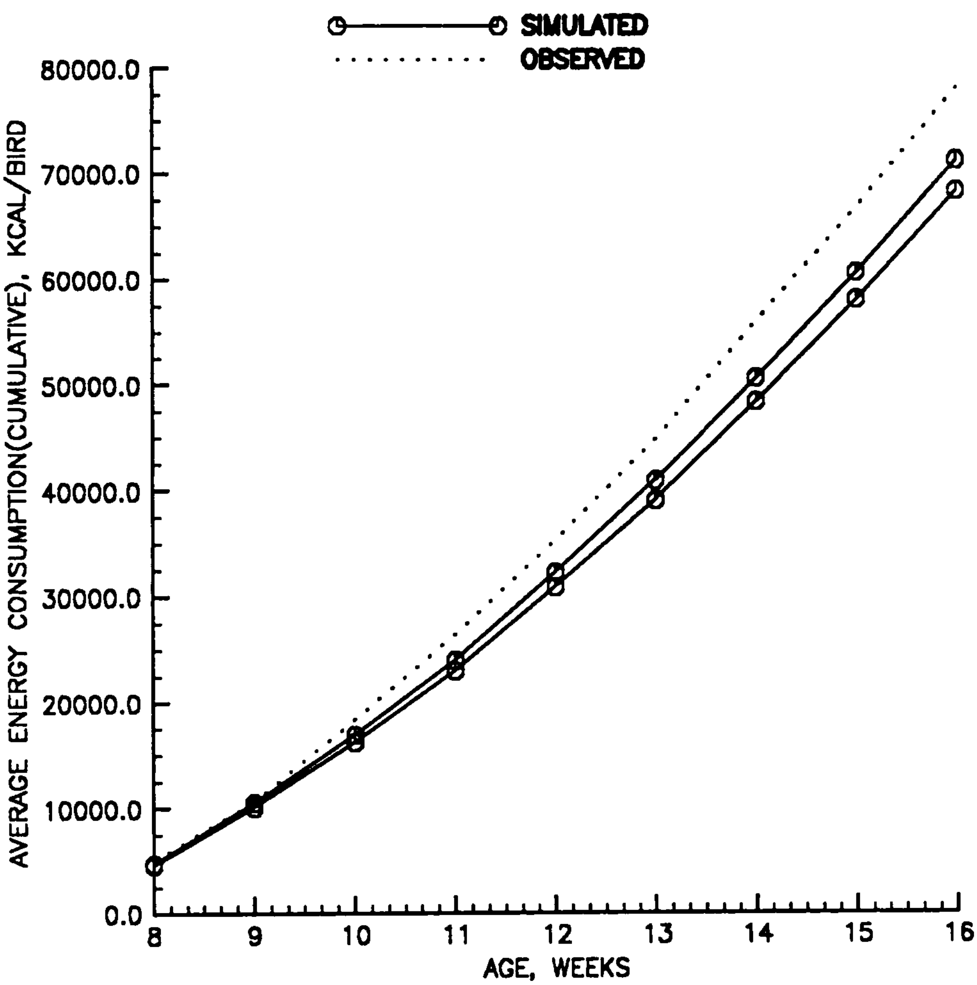

Figure 10. Observed and 95% confidence bands of simulated energy consumption.

Sensitivity Analysis

Sensitivity analysis of the composite model was performed by varying values of input parameters: R-value of the building, ventilation rate, and feed energy concentration.

Original R-value of the building was 4.7 hr ft^2 °F /Btu . The model was run at 50%, 150%, and 200% of the original R-value. Average body weight and cumulative energy consumption are shown in Figure 11 and Table 24, respectively. Decreasing the R-value by 50% resulted in maximum decrease of 5.28% in average body weight at 18 weeks of age and maximum decrease in cumulative energy consumption of 1.34% at 15 weeks of age. Increasing the R-value by 1.5 times resulted in maximum increase of 3.53% in average body weight at 16 weeks of age and maximum increase of 0.98% in cumulative energy consumption at 12 weeks of age. Similarly increasing the R-value by 2.0 times resulted in maximum increase of 5.93% at 15 weeks of age and a maximum increase of 1.69% at 12 weeks of age in cumulative energy consumption. Effect of varying R-value on body weight is greater for 12 to 20 weeks old birds compared to birds younger than 12 weeks and older than 20 weeks.

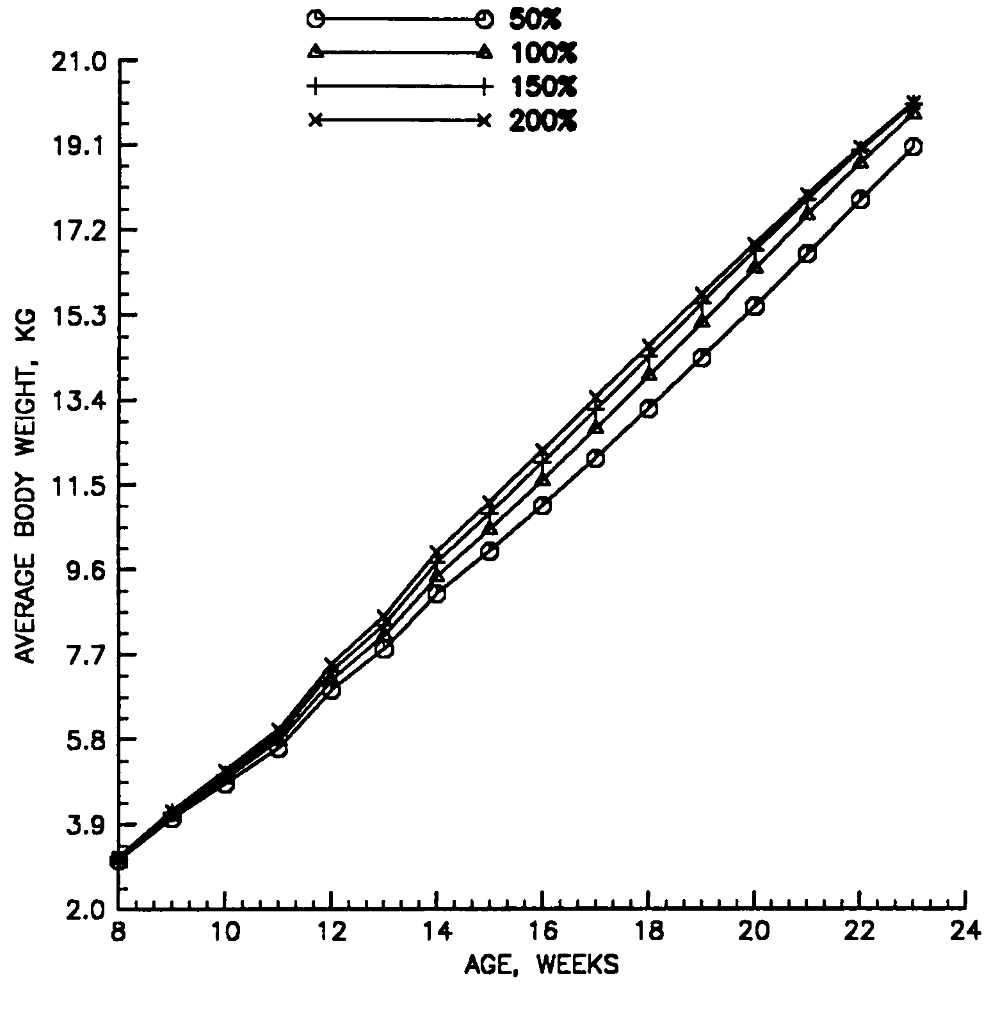

Figure 11. Average body weight at 50%, 100%, 150%, and 200% of the original R-value of the building.

Table 24. Effect of varying R-value on cumulative energy consumption per bird.

Age (weeks)	Body weight (kg) at 50%	100%	150%	200%
8	4665.3	4689.3	4711.5	4730.4
9	10273.6	10348.9	10416.0	10471.9
10	16456.6	16604.5	16736.1	16840.9
11	23230.3	23470.9	23680.4	23840.4
12	31197.4	31569.7	31879.1	32104.7
13	39550.3	40043.5	40432.5	40703.6
14	48882.0	49530.8	50007.1	50317.0
15	58594.2	59388.7	59919.2	60230.5
16	68950.0	69849.1	70404.4	70670.2
17	79835.2	80889.5	81419.5	81578.5
18	91264.7	92383.7	92821.7	92812.5
19	103233.0	104343.1	104589.4	104363.7
20	115785.5	116817.2	116789.2	116311.3
21	128792.5	129639.4	129298.7	128606.4
22	141989.6	142548.0	142020.2	141290.4
23	155437.4	155649.7	155106.0	154545.1
24	167228.0	167214.4	166762.0	166371.9

The effects of varying ventilation rate on average body weight and cumulative energy consumption are shown in Table 25 and Table 26, respectively. Varying the ventilation rate by 20% from its original value of 7475.6 m^3 /hr did not have any significant effect on the bird body weight or energy consumption. However, decreasing the ventilation rate by 20% decreased the supplementary heat required (throughout the growth period) to heat the incoming ventilation air by 20% (from 4.27×10^7 kcal to 3.41×10^7 kcal). Because the model does not consider concentrations of noxious gases in the house, decreasing the ventilation rate might be detremental to birds' health. Increasing the ventilation rate by 20% increased the supplementary heat requiremnt by 20% (from 4.27×10^7 kcal to 5.13×10^7 kcal).

Results of varying feed energy concentration values on average body weight and cumulative energy consumption are shown in Figure 12 and Figure 13, respectively. Maximum body weight reduction of 10.94% occured at 18 weeks of age as a result of decreasing the feed energy concentration values by 10% throughout the feeding regime. Increasing the feed energy concentartion values by 10% resulted in a maximum increase of 11.09% at 17 weeks of age. Decreasing the feed energy concentration by 10% resulted in a maximum decrease of 13.2% in cumulative energy consumption at 8 weeks of age. Increasing the feed energy concentration by 10% resulted in a maximum decrease of 13.03% at 8 weeks of age.

The above analysis shows that R-value of the building and ventilation rate do not have considerable effect on bird body weight or feed energy consumption. However, feed energy concentration has considerable effect on bird body weight and feed energy consumption. Hence, rough estimates of R-value and ventilation rate can be used as

Table 25. Effect of varying ventilation rate on average bird body weight.

Age weeks	Body weight (kg) at ventilation rate, m^3 /hr 5980.5	 7475.6	 8970.7
8	3.1130	3.1190	3.1240
9	4.0850	4.0970	4.1090
10	4.9030	4.9210	4.9370
11	5.7400	5.7620	5.7830
12	7.0990	7.1270	7.1530
13	8.0930	8.1230	8.1500
14	9.4220	9.4530	9.4820
15	10.4730	10.5040	11.5320
16	11.5890	11.6180	11.6440
17	12.7510	12.7780	12.8020
18	13.9390	13.9650	14.9870
19	15.1420	15.1690	15.1910
20	16.3420	16.3720	16.3960
21	16.5300	17.5650	17.5930
22	18.5350	18.7200	18.7570
23	19.7730	19.8280	19.8740
24	20.6950	20.7280	20.8140

Table 26. Effect of varying ventilation rate on cumulative energy consumption per bird.

Age weeks	Cumulative energy consumption (kcal) at ventilation rate, m^3 /hr 5980.5	7475.6	8970.7
8	4683.3	4689.3	4692.2
9	10332.2	10348.9	10356.9
10	16574.8	16604.5	16618.6
11	23425.6	23470.9	23492.4
12	31505.1	31569.7	31600.4
13	39959.8	40043.5	40083.1
14	49425.4	49530.8	49580.6
15	59260.7	59388.7	59449.1
16	69695.8	69849.1	69920.9
17	80706.1	80889.5	80974.6
18	92158.7	92383.7	92488.0
19	104065.1	104343.1	104471.4
20	116476.1	116817.2	116974.2
21	129220.9	129639.2	129832.0
22	142047.1	142548.0	142779.5
23	155078	155649.7	155916.4
24	166606.1	167214.4	167501.4

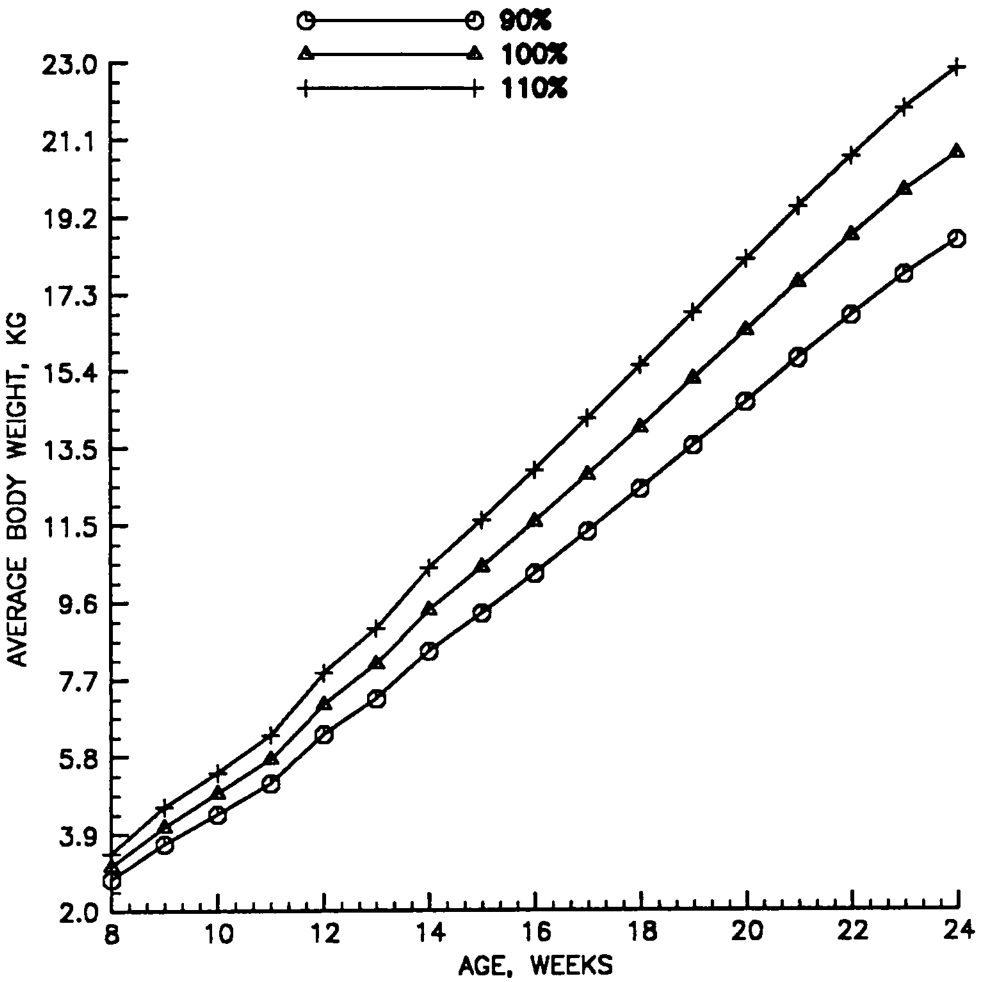

Figure 12. Average bird body weight at 90%, 100% and 110% of the original feed energy concentration values.

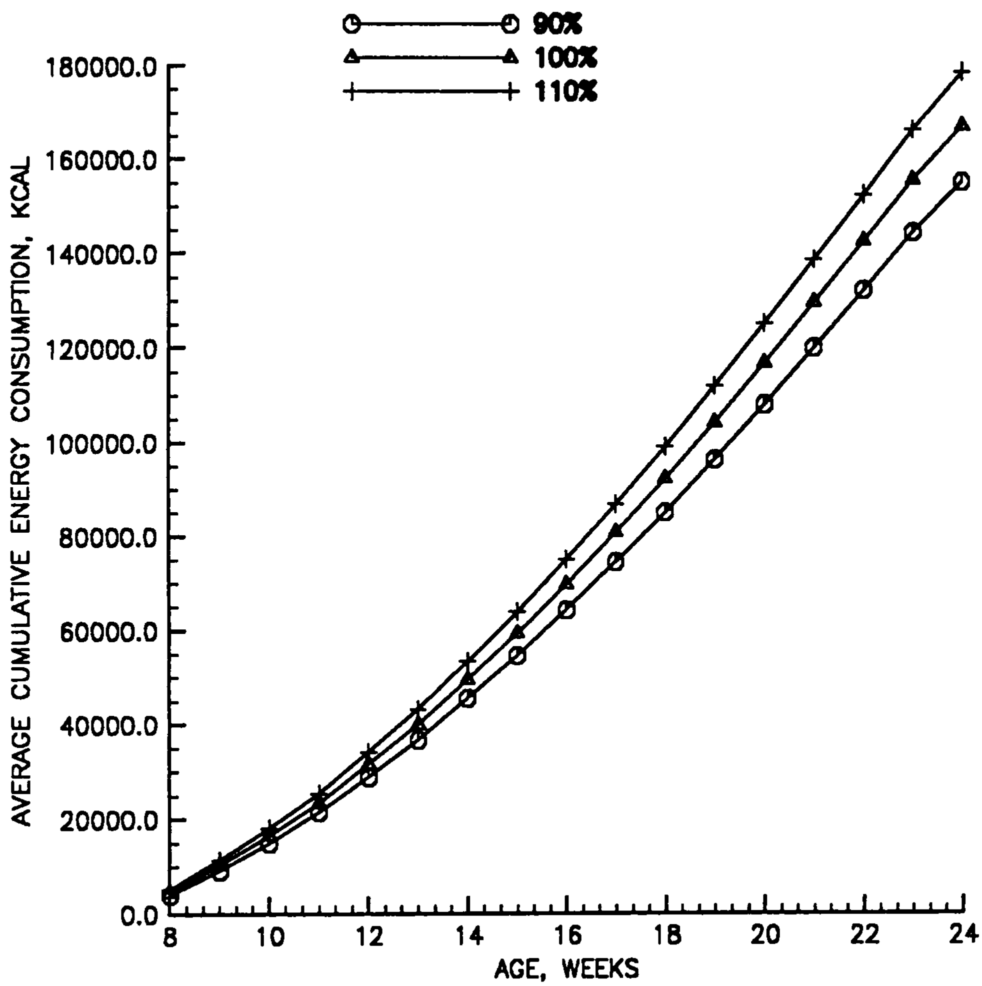

Figure 13. Cumulative energy consumption at 90%, 100% and 110% of the original feed energy concentration values.

input whereas care should be taken in calculating feed energy concentration values that are used as input to the model.

Conclusions and Recommendations for Improvement

Conclusions:

The following conclusions were reached at the end of this research project:

1. The weather model accurately (using an F-test at 5% level) predicted the variation from the normal daily mean dry-bulb temperature for 333 days out of 365 days of a year at Roanoke, Virginia.

2. The weather model also accurately (using an F-test at 5% level) predicted the variation from the normal daily minimum dry-bulb temperature for 356 days out of 365 days of a year at Roanoke, Virginia.

3. The assumption that the daily average dew-point temperature is the same as the daily minimum temperature for the months of May through October, and 2.0°C

less than the daily minimum temperature for the months of November through April, was valid for Roanoke, Virginia.

4. The house temperature predicted by the house environment submodel was close to the observed values (Figure 7) except when birds were young and the daily average outdoor temperature was below 2.0°C . The error, perhaps, is not from the model but due to insufficient validation data on the actual energy used in heating the house on very cold days.

5. The flock performance submodel predicted the daily average bird weight at marketing age (16 weeks) with an error of 0.06%. However, the error in prediction was greater when the birds were younger than 11 weeks. This was, possibly, because the information regarding the effects of feed energy concentration on bird weight gain used in building the model came from older birds and might not be as applicable to younger birds.

6. The flock performance submodel underpredicted the energy consumption of birds. This was likely due to the fact that the data used in developing the energy consumption part of the model came from birds reared in cages. Therefore, the model did not include the energy needed by the birds for moving around on the floor.

7. The observed average bird weights were within the 95% confidence limits of the predicted average bird weights except at 14 weeks of age.

8. The observed cumulative energy consumption values were consistently higher than the upper limits of 95% confidence bands of the predicted cumulative en-

ergy consumption values. This was likely due to the fact that the data used to build the energy consumption model was obtained from birds reared on a litter floor.

9. The model is more sensitive to feed energy concentration compared to other input parameters.

Recommendations for model improvement:

1. The weather prediction submodel needs to be validated for more geographical locations.

2. The assumption relating the average daily dew-point temperature to the daily minimum temperature needs to be validated for more geographical locations.

3. The weather prediction submodel needs to be tested for prediction of outdoor humidity ratio.

4. The flock performance submodel needs improvement in prediction of body weights for younger birds. This could be accomplished by gathering the information regarding the effects of feed energy concentration on weight gain for younger birds.

5. The flock performance submodel needs improvement in predicting energy consumption which will require information regarding the comparison of cage and litter grown birds.

6. The model needs to be validated for female birds.

7. The model could be improved by including the effects of population density, if any, on the performance of birds.

8. The model could be improved by including the effects of light, if any, on the performance of birds.

9. The model needs improvement in predicting mortality rates more accurately. This could be accomplished by including the effect of environment, diet, population density, and other factors on mortality rates of turkeys.

10. The model was tested using data from only one flock raised during the winter season. The model needs further testing using data from other seasons.

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Appendix A. Observed Daily Average Temperature at Roanoke, Virginia

Table 27. Observed daily average temperature (°F) at Roanoke airport, Virginia.

Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
1	38	32	23	33	33	33	55	42	47	39	19	38	53	37	33	40	39	31	57	35
2	39	24	26	35	33	42	39	29	34	34	24	29	31	38	34	33	41	33	54	36
3	38	34	32	29	32	37	29	35	34	41	26	27	12	39	59	32	37	38	39	47
4	35	32	18	27	37	37	47	40	39	25	36	27	24	32	22	44	31	42	36	37
5	33	21	17	33	40	37	43	36	38	18	33	36	29	30	20	37	36	43	34	33
6	33	25	17	32	33	28	31	40	30	23	30	38	33	30	26	38	40	46	37	37
7	41	28	26	20	29	39	26	42	39	29	24	38	40	32	29	48	44	37	39	27
8	45	18	26	7	26	37	21	35	34	29	22	47	33	37	19	31	41	39	34	22
9	36	24	41	6	33	37	19	49	48	19	27	23	21	35	24	24	36	45	29	32
10	41	32	25	18	38	46	22	44	39	26	24	12	30	30	21	6	40	37	27	44
11	29	23	27	26	44	53	24	53	56	32	15	20	25	39	16	8	44	31	33	38
12	36	21	24	33	47	48	22	30	41	41	18	23	24	38	13	18	32	23	26	48
13	46	30	25	31	38	56	23	26	29	38	13	28	32	30	21	21	34	26	31	33
14	49	34	25	37	51	42	32	29	22	39	33	30	34	40	36	23	37	35	37	28
15	44	29	29	31	39	17	42	48	27	34	34	22	26	50	36	25	35	31	25	31
16	33	33	28	36	28	8	40	59	34	32	15	18	36	44	30	23	28	31	26	40
17	38	29	39	33	29	26	48	58	30	26	5	29	42	45	24	5	31	39	35	43
18	32	35	48	43	27	44	48	45	37	15	12	30	34	45	33	23	21	33	34	52
19	24	39	45	31	21	48	50	52	43	18	13	25	20	45	45	27	21	23	35	48
20	29	44	37	19	24	44	38	48	34	32	23	29	29	44	37	37	20	18	11	38
21	39	46	37	10	36	54	36	52	27	34	23	17	36	38	36	33	30	13	0	44
22	58	38	38	15	45	43	46	53	36	28	23	22	31	39	41	27	32	17	20	46
23	57	42	42	20	40	53	48	56	39	36	21	24	30	33	40	33	38	28	26	38
24	61	28	49	31	31	59	40	48	44	49	29	27	37	34	41	33	39	38	35	32
25	58	28	35	32	41	48	46	43	50	41	33	38	28	46	40	26	36	44	32	33
26	58	32	32	47	38	39	45	44	41	46	32	32	34	44	42	21	36	45	21	34
27	47	40	26	43	17	33	48	58	46	43	34	29	36	38	48	19	40	45	30	18
28	38	46	30	41	24	43	44	52	54	32	27	21	33	42	40	32	37	41	35	13
29	40	48	37	54	33	33	33	50	60	41	13	18	32	32	38	38	39	36	29	26
30	37	50	53	36	46	38	26	49	44	37	24	22	31	25	29	39	49	34	28	30
31	43	46	53	39	23	33	30	51	41	44	21	22	30	22	25	50	47	27	39	35
32	57	40	46	44	15	33	34	48	36	40	26	22	24	17	25	41	39	30	39	43
33	54	45	43	51	20	33	48	51	35	23	30	31	27	16	33	31	44	38	33	54
34	38	44	40	31	24	36	42	44	33	31	36	24	28	19	17	36	41	41	27	46
35	37	42	37	16	28	24	44	31	30	44	42	21	36	23	22	42	29	43	27	40
36	44	39	49	32	42	26	45	30	35	43	29	25	23	26	22	37	26	33	27	52
37	42	40	44	36	41	34	37	29	43	39	17	17	21	28	33	33	30	29	39	44
38	28	37	41	38	33	28	44	45	30	27	20	20	28	32	35	28	34	23	30	35
39	19	38	37	43	31	22	38	32	34	32	22	23	30	30	36	36	32	31	22	41
40	22	38	35	38	20	30	25	24	30	38	32	28	20	33	31	40	31	48	29	41
41	30	24	35	37	21	29	25	27	25	47	49	30	17	30	33	31	31	45	37	37
42	38	19	37	38	34	39	26	33	42	53	45	28	16	29	37	35	25	51	34	29
43	33	25	35	36	42	35	26	43	42	43	37	34	27	30	16	31	30	55	33	25
44	34	26	27	38	40	42	30	50	35	55	41	30	26	27	19	32	28	56	27	22
45	46	35	27	28	27	45	32	52	36	47	43	34	22	39	36	40	32	54	34	21
46	56	37	30	31	36	45	38	39	43	49	34	36	33	42	38	47	41	54	28	29

cont......

Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
47	50	41	33	38	39	40	24	32	41	61	25	32	35	35	42	51	36	50	27	37
48	33	36	35	34	45	36	19	30	47	60	24	38	17	23	51	42	44	58	40	45
49	33	27	39	44	55	33	23	43	49	56	22	35	10	30	53	32	43	57	40	55
50	35	33	40	45	58	29	38	43	45	55	36	31	22	35	52	38	42	56	42	55
51	36	38	40	31	64	25	36	40	39	50	34	38	26	43	50	47	42	48	43	44
52	35	21	40	32	56	38	39	42	40	51	28	30	42	55	49	46	47	44	44	52
53	28	21	32	47	50	40	31	52	43	47	41	23	49	61	49	38	48	43	58	36
54	33	33	38	42	41	27	38	41	61	35	50	25	41	60	46	50	51	44	59	39
55	20	36	44	42	40	40	41	38	54	46	55	26	41	51	42	63	38	54	66	33
56	13	32	40	35	46	43	39	30	45	53	56	46	41	39	47	40	35	45	60	32
57	23	31	36	23	45	44	49	27	47	55	56	33	35	27	45	27	35	42	52	28
58	28	33	36	40	54	38	41	34	41	56	49	30	38	34	45	27	34	35	48	34
59	37	37	32	47	54	50	41	45	43	40	38	29	40	38	53	33	40	35	42	32
60	32	32	31	40	53	59	42	55	40	62	36	33	42	17	50	35	50	28	43	31
			29×				28×				47×				64×				35×	
61	43	44	34	52	45	64	46	57	27	62	36	25	48	19	41	48	54	35	53	36
62	59	32	39	48	35	41	52	62	28	66	42	31	47	24	39	41	57	37	44	40
63	47	42	39	39	29	35	56	68	34	65	59	25	49	35	25	30	60	36	42	39
64	54	49	40	49	40	38	54	62	33	70	55	26	60	44	44	49	55	41	54	41
65	61	46	37	43	47	37	49	53	43	52	49	36	45	43	38	39	54	44	40	37
66	43	45	36	44	41	49	47	64	48	47	44	33	42	46	36	35	60	38	41	29
67	40	47	42	52	32	46	57	67	35	44	45	31	41	63	37	32	52	38	54	26
68	46	62	38	46	38	33	56	65	28	35	51	34	49	48	36	40	45	25	57	51
69	52	58	33	43	39	38	58	62	32	40	52	43	51	44	36	41	43	31	53	59
70	64	56	29	50	47	37	52	43	39	47	58	51	34	41	41	48	41	38	42	56
71	55	44	29	45	48	54	63	39	40	43	58	45	43	34	44	59	41	35	55	44
72	45	40	36	39	58	65	58	36	50	51	61	45	46	30	54	60	49	37	52	45
73	62	32	40	33	57	51	66	39	37	43	57	59	50	37	39	52	49	50	53	51
74	59	44	37	29	61	51	65	44	42	46	57	55	33	45	47	41	58	49	47	56
75	43	50	40	29	55	47	61	45	40	42	58	42	37	48	40	38	50	57	43	49
76	35	53	45	34	38	47	50	40	39	31	52	36	46	55	41	57	43	48	45	46
77	27	59	46	40	40	50	41	46	37	43	63	36	49	46	39	56	48	54	37	46
78	32	59	54	46	48	48	46	56	48	39	47	53	56	42	32	53	51	57	45	65
79	33	63	55	42	38	48	42	46	54	57	53	54	56	51	26	47	56	57	57	44
80	43	69	56	46	43	57	37	45	54	58	42	57	55	51	40	53	47	50	45	31
81	42	66	44	40	55	51	35	43	55	44	45	53	54	45	32	45	37	45	35	36
82	45	48	42	46	37	37	45	47	57	43	42	61	51	46	39	44	39	45	48	45
83	48	41	49	42	32	34	47	42	58	51	45	57	49	47	41	49	35	47	54	57
84	53	48	48	46	32	31	45	35	49	57	50	41	38	46	43	52	43	51	48	55
85	60	52	42	52	31	38	51	43	40	54	55	38	39	40	46	41	41	50	52	57
86	55	59	36	42	36	47	51	55	30	57	50	45	40	46	56	31	40	51	59	56
87	60	64	40	45	55	51	44	58	37	53	64	54	49	43	47	33	46	47	69	50
88	62	65	49	43	53	44	45	48	49	47	68	60	63	56	57	38	40	43	74	57
89	55	67	43	33	44	49	56	50	46	51	68	48	69	53	62	49	38	43	70	64
90	55	63	40	46	50	44	56	49	44	51	57	57	71	54	66	61	42	44	51	69

×

February 29 on leap years

cont......

Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
91	62	52	44	41	55	49	62	63	53	47	51	67	68	52	60	56	47	46	56	67
92	69	43	63	53	53	41	51	63	55	46	64	65	64	58	61	54	49	49	45	68
93	64	46	61	48	47	48	56	59	48	57	64	53	55	59	59	60	46	52	50	61
94	48	59	52	51	54	52	55	63	37	55	49	60	45	59	64	53	55	48	62	65
95	62	56	62	40	53	48	47	53	40	48	49	62	50	50	58	45	48	50	68	67
96	69	51	58	43	44	60	52	43	40	52	41	55	45	49	45	35	59	52	57	62
97	69	53	54	46	43	55	50	48	45	54	41	62	46	53	44	33	58	52	48	65
98	57	62	63	50	54	35	47	51	51	51	50	67	56	57	53	35	62	50	45	63
99	56	64	62	64	57	38	45	42	52	45	44	60	50	60	62	41	56	50	36	47
100	65	53	62	57	55	48	40	45	57	50	54	62	49	57	57	43	56	44	39	44
101	57	54	61	53	56	60	37	49	47	51	66	66	52	57	65	45	46	51	55	54
102	49	53	52	53	61	56	42	60	46	43	69	58	67	58	70	52	51	54	59	59
103	48	59	52	46	69	68	41	68	45	51	66	64	54	53	53	63	54	64	66	55
104	64	65	50	54	57	66	43	68	46	57	69	54	56	60	57	57	54	60	63	55
105	72	58	52	59	48	71	50	57	48	61	65	56	54	46	54	55	52	59	64	60
106	73	54	64	55	54	69	55	54	52	70	63	50	52	48	52	58	46	55	67	46
107	64	52	65	56	61	64	58	49	49	73	64	53	52	45	59	62	43	51	65	45
108	60	65	65	67	64	61	61	53	58	71	65	50	53	55	70	53	36	49	65	56
109	56	69	57	53	60	69	61	58	63	72	69	49	54	55	61	50	35	49	76	59
110	55	63	53	59	64	73	62	54	56	73	62	48	53	62	55	51	43	53	75	63
111	62	67	54	64	61	54	69	57	53	59	65	46	57	63	46	55	48	53	73	58
112	68	65	54	61	54	48	68	63	55	66	68	52	64	61	53	49	50	44	76	43
113	62	58	49	66	45	58	68	59	60	68	66	50	65	80	65	48	52	45	77	44
114	53	60	52	69	56	55	68	48	69	68	61	59	66	69	54	51	52	48	66	56
115	51	54	55	64	59	48	56	51	63	66	55	49	63	66	52	52	50	63	69	64
116	49	55	64	58	60	47	56	56	63	47	47	42	61	54	52	59	62	67	68	69
117	53	59	65	63	55	53	50	59	57	48	53	55	56	48	70	59	64	74	68	72
118	52	51	67	66	63	53	50	66	57	46	67	55	51	57	69	56	69	66	73	68
119	52	45	58	72	57	62	53	73	60	52	55	54	50	51	67	48	70	63	66	68
120	57	56	55	72	50	62	54	75	53	55	54	57	54	50	61	51	67	73	63	65
121	63	67	55	69	54	61	64	62	60	60	57	58	56	59	56	57	70	63	70	70
122	62	63	57	66	51	66	67	53	64	60	68	52	56	58	51	60	71	57	64	59
123	56	71	64	56	47	62	60	62	52	55	71	57	64	60	51	59	65	55	59	52
124	48	67	68	52	53	60	54	63	62	52	67	53	70	66	59	57	52	59	56	52
125	60	57	70	59	55	58	52	51	61	55	71	56	59	65	65	58	56	64	63	64
126	62	52	69	55	64	58	53	54	67	66	74	60	61	70	66	64	54	60	71	73
127	57	51	72	54	59	65	63	49	61	64	71	60	66	67	56	70	60	71	70	75
128	57	57	65	65	65	61	61	51	60	50	64	53	71	55	51	62	58	65	63	72
129	53	63	60	72	62	63	62	64	61	54	51	65	72	48	56	60	52	53	61	56
130	57	70	58	70	60	59	64	62	61	58	49	61	72	53	58	59	54	59	71	56
131	61	67	51	72	61	56	63	54	61	62	55	62	73	70	65	63	58	62	70	64
132	72	72	52	71	65	58	58	65	65	62	57	65	69	75	53	67	58	69	73	60
133	57	69	55	73	63	58	57	62	63	58	70	60	70	74	56	73	61	63	76	55
134	61	59	60	75	62	64	59	63	61	68	74	51	65	65	64	73	67	61	76	52
135	63	67	65	66	56	65	53	70	60	69	67	53	64	56	62	72	72	57	72	62
136	52	72	68	63	65	61	52	74	68	72	63	56	61	59	58	72	55	51	69	70
137	50	65	66	58	69	62	51	76	63	69	75	62	57	60	58	73	53	53	64	72
138	59	64	65	59	69	61	51	74	63	54	76	64	57	67	54	72	54	59	62	70

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Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
139	62	62	68	68	71	64	60	72	69	57	78	73	62	70	48	72	57	72	63	66
140	66	59	72	71	75	64	63	66	72	69	71	69	63	62	52	71	70	73	68	66
141	51	55	67	75	67	65	63	65	74	71	69	73	64	67	59	69	69	74	71	60
142	49	57	67	76	61	69	64	70	76	69	72	63	64	65	65	71	70	73	67	54
143	56	65	68	75	57	64	69	71	73	63	74	66	70	72	70	69	70	69	68	59
144	56	68	69	76	67	64	64	67	77	60	69	71	66	68	69	68	65	67	56	65
145	58	63	69	74	71	65	64	65	75	55	68	74	54	66	71	73	58	69	65	61
146	64	65	68	70	66	58	56	56	70	61	72	72	54	65	70	70	62	75	69	63
147	68	56	61	70	62	56	60	58	73	62	71	69	55	63	66	69	57	69	72	61
148	77	55	67	64	56	59	73	58	69	64	70	69	62	65	65	73	58	70	73	70
149	70	62	75	68	52	66	72	70	70	62	74	71	63	70	69	73	64	64	69	74
150	58	60	78	64	57	71	69	72	73	69	69	72	62	70	70	76	67	54	65	76
151	52	64	75	71	70	66	66	73	73	71	67	75	70	71	73	76	62	53	72	75
152	52	63	75	76	68	59	64	69	70	70	74	75	74	73	62	69	58	59	78	74
153	60	68	72	76	72	65	68	66	66	65	72	72	73	75	69	68	59	73	74	76
154	57	69	63	77	72	68	73	69	68	54	68	69	66	80	73	69	66	76	75	64
155	65	66	62	69	74	69	74	67	71	64	68	66	69	70	75	64	69	67	75	71
156	66	65	70	70	77	74	73	65	74	58	73	67	69	64	77	68	68	70	80	74
157	63	68	72	68	76	68	72	69	72	60	74	68	71	65	71	64	70	78	75	75
158	66	69	78	65	76	69	72	68	68	66	58	74	72	75	71	69	69	78	67	79
159	66	75	79	70	75	66	62	68	63	72	56	72	79	70	72	73	67	79	74	76
160	70	70	70	73	72	74	75	73	60	71	62	71	67	62	81	70	64	79	80	74
161	73	76	61	73	69	63	78	78	62	73	62	66	68	66	82	73	67	78	82	66
162	71	77	69	74	68	58	78	70	60	74	62	68	65	63	74	74	69	78	76	77
163	73	76	75	76	73	62	76	66	69	64	69	73	63	64	75	67	70	78	71	79
164	77	64	74	77	74	70	76	62	69	66	74	67	64	61	79	69	71	79	58	74
165	75	65	76	68	76	76	75	66	70	67	67	62	68	68	81	68	73	81	61	71
166	78	72	76	67	71	76	70	66	72	74	74	62	68	79	81	67	72	76	68	73
167	79	75	67	76	63	74	78	66	74	69	76	68	63	73	79	77	73	70	73	77
168	77	68	65	79	64	69	81	61	73	71	74	75	66	64	73	73	72	77	76	75
169	74	65	72	83	68	74	71	62	76	71	78	79	77	63	69	70	71	81	77	67
170	74	70	77	80	70	73	72	67	77	73	81	79	70	68	74	72	73	82	70	69
171	71	73	76	74	72	70	74	78	80	71	79	74	68	68	74	70	72	77	68	76
172	76	65	73	76	74	70	76	77	73	71	73	68	64	63	77	72	74	76	67	70
173	77	73	69	75	71	63	73	77	72	70	66	74	75	69	79	70	69	72	72	74
174	77	78	74	73	71	58	74	69	72	70	63	71	75	74	76	69	71	67	79	78
175	74	81	78	72	74	61	72	64	76	71	65	71	66	69	74	64	73	74	79	76
176	79	79	78	76	77	66	73	66	77	73	72	72	61	65	80	69	79	72	79	70
177	68	82	74	76	78	67	73	66	74	76	79	78	60	73	69	74	73	68	74	69
178	65	74	82	68	77	69	75	63	76	77	75	84	64	76	64	74	78	70	67	79
179	67	65	81	63	80	68	73	60	76	50	78	84	68	81	65	74	78	77	70	85
180	71	72	81	67	79	72	72	65	75	73	80	77	71	82	68	76	74	69	73	83
181	75	83	78	77	75	66	74	70	74	73	74	80	72	71	70	76	66	73	68	80
182	72	84	79	86	78	75	74	77	72	68	79	76	68	70	69	69	76	71	65	71
183	74	83	75	85	76	76	77	77	72	66	75	75	71	77	69	67	81	71	69	75
184	73	70	76	81	71	76	80	79	76	66	70	75	73	79	68	78	80	72	74	70

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Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
185	70	70	75	82	67	72	80	71	67	66	75	76	70	82	74	78	78	74	77	70
186	67	69	81	72	67	63	78	70	62	68	80	69	65	80	74	68	74	78	72	77
187	67	74	80	70	76	62	71	73	74	67	87	67	61	80	76	74	71	74	76	81
188	70	73	77	71	75	62	74	76	74	69	89	71	65	72	77	73	64	73	76	81
189	75	75	71	76	76	68	79	78	75	73	88	78	64	78	77	78	68	65	80	83
190	77	71	66	74	80	70	80	77	77	74	85	79	65	76	82	77	72	68	84	84
191	75	75	73	75	80	72	80	77	76	71	81	81	68	77	83	77	74	78	79	76
192	80	73	76	72	79	71	76	75	75	78	77	73	72	78	79	77	72	82	78	78
193	81	74	77	76	70	73	69	71	71	77	81	70	77	82	80	76	75	80	77	81
194	76	78	75	75	73	79	74	71	72	70	83	68	78	76	79	74	81	76	79	80
195	72	79	72	78	77	78	80	76	71	75	85	74	77	77	83	76	81	76	78	80
196	69	79	74	81	71	77	76	79	70	83	80	77	80	80	74	78	80	78	81	74
197	68	80	75	77	76	77	69	75	75	75	80	71	79	86	70	77	84	78	79	78
198	70	80	79	72	75	78	65	71	73	72	83	73	77	85	80	79	82	76	78	84
199	71	79	81	74	74	79	71	76	73	68	88	73	77	77	77	77	80	75	76	85
200	72	77	82	75	73	79	71	74	76	70	86	76	76	80	77	78	84	68	80	86
201	71	76	80	79	71	81	76	73	76	75	88	76	72	84	82	79	86	69	84	86
202	73	72	77	69	71	82	79	69	78	80	86	69	72	83	79	75	87	69	82	83
203	73	78	78	64	70	83	78	69	77	79	79	83	60	78	77	77	83	70	82	80
204	75	78	80	70	70	83	73	64	78	79	71	85	76	75	71	77	80	76	73	80
205	79	80	73	79	69	84	73	73	80	83	74	80	76	72	69	74	80	80	71	80
206	78	81	76	79	73	80	73	74	75	75	75	76	77	74	73	76	71	75	71	81
207	80	74	76	78	78	78	76	74	70	68	77	76	75	78	80	79	73	74	78	78
208	75	73	76	78	77	76	78	76	71	79	66	78	77	76	84	79	75	74	72	79
209	77	79	80	80	72	74	77	77	75	78	68	77	78	74	82	81	75	69	75	81
210	77	71	75	79	74	66	77	76	75	78	72	75	75	74	72	72	74	67	75	81
211	74	73	74	78	73	63	73	72	76	78	79	81	76	75	68	74	76	68	79	77
212	73	74	73	80	73	73	75	72	79	75	78	80	77	77	67	73	79	71	80	73
213	75	78	76	82	74	74	74	72	79	71	79	77	80	81	71	75	79	77	69	75
214	75	78	76	78	72	74	78	75	79	66	76	78	80	81	75	71	79	80	71	80
215	80	78	74	76	78	77	72	74	79	66	77	78	77	82	78	76	81	80	67	79
216	78	77	70	76	79	77	75	73	81	68	79	73	73	79	80	76	78	80	67	75
217	77	78	74	73	69	72	74	72	78	71	84	78	76	79	83	81	80	78	67	75
218	74	80	73	75	69	69	76	67	77	76	85	77	78	80	77	79	80	78	72	76
219	70	80	74	74	76	77	77	71	74	73	87	79	78	80	78	78	78	79	77	79
220	73	80	77	74	73	73	78	71	73	72	86	79	81	80	78	77	78	80	79	79
221	76	80	79	65	75	76	80	74	74	69	81	76	82	81	76	74	82	79	78	76
222	77	79	72	64	78	67	79	71	74	68	83	76	82	81	76	76	78	76	78	78
223	73	68	70	72	79	64	79	68	74	71	82	75	75	82	79	71	81	75	79	71
224	70	69	73	70	73	73	77	72	79	75	82	78	63	80	73	71	73	76	79	70
225	67	72	72	74	69	76	79	74	77	78	79	78	63	74	69	69	65	78	81	69
226	70	74	76	74	70	75	77	75	79	76	79	77	69	78	71	71	66	78	82	72
227	71	76	79	76	72	75	74	73	77	74	79	80	67	81	76	72	67	76	80	75
228	70	78	75	79	72	66	73	74	78	70	81	80	60	78	79	74	73	75	80	78
229	72	82	78	79	74	73	75	75	76	69	80	81	62	67	72	77	76	75	71	79
230	75	81	78	76	69	81	74	72	75	69	70	76	71	65	65	72	83	70	71	76

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Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
231	77	79	78	78	74	78	72	72	72	67	67	79	77	77	65	72	85	74	75	69
232	76	80	77	77	77	71	71	73	76	66	69	79	75	76	68	76	86	71	77	69
233	70	85	71	80	79	70	69	70	78	73	71	68	71	74	64	72	90	67	73	75
234	73	81	70	71	74	72	72	74	81	77	74	71	68	69	67	64	88	71	68	75
235	71	82	70	72	75	74	71	73	79	76	72	74	73	73	69	72	83	73	67	72
236	68	82	71	69	66	77	71	76	79	76	73	77	74	73	73	79	73	68	68	71
237	73	81	74	70	68	78	74	74	80	79	66	81	74	73	72	77	72	69	73	66
238	76	70	75	70	72	76	75	75	79	78	71	79	76	74	69	66	75	68	75	75
239	74	64	69	73	75	77	78	76	78	78	75	77	75	74	71	68	78	71	76	78
240	68	63	68	75	70	72	82	77	74	74	80	79	76	75	68	71	81	73	72	60
241	69	62	71	76	68	72	83	78	73	75	79	81	76	75	68	61	80	75	73	56
242	71	62	74	78	70	71	79	77	75	65	81	77	77	74	75	64	76	76	75	57
243	71	62	73	79	71	69	80	72	73	61	77	77	75	76	77	69	78	70	75	65
244	63	62	74	74	70	66	80	72	73	64	80	73	71	79	75	74	73	66	71	63
245	61	68	75	72	74	67	80	69	78	67	80	70	76	78	76	78	71	74	75	61
246	63	68	73	79	72	69	80	72	78	66	79	75	75	78	75	71	73	77	78	67
247	63	69	74	79	71	73	77	64	76	71	78	74	75	74	67	65	76	65	79	65
248	67	70	75	77	76	62	76	60	72	73	79	72	71	79	70	62	82	62	79	72
249	71	68	78	74	76	64	77	59	70	66	78	73	75	78	72	66	83	59	79	69
250	70	66	77	71	77	63	77	63	65	64	72	52	71	76	70	67	82	60	80	65
251	70	66	75	73	73	67	72	67	74	71	69	77	64	70	70	67	76	60	81	63
252	65	67	66	76	75	71	71	68	72	73	66	82	59	72	63	67	76	64	82	62
253	67	71	62	77	74	61	64	74	68	61	70	71	47	75	63	66	80	71	81	66
254	57	65	60	71	75	62	68	74	75	61	64	74	68	68	72	68	79	71	73	70
255	58	65	62	67	66	72	71	76	69	65	60	75	67	70	72	70	81	72	61	69
256	60	62	64	72	65	75	65	76	58	66	68	68	69	72	71	70	70	73	54	67
257	59	66	66	76	66	75	73	66	53	67	75	62	72	76	72	71	68	75	56	65
258	64	66	68	76	70	70	69	62	57	61	68	72	63	74	70	78	63	61	59	68
259	69	66	70	78	73	72	66	62	64	69	63	74	60	67	68	77	63	55	61	69
260	72	69	73	76	72	69	65	64	64	67	73	78	59	72	59	69	73	57	65	57
261	71	64	69	76	69	78	62	69	64	67	73	79	64	74	58	70	70	53	66	62
262	71	67	58	74	73	74	56	66	71	67	76	83	66	73	57	66	73	58	67	72
263	74	68	57	68	76	63	63	68	71	65	73	75	57	73	64	61	72	68	67	72
264	73	68	59	75	64	63	65	65	65	59	63	79	66	78	63	60	63	73	67	75
265	62	67	63	79	59	68	70	58	58	56	64	77	70	80	65	56	51	70	69	71
266	55	71	63	80	64	61	76	51	60	58	66	63	61	76	59	56	52	70	71	72
267	56	70	67	77	66	64	72	46	66	65	72	61	59	67	57	55	50	75	66	75
268	57	71	66	77	61	71	69	56	63	63	74	67	60	66	57	61	52	76	61	78
269	58	69	65	77	66	73	68	59	66	65	73	63	63	62	63	58	58	64	67	79
270	64	64	66	63	69	73	71	59	61	68	67	61	63	54	67	62	59	50	64	77
271	63	64	64	58	71	68	74	68	56	66	61	64	62	53	62	62	62	47	60	73
272	51	63	56	54	70	67	73	67	58	58	60	54	67	63	57	63	63	52	58	74
273	51	66	59	61	68	54	64	58	62	58	62	60	69	60	63	63	57	53	61	75
274	61	64	62	60	69	48	59	53	62	59	66	63	71	66	61	64	57	53	66	78
275	61	66	72	67	74	53	64	45	53	57	67	62	63	67	54	69	66	50	60	73
276	65	67	69	69	73	56	68	41	47	64	54	61	60	59	41	72	65	54	61	73

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Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
277	69	48	67	58	70	59	71	46	53	57	54	61	57	51	47	71	67	65	69	79
278	69	47	59	55	72	60	67	55	58	61	53	53	52	47	58	70	71	65	60	70
279	66	48	61	61	64	62	57	58	66	62	56	56	52	50	61	70	64	62	52	59
280	52	59	63	61	54	59	59	61	60	63	51	51	53	54	54	67	57	61	50	51
281	56	54	63	65	51	60	66	53	56	65	53	45	55	60	47	67	56	63	54	58
282	64	59	58	67	54	53	67	51	68	54	58	44	63	70	46	69	59	68	63	64
283	59	59	59	68	56	46	71	56	65	50	50	53	42	60	47	61	57	65	67	59
284	53	64	60	70	58	47	63	58	68	45	51	51	45	64	49	55	57	63	72	56
285	48	66	68	71	59	59	61	63	61	47	51	61	52	53	48	62	66	64	62	55
286	50	67	69	68	59	62	61	63	59	57	46	65	51	52	45	59	64	63	68	62
287	60	65	65	70	63	62	64	66	68	51	49	54	44	50	45	56	56	64	71	60
288	57	67	54	70	62	51	67	62	69	53	57	43	47	58	52	61	55	61	73	51
289	61	67	60	52	64	49	62	56	69	56	45	42	56	61	60	52	55	66	65	47
290	62	69	50	47	63	62	48	57	58	42	48	44	58	61	45	47	59	62	57	53
291	57	67	47	50	58	48	54	56	60	41	48	47	59	69	54	45	62	68	64	49
292	47	62	58	51	60	38	52	43	55	37	49	56	59	64	43	53	62	70	68	48
293	48	58	66	52	58	35	59	41	49	47	51	55	64	54	39	59	52	74	65	50
294	53	61	58	58	60	38	53	40	58	45	49	54	68	57	49	53	48	74	51	54
295	48	58	53	62	60	48	52	47	65	44	56	61	68	58	54	45	47	72	56	62
296	49	61	43	58	63	53	55	57	60	42	54	66	56	46	52	43	52	68	62	63
297	51	57	38	57	63	63	56	54	59	46	49	48	48	45	35	42	60	62	64	61
298	54	48	44	63	65	50	56	62	70	54	55	50	49	46	35	45	57	61	63	56
299	51	44	59	57	65	47	59	58	60	45	59	60	43	47	47	53	53	71	53	56
300	51	49	58	53	59	43	58	54	57	37	62	53	42	43	58	50	50	67	55	61
301	48	51	46	52	64	55	53	53	62	34	65	50	50	58	51	53	58	68	56	57
302	45	44	41	50	62	58	47	59	64	46	57	51	57	51	45	54	57	70	49	53
303	42	45	40	57	64	52	47	63	49	41	49	49	54	41	47	57	43	63	50	61
304	48	46	52	57	67	48	53	66	49	48	45	50	50	47	44	62	47	60	52	53
305	49	60	57	58	69	51	55	66	47	40	51	55	57	57	53	64	49	62	57	51
306	56	65	62	56	74	62	58	67	58	37	57	54	57	47	56	64	53	52	55	61
307	52	63	60	50	57	67	55	68	60	42	63	53	48	45	58	62	61	42	54	49
308	50	53	49	39	43	56	50	69	63	41	70	55	43	52	59	51	49	45	57	54
309	48	56	42	49	43	51	46	64	66	38	67	55	42	47	57	38	41	55	51	52
310	34	55	49	52	45	45	41	51	63	41	64	57	46	45	50	37	50	44	55	60
311	33	56	52	58	42	42	38	47	60	44	59	56	42	59	46	42	45	44	54	52
312	34	45	47	51	32	50	46	50	68	27	59	49	40	61	49	49	48	44	48	57
313	36	38	48	48	34	52	40	48	62	34	61	50	51	59	47	54	49	52	50	61
314	45	38	53	52	44	49	32	48	51	50	55	50	56	51	42	49	57	53	56	51
315	50	38	52	59	48	55	31	50	51	41	45	56	49	39	45	49	45	53	63	46
316	54	36	54	55	54	45	43	49	54	34	35	53	44	43	41	62	35	43	59	46
317	60	39	45	55	60	50	53	43	47	29	33	55	48	51	39	42	35	45	63	33
318	49	41	35	51	49	61	63	44	37	28	38	59	40	53	43	32	40	49	66	26
319	46	52	26	45	60	40	63	36	41	36	47	58	41	53	49	38	41	52	64	35
320	34	54	40	36	63	33	49	40	54	38	52	52	45	45	49	35	42	50	49	50
321	31	55	40	35	51	43	40	42	51	39	56	49	49	36	51	38	42	43	59	48
322	42	53	47	35	51	39	41	40	54	52	48	53	57	40	49	46	48	39	57	46

cont......

Day	Year																			
	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
323	50	38	47	46	56	42	52	48	52	60	47	45	52	38	50	51	57	44	64	44
324	47	33	33	54	44	46	46	53	51	49	43	44	57	34	47	50	50	38	66	40
325	42	37	32	44	41	36	47	42	51	42	52	43	54	37	34	56	52	32	52	42
326	43	52	38	45	29	37	51	40	38	34	46	48	56	44	33	54	56	34	46	39
327	46	46	49	34	26	35	54	41	36	33	41	44	58	39	33	61	51	41	47	40
328	39	50	48	21	31	38	63	47	42	35	51	49	65	45	33	46	51	49	47	52
329	33	45	41	19	33	31	63	41	41	45	41	39	63	40	38	36	40	48	48	45
330	47	45	44	37	30	44	49	32	36	43	30	33	58	34	38	45	50	48	55	47
331	49	53	37	49	37	48	60	31	50	58	23	36	53	36	51	48	43	49	65	53
332	45	57	41	57	41	49	55	42	42	50	38	46	48	40	40	38	53	50	66	51
333	34	53	38	50	40	38	39	41	39	36	39	36	32	39	39	50	43	41	52	54
334	37	42	37	57	41	35	48	32	48	20	39	45	30	46	30	54	43	44	46	42
335	41	34	37	48	35	41	48	35	46	23	54	39	36	54	33	54	42	44	47	39
336	37	49	34	54	29	49	40	36	38	37	43	45	30	51	42	56	37	41	37	41
337	33	47	38	46	25	52	47	37	43	25	45	41	31	36	41	60	44	47	30	44
338	42	41	28	51	34	55	52	33	40	33	46	58	43	37	38	64	50	37	32	41
339	42	38	34	39	37	57	60	29	48	34	45	44	45	44	35	64	53	35	40	35
340	44	36	28	33	39	54	46	35	55	27	34	42	42	53	35	57	45	26	38	35
341	50	31	32	26	52	36	38	27	45	43	20	41	44	60	42	45	35	23	36	38
342	53	28	38	32	56	33	35	42	35	31	25	58	39	59	44	41	36	40	44	43
343	43	24	38	43	51	55	39	30	39	28	31	48	34	58	28	38	37	41	47	51
344	43	25	38	53	53	59	38	31	35	34	27	26	48	48	25	30	47	42	46	51
345	38	21	47	47	55	43	26	40	45	45	24	25	49	35	30	40	44	50	49	40
346	49	29	38	53	51	37	33	42	42	51	26	34	53	40	29	26	48	45	57	39
347	48	43	35	43	50	51	38	39	43	35	44	41	54	49	29	22	50	57	44	27
348	53	37	43	41	44	45	38	40	44	30	52	32	37	42	29	26	44	54	29	28
349	43	22	35	41	57	42	32	32	56	34	46	41	31	34	34	31	44	62	31	44
350	38	25	27	35	66	28	31	43	44	45	40	39	43	39	32	45	40	52	35	40
351	44	34	30	42	45	22	24	33	36	44	41	42	32	33	32	35	37	60	41	44
352	44	34	30	45	27	35	23	30	25	44	43	42	31	40	29	28	33	61	31	42
353	60	43	37	49	32	48	26	38	21	47	45	41	38	39	22	27	31	59	24	44
354	53	44	30	50	47	52	31	34	31	41	36	41	30	21	19	34	26	54	23	39
355	51	36	25	44	52	43	31	43	35	22	35	43	36	20	18	32	27	48	21	29
356	48	34	35	47	37	51	24	41	29	21	32	35	37	20	11	33	40	51	24	30
357	28	37	30	53	28	45	38	45	29	35	31	39	49	38	47	41	33	41	43	30
358	33	25	32	42	46	45	37	54	26	26	42	35	51	39	39	43	17	37	44	38
359	41	24	25	31	47	50	34	48	30	24	36	42	46	16	31	59	4	41	22	44
360	37	24	29	23	55	44	52	33	39	34	21	45	40	15	32	62	14	36	15	42
361	30	35	29	30	60	40	54	44	39	31	23	31	39	25	37	52	30	54	34	37
362	34	51	33	28	57	45	40	45	35	46	21	28	41	32	37	57	35	63	35	40
363	30	35	36	24	48	36	41	48	42	27	29	27	45	41	34	48	28	65	35	34
364	23	30	37	25	55	42	41	52	39	28	30	34	47	39	27	34	18	55	34	36
365	24	36	40	28	43	52	37	39	42	28	41	37	38	33	26	36	22	45	29	37

Appendix B. Computer Program

```
C*********************************************************************
C                                                                    *
C             TURSIM  -  TURKEY SIMULATION MODEL                     *
C                           DEVELOPED BY                             *
C                        RAJBIR SINGH PARMAR                         *
C                                AT                                  *
C              AGRICULTURAL ENGINEERING DEPARTMENT                   *
C              VIRGINIA POLYTECHNIC INSTITUTE AND                    *
C                         STATE UNIVERSITY                           *
C                                                                    *
C                             MAY 1989                               *
C                                                                    *
C    THIS PROGRAM SIMULATES WEIGHT GAIN AND ENERGY CONSUMPTION OF    *
C    WHITE TURKEYS ( B.U.T. AND NICHOLS STRAINS)                     *
C    PROGRAM WORKS FOR TURKEYS 6 WEEKS OR OLDER                      *
C                                                                    *
C    USER NEEDS TO PROVIDE INFORMATION IN THE BLOCKS ENCLOSED        *
C    BY ?????? SIGNS IN THIS PROGRAM                                 *
C*********************************************************************
      REAL INTWT,ECONNA(24),ECONAC(24),WT70(24),WTNOW(24)
      REAL WT35(24),WT50(24),WT65(24),WT80(24),WT95(24),WT110(24)
      REAL WTINC(24),INC(168),INCEN(168),TFD(168,1000)
      REAL M35,M50,M65,M80,M95,M110
      REAL CV35,CV50,CV65,CV80,CV95,CV110
      REAL GIS35,GIS50,GIS65,GIS80,GIS95,GIS110,GTIS
      REAL ATISH,SDTISH,SD,VNORM,TWTYR
      REAL TWT(168,1000),SWT(1000),T(533),TMN(533)
      REAL HMEANP,TMPHRP,HMEAN(24),TMPHR,TMAX,WO,TDP,SPVOL(24)
      REAL AREA,VOL,R,VENT,QS,QSUPP,HP,C1,C2,INTEMP,AVGWT(168,1000)
      INTEGER AGEDAY,BDATE,SEX,NUM,FDTYPE,EWK,IWK,WK
      INTEGER EDATE,IEND,LIFE,AGEWK,IDAYS,ISEED,DATE,DAYS
      REAL MORT(24),MORTD(168),TEC(168,1000)
      REAL WOP,WIP,WI,RH,SUMRH,INRH,QL,PW,PWS
      REAL TAV(12),TMINAV(12)
C***  MORT(I) = PERCENT WEEKLY MORTALITY TILL THE END OF WEEK I
C***  = (TOTAL NO. OF BIRDS DIED TILL THE END OF WEEK I)/( TOTAL
C***  NO. OF BIRDS STARTED WITH DURING WEEK 1)
C***  MORTALITY DATA USED IN THIS PROGRAM WAS OBSERVED AT A FARM
C***  NEAR HARRISONBURG, VIRGINIA
      DATA MORT/.844,1.687,2.531,3.375,4.219,5.063,5.907,6.372,
     *6.682,7.128,7.650,8.232,8.658,9.142,9.723,10.40,11.07,11.74,
     *12.41,13.08,13.75,14.42,15.09,15.76/
      CP=0.24
      IN=30
C*********************************************************************
C                                                                    *
C                         INPUT FILE 1                               *
C       GENERAL INFORMATION ABOUT BIRD, FEED, AND BUILDING           *
C  ??????????????????????????????????????????????????????????????????
C  ? AGEDAY - STARTING AGE OF BIRDS (DAYS),     MINIMUM 42 DAYS ?   *
```

```
C  ? BDATE  - JULIAN DATE ON WHICH BIRDS ARE AGEDAY OLD           ?   *
C  ?          (E.G. FOR MARCH 3  BDATE = 62)                      ?   *
C  ? SEX    - SEX OF BIRDS                                        ?   *
C  ?          = 1 FOR MALES                                       ?   *
C  ?          = 2 FOR FEMALES                                     ?   *
C  ? NUM    - TOTAL NUMBER OF BIRDS STARTED WITH FROM NURSERY    ?   *
C  ? INTWT  - AVERAGE WEIGHT OF BIRDS WHEN AGEDAY OLD (KG)       ?   *
C  ? FDTYPE - TYPE OF FEED INTENDED TO BE FED                    ?   *
C  ?          = 1 FOR HIGH ENERGY FEED                           ?   *
C  ?          = 2 FOR HIGH PROTEIN LOW ENERGY FEED               ?   *
C  ? AREA   - AREA OF INNER SURFACES OF THE HOUSE INVOLVED IN    ?   *
C  ?          HEAT TRANSFER (SQUARE METERS)                      ?   *
C  ?          = AREA OF ALL WALLS + AREA OF CEILING              ?   *
C  ? VOL    - VOLUME OF HOUSE (CUBIC METERS)                     ?   *
C  ? R      - OVERALL R-VALUE OF THE BUILDING (BRITISH UNITS)    ?   *
C  ? VENT   - VENTILATION RATE (CUBIC METERS PER HOUR)           ?   *
C  ????????????????????????????????????????????????????????????
C                                                                     *
C*********************************************************************
      READ(1,1001) AGEDAY,BDATE,SEX,NUM,INTWT,FDTYPE,AREA,VOL,R,VENT
 1001 FORMAT(I3,1X,I3,1X,I1,1X,I4,1X,F5.2,1X,I1,1X,F7.1,1X,F7.1,1X,
     *F4.1,1X,F7.1)
C**** SIMULATION IS PERFORMED UPTO 24 WEEKS FOR MALE AND 22 WEEKS
C**** FOR FEMALE BIRDS
C**** EWK = LAST WEEK OF SIMULATION
      IF(SEX .EQ. 1) EWK=24
      IF(SEX .EQ. 2) EWK=22
C*********************************************************************
C                                                                     *
C                            INPUT FILE 2                             *
C                    FEED ENERGY CONCENTRATION DATA                   *
C  ????????????????????????????????????????????????????????????      *
C  ? WK           - AGE OF BIRDS IN WEEK                        ?    *
C  ? ECONNA(IWK)  - NATIONAL AVERAGE OF FEED ENERGY             ?    *
C  ?                CONCENTRATION DURING WEEK WK (KCAL/lb OF    ?    *
C  ?                OF FEED FOR LAST YEAR                       ?    *
C  ?                CAN BE OBTAINED FROM THE MAGAZINE 'TURKEY   ?    *
C  ?                WORLD' JANUARY ISSUE OF CURRENT YEAR        ?    *
C  ? ECONAC(IWK)  - ENERGY CONCENTRATION OF THE FEED BEING      ?    *
C  ?                INTENDED TO BE FED DURING WEEK WK OF        ?    *
C  ?                OF BIRD'S LIFE (KCAL/lb OF FEED)            ?    *
C  ????????????????????????????????????????????????????????????      *
C                                                                     *
C*********************************************************************
      DO 101 IWK=6,EWK
         READ(2,2001) WK,ECONNA(IWK),ECONAC(IWK)
 2001    FORMAT(I2,1X,F6.1,1X,F6.1)
C*********************************************************************
C                                                                     *
C                             INPUT FILE 3                            *
```

```
C                 WEIGHT INFORMATION FOR MALE BIRDS                    *
C     (THIS FILE NOT NEEDED IF SIMULATING ONLY FEMALE TURKEYS)        *
C                                                                      *
C    WK           - AGE OF BIRDS IN WEEKS                              *
C    WT70(IWK)    - NATIONAL AVERAGE OF WEIGHT OF MALE BIRDS WHEN      *
C                   WK WEEKS OLD DURING 1970, kg                       *
C                   OBTAINED FROM THE MAGAZINE 'TURKEY WORLD'          *
C  ??????????????????????????????????????????????????????????????     *
C  ? WTNOW(WK)    - NATIONAL AVERAGE OF WEIGHT OF MALE BIRDS WHEN?     *
C  ?                WK WEEKS OLD DURING LAST YEAR, kg            ?     *
C  ?                CAN BE OBTAINED FROM THE MAGAZINE 'TURKEY    ?     *
C  ?                WORLD' JANUARY ISSUE OF THIS YEAR            ?     *
C  ??????????????????????????????????????????????????????????????     *
C    WT50(IWK)    - WEIGHT GAIN FOR MALE BIRDS WHEN WK WEEKS OLD       *
C                   WHEN HOUSE TEMPERATURE IS 50 DEGREE F (KG)         *
C    WT65(IWK)    - WEIGHT GAIN FOR MALE BIRDS WHEN WK WEEKS OLD       *
C                   WHEN HOUSE TEMPERATURE IS 65 DEGREE F (KG)         *
C    WT80(IWK)    - WEIGHT GAIN FOR MALE BIRDS WHEN WK WEEKS OLD       *
C                   WHEN HOUSE TEMPERATURE IS 80 DEGREE F (KG)         *
C    WT95(IWK)    - WEIGHT GAIN FOR MALE BIRDS WHEN WK WEEKS OLD       *
C                   WHEN HOUSE TEMPERATURE IS 95 DEGREE F (KG)         *
C    NOTE:                                                             *
C         THE VALUES OF WT50(IWK),WT65(IWK),WT80(IWK),WT95(IWK)        *
C         WERE CALCULATED FROM THE EXPERIMENT CONDUCTED BY DR.         *
C         LEIGHTON AND MR. ALBUQUERQUE AT VIRGINIA TECH, 1969-70       *
C         PARTIAL INFORMATION ABOUT THIS DATA IS AVAILABLE IN          *
C         REFERENCE 1, SEE LIST OF REFERENCES AT THE END OF            *
C         THIS PROGRAM                                                 *
C         REST OF THE DATA WAS UNPUBLISHED AND WAS BORROWED FROM       *
C         DR. LEIGHTON AT VIRGINIA TECH POULTRY SCIENCE DEPT.          *
C                                                                      *
C***********************************************************************
      IF(SEX .EQ. 2) GO TO 9001
      READ(3,3001) WK,WT70(IWK),WTNOW(IWK),WT50(IWK),WT65(IWK),
     *WT80(IWK),WT95(IWK)
      GO TO 9002
C***********************************************************************
C                                                                      *
C                           INPUT FILE 4                               *
C                 WEIGHT INFORMATION FOR FEMALE BIRDS                  *
C      (THIS FILE NOT NEEDED IF SIMULATING ONLY MALE TURKEYS)         *
C                                                                      *
C    WK           - AGE OF BIRDS IN WEEKS                              *
C    WT70(IWK)    - NATIONAL AVERAGE OF WEIGHT OF FEMALE BIRDS         *
C                   WHEN WK WEEKS OLD DURING 1970, kg                  *
C                   OBTAINED FROM THE MAGAZINE 'TURKEY WORLD'          *
C  ??????????????????????????????????????????????????????????????     *
C  ? WTNOW(WK)    - NATIONAL AVERAGE OF WEIGHT OF FEMALE BIRDS WHEN?*
C  ?                WK WEEKS OLD DURING LAST YEAR, kg                ?*
C  ?                CAN BE OBTAINED FROM THE MAGAZINE 'TURKEY        ?*
```

```
C  ?                WORLD' JANUARY ISSUE OF THIS YEAR                ?*
C  ??????????????????????????????????????????????????????????????????*
C    WT50(IWK)    - WEIGHT GAIN FOR FEMALE BIRDS WHEN WK WEEKS OLD  *
C                   WHEN HOUSE TEMPERATURE IS 50 DEGREE F (KG)      *
C    WT65(IWK)    - WEIGHT GAIN FOR FEMALE BIRDS WHEN WK WEEKS OLD  *
C                   WHEN HOUSE TEMPERATURE IS 65 DEGREE F (KG)      *
C    WT80(IWK)    - WEIGHT GAIN FOR FEMALE BIRDS WHEN WK WEEKS OLD  *
C                   WHEN HOUSE TEMPERATURE IS 80 DEGREE F (KG)      *
C    WT95(IWK)    - WEIGHT GAIN FOR FEMALE BIRDS WHEN WK WEEKS OLD  *
C                   WHEN HOUSE TEMPERATURE IS 95 DEGREE F (KG)      *
C    NOTE:                                                          *
C         THE VALUES OF WT50(IWK),WT65(IWK),WT80(IWK),WT95(IWK)     *
C         WERE CALCULATED FROM THE EXPERIMENT CONDUCTED BY DR.      *
C         LEIGHTON AND MR. ALBUQUERQUE AT VIRGINIA TECH, 1969-70    *
C         PARTIAL INFORMATION ABOUT THIS DATA IS AVAILABLE IN       *
C         REFERENCE 1, SEE LIST OF REFERENCES AT THE END OF         *
C         THIS PROGRAM                                              *
C         REST OF THE DATA WAS UNPUBLISHED AND WAS BORROWED FROM    *
C         DR. LEIGHTON AT VIRGINIA TECH ANIMAL SCIENCE DEPT.        *
C                                                                   *
C********************************************************************
 9001    READ(4,3001) WK,WT70(IWK),WTNOW(IWK),WT50(IWK),WT65(IWK),
     *WT80(IWK),WT95(IWK)
 3001    FORMAT(I2,6(1X,F6.3))
 9002    WT35(IWK)=WT50(IWK)-(WT65(IWK)-WT50(IWK))
         WT110(IWK)=WT95(IWK) + (WT95(IWK)-WT80(IWK))
         WTINC(IWK)=(WTNOW(IWK)-WT70(IWK))/WT70(IWK)
  101 CONTINUE
      IF(SEX .EQ. 2) GO TO 9003
C********************************************************************
C                           INPUT FILE 3                            *
C        COEFFICIENTS OF VARIATION OF WEIGHT GAIN FOR MALE TURKEYS *
C   (THIS FILE NOT NEEDED IF SIMULATING ONLY FEMALE TURKEYS)        *
C                                                                   *
C       CV50    - COEFFICIENT OF VARIATION OF WEIGHT GAIN           *
C                 FOR MALE TURKEYS WHEN HOUSE TEMPERATURE IS        *
C                 50 DEGREE F                                       *
C       CV65    - COEFFICIENT OF VARIATION OF WEIGHT GAIN           *
C                 FOR MALE TURKEYS WHEN HOUSE TEMPEARTURE IS        *
C                 65 DEGREE F                                       *
C       CV80    - COEFFICIENT OF VARIATION OF WEIGHT GAIN           *
C                 FOR MALE TURKEYS WHEN HOUSE TEMPEARTURE IS        *
C                 80 DEGREE F                                       *
C       CV95    - COEFFICIENT OF VARIATION OF WEIGHT GAIN           *
C                 FOR MALE TURKEYS WHEN HOUSE TEMPERATURE IS        *
C                 95 DEGREE F                                       *
C     NOTE:                                                         *
C          COEFFICIENTS OF VARIATION OF WEIGHT GAIN WERE NOT        *
C          AVAILABLE IN LITERATURE.  IT WAS ASSUMED THAT C.V        *
C          HEAT PRODUCTION IS SAME AS C.V. OF WEIGHT GAIN           *
```

```
C          C.V. OF HEAT PRODUCTION WERE CALCULATED USING              *
C          DATA REPORTED BY MALHOTRA (1967)                           *
C          SEE REFERENCE 2 LISTED AT THE END OF THIS PROGRAM          *
C                                                                     *
C**********************************************************************
      READ(3,3002) CV50,CV65,CV80,CV95
 3002 FORMAT(4F7.3)
      GO TO 9004
C**********************************************************************
C                                INPUT FILE 4                         *
C      COEFFICIENTS OF VARIATION OF WEIGHT GAIN FOR FEMALE TURKEYS *
C   (THIS FILE NOT NEEDED IF SIMULATING ONLY MALE TURKEYS)           *
C                                                                     *
C       CV50    - COEFFICIENT OF VARIATION OF WEIGHT GAIN            *
C                 FOR FEMALE TURKEYS WHEN HOUSE TEMPERATURE IS       *
C                 50 DEGREE F                                         *
C       CV65    - COEFFICIENT OF VARIATION OF WEIGHT GAIN            *
C                 FOR FEMALE TURKEYS WHEN HOUSE TEMPERATURE IS       *
C                 65 DEGREE F                                         *
C       CV80    - COEFFICIENT OF VARIATION OF WEIGHT GAIN            *
C                 FOR FEMALE TURKEYS WHEN HOUSE TEMPERATURE IS       *
C                 80 DEGREE F                                         *
C       CV95    - COEFFICIENT OF VARIATION OF WEIGHT GAIN            *
C                 FOR FEMALE TURKEYS WHEN HOUSE TEMPERATURE IS       *
C                 95 DEGREE F                                         *
C     NOTE:                                                           *
C          COEFFICIENTS OF VARIATION OF WEIGHT GAIN WERE NOT         *
C          AVAILABLE IN LITERATURE.  IT WAS ASSUMED THAT C.V         *
C          HEAT PRODUCTION IS SAME AS C.V. OF WEIGHT GAIN            *
C          C.V. OF HEAT PRODUCTION WERE CALCULATED USING             *
C          DATA REPORTED BY MALHOTRA (1967)                          *
C          SEE REFERENCE 2 LISTED AT THE END OF THIS PROGRAM         *
C                                                                     *
C**********************************************************************
 9003 READ(4,3002) CV50,CV65,CV80,CV95
 9004 CV35=CV50
      CV110=CV95
      IF(SEX .EQ. 2) GO TO 9005
      IF(FDTYPE .EQ. 2) GO TO 8001
C****  SET MAINTENANCE ENERGY REQUIREMENT COEFFICIENTS FOR MALE
C****  BIRDS FED HIGH ENERGY DIET
C****  M35 = MAINTENANCE ENERGY COEFFICIENT AT 35 DEGREE F
C****  M95 = MAINTENANCE ENERGY REQUIREMENT COEFFICIENT AT 80 F
C****  AND SO ON
C****  MODEL DEVELOPED BY HURWITZ ET AL. (1980) WAS USED TO
C****  CALCULATE ENERGY REQUIREMENTS OF BIRDS.  ENERGY REQUIREMENT
C****  WAS BROKEN INTO MAINTENANCE AND WEIGHT GAIN REQUIREMENTS
C****  SEE REFERENCE 3 AT THE END OF THIS PROGRAM
      M35=2.730
      M50=2.652
```

```
      M65=2.47
      M80=2.180
      M95=2.543
      M110=2.905
      GO TO 9006
C****  SET MAINTENANCE ENERGY REQUIREMENT COEFFICIENTS FOR MALE
C****  BIRDS FED HIGH PROTEIN DIET
 8001 M35=2.478
      M50=2.604
      M65=2.730
      M80=2.431
      M95=2.603
      M110=2.775
      GO TO 9006
C****  SET MAINTENANCE ENERGY REQUIREMENT COEFFICIENTS FOR FEMALE
C****  BIRDS FED HIGH ENERGY DIET
C****  M35 = MAINTENANCE ENERGY COEFFICIENT AT 35 DEGREE F
C****  M95 = MAINTENANCE ENRGY REQUIREMENT COEFFICIENT AT 80 F
C****  AND SO ON
C****  MODEL DEVELOPED BY HURWITZ ET AL. (1980) WAS USED TO
C****  CALCULATE ENERGY REQUIREMENTS OF BIRDS.  ENERGY REQUIREMENT
C****  WAS BROKEN INTO MAINTENANCE AND WEIGHT GAIN REQUIREMENTS
C****  SEE REFERENCE 3 AT THE END OF THIS PROGRAM
 9005 IF(FDTYPE .EQ. 2) GO TO 8003
      M35=2.784
      M50=2.602
      M65=2.420
      M80=2.247
      M95=2.700
      M110=3.153
      GO TO 9006
C****  SET MAINTENANCE ENERGY REQUIREMENT COEFFICIENTS FOR FEMALE
C****  BIRDS FED HIGH PROTEIN DIET
 8003 M35=2.298
      M50=2.424
      M65=2.550
      M80=2.164
      M95=2.522
      M110=2.910
 9006 IWK=AGEDAY/7
C****    EDATE = JULIAN DATE ON WHICH SIMULATION ENDS, CAN BE >365
      IF(SEX .EQ. 1) EDATE=BDATE+(168-AGEDAY)
      IF(SEX .EQ. 2) EDATE=BDATE+(154-AGEDAY)
C
C   ASSIGN INITIAL WEIGHT TO EACH BIRD
C
C**** A COEFFICIENT OF VARIATION OF 0.2846 FOR BODY WEIGHTS OF MALE
C**** BIRDS WAS OBSERVED AT A VIRGINIA FARM
      DO 102 I=1,IN
        SD=INTWT*0.2846
```

```
          CALL SNORM(INTWT,SD,VNORM)
          TWT(1,I)=VNORM
  102 CONTINUE
      IF(SEX .EQ. 1) IEND=168
      IF(SEX .EQ. 2) IEND=154
      IF(SEX .EQ. 1) LIFE=168-AGEDAY
      IF(SEX .EQ. 2) LIFE=154-AGEDAY
      DO 103 I=AGEDAY+1,IEND
         AGEWK=I/7
         IDAYS=MOD(I,7)
      GIS35=((WT35(AGEWK+1)-WT35(AGEWK))/7.0*IDAYS+WT35(AGEWK))/7.0
      GIS50=((WT50(AGEWK+1)-WT50(AGEWK))/7.0*IDAYS+WT50(AGEWK))/7.0
      GIS65=((WT65(AGEWK+1)-WT65(AGEWK))/7.0*IDAYS+WT65(AGEWK))/7.0
      GIS80=((WT80(AGEWK+1)-WT80(AGEWK))/7.0*IDAYS+WT80(AGEWK))/7.0
      GIS95=((WT95(AGEWK+1)-WT95(AGEWK))/7.0*IDAYS+WT95(AGEWK))/7.0
      GIS110=((WT110(AGEWK+1)-WT110(AGEWK))/7.0*IDAYS+WT110(AGEWK))/7.0
      INC(I)=(WTINC(AGEWK+1)-WTINC(AGEWK))/7.0*IDAYS+WTINC(AGEWK)
      INCEN(I)=(ECONAC(AGEWK)-ECONNA(AGEWK))/ECONNA(AGEWK)
  103 CONTINUE
C*********************************************************************
C                                                                    *
C                          INPUT FILE 5                              *
C                  MONTHLY NORMAL TEMPERATURE DATA                   *
C  ?????????????????????????????????????????????????????????????????*
C  ? MONTH     - NUMBER OF MONTH (E.G. JAN =1  FEB=2 AND  SO ON    ?*
C  ? TAV(I)    - NORMAL TEMPERATURE FOR MONTH I (DEGREE C)         ?*
C  ? TMINAV(I) - NORMAL MINIMUM TEMPERATURE FOR MONTH I (DEGREE C)?*
C??????????????????????????????????????????????????????????????????*
C                                                                    *
C     NOTE:                                                          *
C          VALUES OF TAV(I) AND TMINAV(I) FOR MOST PLACES IN THE    *
C          UNITED STATES ARE AVAILABLE IN 'CLIMATE NORMALS FOR       *
C          THE U.S.' COMPILED BY NATIONAL CLIMATIC CENTER OF         *
C          ENVIRONMENTAL DATA INFORMATION SERVICE.                   *
C                                                                    *
C*********************************************************************
      DO 501 I=1,12
      READ(5,5001) MONTH,TAV(I),TMINAV(I)
 5001 FORMAT(I2,1X,F5.2,1X,F5.2)
  501 CONTINUE
      DO 104 I=1,25
         ISEED=76521*I
C
C     CALL SUBROUTINE THAT CALCULATES OUTSIDE DAILY MEAN
C     AND DAILY MINIMUM TEMPERATURES
C
         CALL OUTENV(BDATE,EDATE,TAV,TMINAV,T,TMN,ISEED)
C**** INITIALIZE TEMPEARTURE AND SPECIFIC HUMIDITY VALUES
      HMEANP=TMN(1)
      TMPHRP=HMEANP
```

```
      TMPMIN=HMEANP
      WIP=.0025
      WOP=.0020
      N=1
      DATE=BDATE
      TWTYR=0.0
      AVGWT(I,1)=INTWT
      DO 105 ID=1,LIFE
C**** CALCULATE MORTALITY RATE FOR EACH DAY
         AGEWK=(AGEDAY+ID)/7
         DAYS=MOD((AGEDAY+ID),7)
         MORTD(ID)=(MORT(AGEWK+1)-MORT(AGEWK))/7.0*DAYS+MORT(AGEWK)
        N=N+1
        DATE=DATE+1
C****  CALCULATE DAILY MAXIMUM TEMPERATURE
        TMAX=T(N)*2.0-TMN(N)
C**** DETERMINE THE MONTH OF THE YEAR
        IF(DATE .LE. 365) DATE=DATE
      IF(DATE .GT. 365) DATE=DATE-365
      IF(DATE .LE. 31) IMON=1
      IF(DATE .GT. 31 .AND. DATE .LE. 59) IMON=2
      IF(DATE .GT. 59 .AND. DATE .LE. 90) IMON=3
      IF(DATE .GT. 90 .AND. DATE .LE. 120) IMON=4
      IF(DATE .GT. 120 .AND. DATE .LE. 151) IMON=5
      IF(DATE .GT. 151 .AND. DATE .LE. 181) IMON=6
      IF(DATE .GT. 181 .AND. DATE .LE. 212) IMON=7
      IF(DATE .GT. 212 .AND. DATE .LE. 243) IMON=8
      IF(DATE .GT. 243 .AND. DATE .LE. 273) IMON=9
      IF(DATE .GT. 273 .AND. DATE .LE. 304) IMON=10
      IF(DATE .GT. 304 .AND. DATE .LE. 334) IMON=11
      IF(DATE .GT. 334 .AND. DATE .LE. 365) IMON=12
C**** DETERMINE THE DAILY DEW POINT TEMPERATURE USING THE ASSUMPTION
C**** THAT DEW-POINT TEMPERATURE IS SAME AS DAILY MINIMUM TEMP. FOR
C**** MONTHS OF MAY THROUGH OCTOBER AND DEW-POINT TEMP. IS 2.0 C
C**** LESS THAN THE MINIMUM TEMP. FOR THE MONTHS OF NOVEMBER
C**** THROUGH APRIL.
      IF(IMON .GT. 4 .AND. IMON .LE. 10) TDP=OMIN
      IF(IMON .LE. 4 .OR. IMON .GT. 10) TDP=OMIN-2.0
C**** CALCULATE THE OUTSIDE SPECIFIC HUMIDITY USING THE EQUATION
C**** REPORTED BY REECE AND LOTT (1982)
C**** SEE REFERENCE 4 AT THE END OF THIS PROGRAM
      WO=(2.027*EXP(1+0.038*TDP)+0.005833*(TDP**2)+0.04733*
     *TDP)/7000.0
      SUM=0.0
      DO 106 IHR=1,24
C****  CALCULATE HOURLY TEMPERATURE FROM DAILY MAX AND MIN TEMP
C****  USING THE EQUATION REPORTED BY KOON ET AL. (1987)
C****  SEE REFERENCE 5 AT THE END OF THIS PROGRAM
         TMPHR=T(N)+(TMAX-TMN(N))/2.0*(SIN(0.26179*(IHR+13.0))+
```

```
     *SIN(0.26179*(IHR+13.0)*2.0)/3.0)
C**** CALCULATE SPECIFIC VOLUME OF INCOMING VENTILATION AIR
      SPVOL(IHR)=0.28705/101.325*(TMPHR+273.16)*(1.0+1.6078*WO)
      C1=VOL/SPVOL(IHR)*CP
      C2=1.0/R*4.882*AREA+VENT/SPVOL(IHR)*CP
C**** CALCULATE SENSIBLE HEAT PRODUCED BY BIRDS, KCAL/HR/BIRD
C**** EQUATION DEVELOPED BY MALHOTRA (1967) WAS USED TO CALCULATE
C**** SENSIBLE HEAT PRODUCTION OF BIRDS.
C**** SEE REFERENCE 2 AT THE END OF THIS PROGRAM
      QS1=0.328*HMEANP+1.414*AVGWT(I,ID)+3.033*ISEX-
     *0.021*HMEANP**2-2.786
C**** CALCULATE TOTAL SENSIBLE HEAT PRODUCED IN THE HOUSE, KCAL/HR
C**** BY MULTIPLYING BY NUMBER OF BIRDS PRESENT IN THE HOUSE
      QS=QS1*NUM*(1.0-MORTD(ID)/100.0)
      IF(QS .LT. 0.0) QS=0.0
C**** CALCULATE AMOUNT OF SUPPLEMENTARY HEAT PROVIDED IN THE HOUSE
C**** FOR THIS MODEL IT WAS ASSUMED THAT THE VENTILATION AIR IS
C**** HEATED TO 50 DEGREE F IF THE OUTSIDE TEMP DROPS BELOW 50 F
      QSUPP=(10.0-TMPHR)*VENT/SPVOL(IHR)*CP
      IF(QSUPP .LT. 0.0) QSUPP=0.0
C**** CALCULATE RATE OF HEAT GENERATION INSIDE THE HOUSE
      HP=QS+QSUPP
C**** CALCULATE INSIDE TEMPERATURE
      HMEAN(IHR)=(HMEANP+HP/C1-(C2/(2*C1))*(HMEANP-TMPHRP-TMPHR))/
     *(1.0+C2/(2*C1))
      SUM=SUM+HMEAN(IHR)
      HMEANP=HMEAN(IHR)
      TMPHRP=TMPHR
      TMPMIN=MIN(HMEAN(IHR),TMPMIN)
  106 CONTINUE
C**** CALCULATE DAILY INSIDE TEMPERATURE
      INTEMP=(SUM/24.0)*9.0/5.0+32.0
C**** INSIDE RELATIVE HUMIDITY CALCULATIONS
      SUMRH=0.0
      TDPI=TMPMIN
      DO 504 IHR=1,24
C**** CALCULATE LATENT HEAT PRODUCED BY THE BIRDS, KCAL/HR/BIRD
C**** EQUATION DEVELOPED BY MALHOTRA (1967) WAS USED TO CALCULATE
C**** LATENT HEAT PRODUCTION.
C**** SEE REFERENCE 2 AT THE END OF THIS PROGRAM
      QL1=3.084+0.286*HMEAN(IHR)+0.329*AVGWT(I,ID)-1.162*SEX
C**** CALCULATE RATE OF LATENT HEAT PRODUCTION INSIDE THE HOUSE
C**** KCAL/HR
      QL=QL1*NUM*(1.0-MORTD(ID)/100.0)
      CL1=VOL/SPVOL(IHR)
      CL2=VENT/(2*SPVOL(IHR))
C**** CALCULATE INSIDE SPECIFIC HUMIDITY
      WI=WIP*(CL1-CL2)/(CL1+CL2)+CL2*2.0*((WO+WOP)/(2.0*(CL1+CL2)))+
     *QL/(540.0*(CL1+CL2))
C**** CALCULATE PARTIAL PRESSURE OF WATER VAPORS INSIDE THE HOUSE
```

```
C**** USING THE EQUATION DEVELOPED BY WILHELM (1976)
C**** SEE REFERENCE 6 AT THE END OF THIS PROGRAM
C     PW=101.325*WI/(0.62198+WI)
      IF(TDPI .LT. 0.0 ) PW=EXP(24.2779-6238.64/(TDPI+273.16)-
     *0.344438*ALOG(TDPI+273.16))
      IF(TDPI .GT. 0.0) PW=EXP(-7511.52/(TDPI+273.16)+89.63121+
     *0.023998970*(TDPI+273.16)-1.165455*(10.0**(-5))*(TDPI+
     *273.16)**2-1.2810336*(10.0**(-8))*(TDPI+273.16)**3+2.0998405*
     *(10.0**(-11))*(TDPI+273.16)**4-12.150799*ALOG(TDPI+273.16))
C**** CALCULATED PARTIAL PRESSURE OF WATER VAPORS IN SATURATED
C**** AIR INSIDE THE HOUSE USING THE EQUATIONS REPORTED BY
C**** WILHELM (1976)
C**** SEE REFERENCE 6 AT THE END OF THIS PROGRAM
      IF(HMEAN(IHR) .LT. 0.0 ) PWS=EXP(24.2779-6238.64/
     *(HMEAN(IHR)+273.16)-
     *0.344438*ALOG(HMEAN(IHR)+273.16))
      IF(HMEAN(IHR) .GT. 0.0) PWS=EXP(-7511.52/(HMEAN(IHR)+273.16)+
     *89.63121+
     *0.023998970*(HMEAN(IHR)+273.16)-1.165455*(10.0**(-5))*
     *(HMEAN(IHR)+
     *273.16)**2-1.2810336*(10.0**(-8))*
     *(HMEAN(IHR)+273.16)**3+2.0998405*
     *(10.0**(-11))*(HMEAN(IHR)+
     *273.16)**4-12.150799*ALOG(HMEAN(IHR)+273.16))
C**** CALCULATE INSIDE RELATIVE HUMIDITY
      RH=PW/PWS
      SUMRH=SUMRH+RH
      WOP=WO
      WIP=WI
  504 CONTINUE
C**** CALCULATE DAILY INSIDE RELATIVE HUMIDITY (FRACTION) VALUES
      INRH=(SUMRH/24.0)
C
C
C**** CALCULATE LOSS IN WEIGHT GAIN DUE TO HUMIDITY AT VARIOUS
C**** DRY-BULB TEMPERATURE VALUES.
      IF(INRH .LT. 0.5) GO TO 8004
      IF(INRH .GT. 0.9) INRH=0.9
      DH80=(0.01-0.0)/50.0*(INRH*100.0-40.0)+0.0
      DH95=(0.18-0.0)/50.0*(INRH*100.0-50.0)+0.0
      DH110=(0.36-0.18)/50.0*(INRH*100.0-50.0)+0.18
 8004  IF(INTEMP .LT. 35.0) IDRP35=IDRP+1
       IF(INTEMP .LT. 35.0) INTEMP=35.0
      IF(INTEMP .LT. 35.0) GO TO 7001
      IF(INTEMP .GE. 35.0 .AND. INTEMP .LT. 50.0) GO TO 7002
      IF(INTEMP .GE. 50.0 .AND. INTEMP .LT. 65.0) GO TO 7003
      IF(INTEMP .GE. 65.0 .AND. INTEMP .LT. 80.0) GO TO 7004
      IF(INTEMP .GE. 80.0 .AND. INTEMP .LT. 95.0) GO TO 7005
      IF(INTEMP .GE. 95.0 .AND. INTEMP .LT. 110.0) GO TO 7006
      IF(INTEMP .GT. 110.0) WRITE(7,6001)
```

```
 6001 FORMAT('CAUTION  -  INSIDE TEMP. EXCEEDED 110.0 F')
      WRITE(7,6002)
 6002 FORMAT('IRRECOVERABLE DAMAGE MAY HAVE OCCURED')
      GO TO 9007
 7001 WRITE(7,6003)
 6003 FORMAT('CAUTION - INSIDE TEMP DROPPED BELOW 35.0 F')
      WRITE(7,6004)
 6004 FORMAT('IRRECOVERABLE DAMAGE MAY HAVE OCCURED')
      GO TO 9007
C**** CALCULATE AVERAGE WEIGHT GAIN VALUES AT DIFFERENT DRY-BULB
C**** TEMPEARTURES
C**** UM = COEFFICIENT OF MAINTENANCE ENERGY REQUIREMENT
C**** ATISH = AVERAGE OF WEIGHT GAIN
C**** SDTISH = STANDARD DEVIATION WEIGHT GAIN
C**** DH = PERCENT LOSS IN AVERAGE WEIGHT GAIN DUE TO HUMIDITY
 7002 GTIS=(GIS50-GIS35)/15.0*(INTEMP-35.0)+GIS35
      ATISH=GTIS
      SDTISH=((CV50-CV35)/15.0*(INTEMP-35.0)+CV35)*ATISH
      UM=(M50-M35)/15.0*(INTEMP-35.0)+M35
      GO TO 1010
 7003 GTIS=(GIS65-GIS50)/15.0*(INTEMP-50.0)+GIS50
      ATISH=GTIS
      SDTISH=((CV65-CV50)/15.0*(INTEMP-50.0)+CV50)*ATISH
      UM=(M65-M50)/15.0*(INTEMP-50.0)+M50
      GO TO 1010
 7004 GTIS=(GIS80-GIS65)/15.0*(INTEMP-65.0)+GIS65
      ATISH=GTIS
      SDTISH=((CV80-CV65)/15.0*(INTEMP-65.0)+CV65)*ATISH
      UM=(M80-M65)/15.0*(INTEMP-65.0)+M65
      GO TO 1010
 7005 GTIS=(GIS95-GIS80)/15.0*(INTEMP-80.0)+GIS80
      DH=(DH95-DH80)/15.0*(INTEMP-80.0)+DH80
      ATISH=GTIS-DH*GTIS
      SDTISH=((CV95-CV80)/15.0*(INTEMP-80.0)+CV80)*ATISH
      UM=(M95-M80)/15.0*(INTEMP-80.0)+M80
      GO TO 1010
 7006 GTIS=(GIS110-GIS95)/15.0*(INTEMP-95.0)+GIS95
      DH=(DH110-DH95)/15.0*(INTEMP-95.0)+DH95
      ATISH=GTIS-DH*GTIS
      SDTISH=((CV110-CV95)/15.0*(INTEMP-95.0)+CV95)*ATISH
      UM=(M110-M95)/15.0*(INTEMP-95.0)+M95
 1010 TWTDAY=0.0
C**** DETERMINE DAILY WEIGHT OF EACH OF REPRESENTATIVE 30 BIRDS
      DO 107 INUM=1,IN
         CALL SNORM(ATISH,SDTISH,VNORM)
         TWT(N,INUM)=TWT(N-1,INUM)+VNORM*(1+INC(ID+AGEDAY))
         SWT(INUM)=TWT(N,INUM)*(1+INCEN(ID+AGEDAY))
         TWTDAY=TWTDAY+SWT(INUM)
```

```
  107 CONTINUE
C**** CALCULATE AVERAGE DAILY WEIGHT AND ENERGY CONSUMPTION VALUES
C**** FOR EACH OF 25 RUNS OF SIMULATION
      AVGWT(I,N)=TWTDAY/IN
      TEC(I,N)=TEC(I,N-1)+UM*((AVGWT(I,N)*1000.0)**.67)+
     *(AVGWT(I,N)-AVGWT(I,N-1))*01.15*1000.0
      TFD(I,N)=(TEC(I,N)-TEC(I,N-1))/ECONAC(AGEWK)
  105 CONTINUE
  104 CONTINUE
      WRITE(6,2221)
 2221 FORMAT('AGE',1X,'    AVERAGE     ',1X,'   CUMULATIVE   ',1X,
     *' DAILY FEED')
      WRITE(6,2222)
 2222 FORMAT('DAYS',1X,' BIRD WEIGHT ',1X,'     ENERGY CONSU-',1X,
     *' CONSUMPTION')
      WRITE(6,2223)
 2223 FORMAT(4X,'  MEAN    STDEV',1X,'    MPTION/BIRD ',1X,
     *'  KG/DAY/BIRD')
      WRITE(6,2201)
 2201 FORMAT(4X,'                  ',1X,'    SINCE        ')
      WRITE(6,2224) AGEDAY
 2224 FORMAT(4X,'   KG   ',1X,'  KG  ',1X,'    AGE=',I3,1X,'DAYS')
      WRITE(6,2225)
 2225 FORMAT(19X,'    MEAN  ',1X,'  STDEV  ','MEAN ',1X,
     *' STDEV')
      WRITE(6,2226)
 2226 FORMAT(19X,'    KCAL  ',1X,'   KCAL  ')
      TWTALL=0.0
      TWT2=0.0
      TFDALL=0.0
      TFD2=0.0
      DO 108 J=2,LIFE
         AGEWK=(AGEDAY+(J-1))/7
         ICN=AGEDAY+(J-1)
         TWTALL=0.0
         TWT2=0.0
         TECALL=0.0
         TEC2=0.0
         TFDALL=0.0
         TFD2=0.0
C**** DETERMINE DAILY MEAN BIRD WEIGHT AND ENERGY CONSUMPTION
C**** VALUES.  SINCE MEAN IS COMPUTED FROM AVERAGE DAILY WEIGHT
C**** AND ENERGY CONSUMPTION VALUES (AVERAGE OF 30 REPRESENTATIVE
C**** BIRDS) MEANS OF DAILY BODY WEIGHT AND ENERGY CONSUMPTION
C**** ARE NORMALLY DISTRIBUTED.
         DO 109 I=1,25
            TWTALL=TWTALL+AVGWT(I,J)
            TWT2=TWT2+AVGWT(I,J)**2
            TECALL=TECALL+TEC(I,J)
            TEC2=TEC2+TEC(I,J)**2
```

```
          TFDALL=TFDALL+TFD(I,J)
          TFD2=TFD2+TFD(I,J)**2
 109    CONTINUE
      AVWT=TWTALL/25.0
      SDAVWT=SQRT((TWT2-(TWTALL**2)/25.0)/24.0)
      ATEC=TECALL/25.0
      SDTEC=SQRT((TEC2-(TECALL**2)/25.0)/24.0)
      AVFD=TFDALL/25.0
      TAVFD=TAVFD+AVFD
      SDFD=SQRT((TFD2-(TFDALL**2)/25.0)/24.0)
       IF(ECONAC(AGEWK) .NE. ECONAC(AGEWK-1) .AND. MOD(ICN,7) .EQ.
     *0) GO TO 7011
       WRITE(6,2227) AGEDAY+(J-1),AVWT,SDAVWT,ATEC,SDTEC,AVFD,SDFD
2227   FORMAT(I3,1X,F7.3,1X,F7.3,1X,F8.1,1X,F8.1,1X,F6.3,1X,F6.3)
       GO TO 108
7011   WRITE(6,1227) AGEDAY+(J-1),AVWT,SDAVWT,ATEC,SDTEC,AVFD,SDFD
1227   FORMAT(I3,1X,F7.3,1X,F7.3,1X,F8.1,1X,F8.1,1X,F6.3,1X,F6.3,1X,
     *'FEED MIX CHANGED')
 108  CONTINUE
       WRITE(7,6778) IDRP35
6778   FORMAT('CAUTION - INSIDE TEMP. DROPPED BELOW 35.0 F',1X,I4,
     *1X,'TIMES')
      IF(IDRP35 .GT. 50) WRITE(7,6779)
6779  FORMAT('CAUTION - RESULTS MAY BE MISLEADING BECAUSE OF
     *EXTREMELY COLD TEMPS. INSIDE THE HOUSE')
      WRITE(6,2228)
2228  FORMAT(//'AVERAGE BIRD WEIGHT ON EACH DAY OF BIRDS LIFE IS')
      WRITE(6,2229)
2229  FORMAT('NORMALLY DISTRIBUTED WITH MEAN AND STANDARD DEVIATIONS')
      WRITE(6,2230)
2230  FORMAT('SHOWN ABOVE.')
      WRITE(6,2231)
2231  FORMAT(/'SIMILARLY CUMULATIVE ENERGY CONSUMPTION PER BIRD ON ')
      WRITE(6,2232)
2232  FORMAT('EACH DAY IS NORMALLY DISTRIBUTED WITH MEAN AND ')
      WRITE(6,2233)
2233  FORMAT('STANDARD DEVIATIONS SHOWN ABOVE.')
      WRITE(6,2236)
2236  FORMAT(//'FEED CONSUMPTION PER DAY PER BIRD IS ALSO NORMALLY')
      WRITE(6,2237)
2237  FORMAT('DISTRIBUTED WITH MEANS AND STANDARD DEVIATIONS')
      WRITE(6,2238)
2238  FORMAT('SHOWN ABOVE')
      WRITE(6,2234)
2234  FORMAT(/'ENERGY CONSUMPTION VALUES SHOWN ABOVE ARE FOR BIRDS')
      WRITE(6,2235)
2235  FORMAT('REARED IN CAGES, FOR BIRDS REARED ON FLOOR, ENERGY')
      WRITE(6,2239)
2239  FORMAT('CONSUMPTION VALUES WILL BE 10 TO 20 PERCENT HIGHER.')
9007  STOP
```

```
      END
C***************************************************************
C  SUBROUTINE OUTENV CALCULATES OUTSIDE DAILY MEAN AND DAILY   *
C  MINIMUM TEMPERATURES.                                        *
C                                                               *
C  INPUT :                                                      *
C         BDATE = BEGINNING DATE (JULIAN)                       *
C                 (E.G. FOR FEB. 3  BDATE=34)                   *
C         EDATE = ENDING DATE (JULIAN)                          *
C         ISEED = SEED FOR RANDOM NUMBER GENERATOR(INTEGER)     *
C         M(I)  = ARRAY OF MEAN MONTHLY TEMPERATURES            *
C         MIN(I)= ARRAY OF MEAN MONTHLY MINIMUM TEMP.           *
C                                                               *
C  OUTPUT :                                                     *
C           T = ONE DIMENSIONAL ARRAY OF MEAN DAILY TEMP        *
C           TMN = ONE DIMENSIONAL ARRAY OF DAILY MINIMUM TEMP   *
C***************************************************************
      SUBROUTINE OUTENV(BDATE,EDATE,M,MIN,T,TMN,ISEED)
      INTEGER NR,ISEED,BDATE,EDATE,DATE
      REAL R(168),T(533),RHO,TMN(533)
      REAL M(12),SIGMA(12),DAYS(12),MIN(12)
      NR=168
      NUM=533
      DAYS(1)=31
      DAYS(2)=28
      DAYS(3)=31
      DAYS(4)=30
      DAYS(5)=31
      DAYS(6)=30
      DAYS(7)=31
      DAYS(8)=31
      DAYS(9)=30
      DAYS(10)=31
      DAYS(11)=30
      DAYS(12)=31
C***CALCULATE STANDARD DEVIATION OF TEMPERATURE IN EACH MONTH
C****
      DO 100 J=1,12
         SIGMA(J)=5.72-0.122*M(J)
  100 CONTINUE
C****
C****
      CALL TMIN(BDATE,EDATE,MIN,TMN,ISEED)
      RHO=0.65
      IF(BDATE .LE. 31) ISMON=1
      IF(BDATE .GT. 31 .AND. BDATE .LE. 59) ISMON=2
      IF(BDATE .GT. 59 .AND. BDATE .LE. 90) ISMON=3
      IF(BDATE .GT. 90 .AND. BDATE .LE. 120) ISMON=4
      IF(BDATE .GT. 120 .AND. BDATE .LE. 151) ISMON=5
```

```
      IF(BDATE .GT. 151 .AND. BDATE .LE. 181) ISMON=6
      IF(BDATE .GT. 181 .AND. BDATE .LE. 212) ISMON=7
      IF(BDATE .GT. 212 .AND. BDATE .LE. 243) ISMON=8
      IF(BDATE .GT. 243 .AND. BDATE .LE. 273) ISMON=9
      IF(BDATE .GT. 273 .AND. BDATE .LE. 304) ISMON=10
      IF(BDATE .GT. 304 .AND. BDATE .LE. 334) ISMON=11
      IF(BDATE .GT. 334 .AND. BDATE .LE. 365) ISMON=12
      T(BDATE)=M(ISMON)
      N=1
C     CALL GGNML(DSEED,NR,R)
         DO 502 IR=1,NR
            CALL SNORM(0.0,1.0,DNORM)
            R(IR)=DNORM
  502    CONTINUE
         DO 101 I=BDATE+1,EDATE
            IF(I .LE. 365) DATE=I
            IF(I .GT. 365) DATE=I-365
      IF(DATE .LE. 31) IMON=1
      IF(DATE .GT. 31 .AND. DATE .LE. 59) IMON=2
      IF(DATE .GT. 59 .AND. DATE .LE. 90) IMON=3
      IF(DATE .GT. 90 .AND. DATE .LE. 120) IMON=4
      IF(DATE .GT. 120 .AND. DATE .LE. 151) IMON=5
      IF(DATE .GT. 151 .AND. DATE .LE. 181) IMON=6
      IF(DATE .GT. 181 .AND. DATE .LE. 212) IMON=7
      IF(DATE .GT. 212 .AND. DATE .LE. 243) IMON=8
      IF(DATE .GT. 243 .AND. DATE .LE. 273) IMON=9
      IF(DATE .GT. 273 .AND. DATE .LE. 304) IMON=10
      IF(DATE .GT. 304 .AND. DATE .LE. 334) IMON=11
      IF(DATE .GT. 334 .AND. DATE .LE. 365) IMON=12
               N=N+1
        T(N)=M(IMON)+RHO*( T(N-1)-M(IMON) ) + SIGMA(IMON)*R(N)*
     *SQRT(1.0-RHO**2)
  101   CONTINUE
        RETURN
        END
C
C
C***************************************************************
C  SUBROUTINE TMIN CALCULATES OUTSIDE DAILY MINIMUM            *
C  TEMPERATURES                                                *
C                                                              *
C  INPUT :                                                     *
C         BDATE = BEGINNING DATE (JULIAN)                      *
C                 (E.G. FOR FEB. 3  BDATE=34)                  *
C         EDATE = ENDING DATE (JULIAN)                         *
C         ISEED = SEED FOR RANDOM NUMBER GENERATOR(INTEGER)    *
C         M(I)  = ARRAY OF MEAN MONTHLY TEMPERATURES           *
C                                                              *
C  OUTPUT :                                                    *
```

```
C          TMN = ONE DIMENSIONAL ARRAY OF DAILY MINIMUM TEMP *
C****************************************************************
      SUBROUTINE TMIN(BDATE,EDATE,M,TMN,ISEED)
      INTEGER NR,ISEED,BDATE,EDATE,DATE,ISMON,IMON
      REAL R(168),TMN(533),RHO
      REAL M(12),SIGMA(12),DAYS(12)
      NR=168
      DAYS(1)=31
      DAYS(2)=28
      DAYS(3)=31
      DAYS(4)=30
      DAYS(5)=31
      DAYS(6)=30
      DAYS(7)=31
      DAYS(8)=31
      DAYS(9)=30
      DAYS(10)=31
      DAYS(11)=30
      DAYS(12)=31
C***CALCULATE STANDARD DEVIATION OF TEMPERATURE IN EACH MONTH
      DO 100 J=1,12
         SIGMA(J)=5.72-0.122*M(J)
  100 CONTINUE
C****
C****
      RHO=0.65
      IF(BDATE .LE. 31) ISMON=1
      IF(BDATE .GT. 31 .AND. BDATE .LE. 59) ISMON=2
      IF(BDATE .GT. 59 .AND. BDATE .LE. 90) ISMON=3
      IF(BDATE .GT. 90 .AND. BDATE .LE. 120) ISMON=4
      IF(BDATE .GT. 120 .AND. BDATE .LE. 151) ISMON=5
      IF(BDATE .GT. 151 .AND. BDATE .LE. 181) ISMON=6
      IF(BDATE .GT. 181 .AND. BDATE .LE. 212) ISMON=7
      IF(BDATE .GT. 212 .AND. BDATE .LE. 243) ISMON=8
      IF(BDATE .GT. 243 .AND. BDATE .LE. 273) ISMON=9
      IF(BDATE .GT. 273 .AND. BDATE .LE. 304) ISMON=10
      IF(BDATE .GT. 304 .AND. BDATE .LE. 334) ISMON=11
      IF(BDATE .GT. 334 .AND. BDATE .LE. 365) ISMON=12
      TMN(BDATE)=M(ISMON)
      N=1
C     CALL GGNML(DSEED,NR,R)
         DO 503 IR=1,NR
            CALL SNORM(0.0,1.0,TNORM)
            R(IR)=TNORM
  503    CONTINUE
         DO 101 I=BDATE+1,EDATE
            IF(I .LE. 365) DATE=I
            IF(I .GT. 365) DATE=I-365
      IF(DATE .LE. 31) IMON=1
      IF(DATE .GT. 31 .AND. DATE .LE. 59) IMON=2
```

```
      IF(DATE .GT. 59 .AND. DATE .LE. 90) IMON=3
      IF(DATE .GT. 90 .AND. DATE .LE. 120) IMON=4
      IF(DATE .GT. 120 .AND. DATE .LE. 151) IMON=5
      IF(DATE .GT. 151 .AND. DATE .LE. 181) IMON=6
      IF(DATE .GT. 181 .AND. DATE .LE. 212) IMON=7
      IF(DATE .GT. 212 .AND. DATE .LE. 243) IMON=8
      IF(DATE .GT. 243 .AND. DATE .LE. 273) IMON=9
      IF(DATE .GT. 273 .AND. DATE .LE. 304) IMON=10
      IF(DATE .GT. 304 .AND. DATE .LE. 334) IMON=11
      IF(DATE .GT. 334 .AND. DATE .LE. 365) IMON=12
              N=N+1
        TMN(N)=M(IMON)+RHO*( TMN(N-1)-M(IMON) ) + SIGMA(IMON)*R(N)*
     *SQRT(1.0-RHO**2)
 101    CONTINUE
        RETURN
        END

C************************************************************
C                                                           *
C       NORMAL RANDOM VARIATE GENERATOR                     *
C                                                           *
C       XMN    = MEAN OF NORMAL DISTRIBUTION                *
C       STD    = STANDARD DEVIATION OF NORMAL DISTRIBUTION  *
C                                                           *
C                                                           *
C************************************************************
C
       SUBROUTINE SNORM(XMN,STD,RNORM)
       REAL*4 XMN,STD,ENORM,RNORM
       INTEGER*4 IEVEN
       DATA IEVEN/0/
C
       IF (IEVEN .GT. 1) GO TO 20
 10    CALL RANDN(RN1)
       CALL RANDN(RN2)
       UA = 2. * RN1 - 1.
       UB = 2. * RN2 - 1.
       W = UA * UA + UB * UB
       IF (W .GT. 1.0) GO TO 10
       W = SQRT(-2. * ALOG(W)/W)
       RNORM = UA * W
       ENORM = UB * W
       IEVEN = 2
       GO TO 30
 20    IEVEN = 1
       RNORM = ENORM
 30    RNORM = RNORM*STD + XMN
       RETURN
       END
C*************************************************************
```

```
C                                                                *
C       UNIFORM RANDOM NUMBER GENERATOR                          *
C                                                                *
C       FYL = RANDOM NUMBER GENERATOR SEED                       *
C                                                                *
C*****************************************************************
C
C******THE FOLLOWING SUBROUTINE GENERATES A UNIFORM RANDOM NUMBER ON
C******THE INTERVAL 0 - 1
       SUBROUTINE RANDN(YFL)
       DIMENSION K(4)
       DATA K/2510,7692,2456,3765/
       K(4) = 3*K(4)+K(2)
       K(3) = 3*K(3)+K(1)
       K(2) = 3*K(2)
       K(1) = 3*K(1)
       I = K(1)/1000
       K(1) = K(1) - I*1000
       K(2) = K(2) + I
       I = K(2)/100
       K(2) = K(2) - 100*I
       K(3) = K(3) + I
       I = K(3)/1000
       K(3) = K(3) - I*1000
       K(4) = K(4) + I
       I = K(4)/100
       K(4) = K(4) - 100*I
       YFL = (((FLOAT(K(1))*.001+FLOAT(K(2)))*.01+FLOAT(K(3)))*.001+
     *FLOAT(K(4)))*.01
       RETURN
       END
C*******************************************************************
C                                                                  *
C                             REFERENCES                           *
C                                                                  *
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C 6.  WILHELM, L. R. 1976. NUMERICAL CALCULATION OF PSYCHROMETRIC *
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C     21,325.                                                     *
C                                                                 *
C******************************************************************
```

Appendix C. Input Files

```
*****************************************************************
*                                                               *
*                         INPUT FILE 1                          *
*                                                               *
*****************************************************************
```

```
 49 356 1 5163 02.32 1  4807.5  7760.5 04.7 7475.6
```

```
****************************************************************
*                                                              *
*                        INPUT FILE 2                          *
*                                                              *
****************************************************************
```

```
06 1365.0 1365.0
07 1365.0 1365.0
08 1357.0 1365.0
09 1361.0 1425.0
10 1365.0 1425.0
11 1369.0 1425.0
12 1372.0 1530.0
13 1376.0 1530.0
14 1373.0 1575.0
15 1380.0 1575.0
16 1382.0 1575.0
17 1382.0 1575.0
18 1382.0 1575.0
19 1382.0 1575.0
20 1382.0 1575.0
21 1382.0 1575.0
22 1382.0 1575.0
23 1382.0 1575.0
24 1382.0 1575.0
```

```
*****************************************************************
*                                                               *
*                        INPUT FILE 3                           *
*                                                               *
*****************************************************************
```

```
06 01.587 01.855 00.505 00.485 00.514 00.500
07 02.086 02.426 00.505 00.485 00.514 00.500
08 02.585 02.998 00.609 00.637 00.515 00.545
09 03.265 03.683 00.609 00.637 00.515 00.545
10 03.946 04.368 00.597 00.620 00.558 00.453
11 04.604 05.152 00.597 00.620 00.558 00.453
12 05.262 05.937 00.503 00.449 00.428 00.457
13 05.942 06.792 00.503 00.449 00.428 00.457
14 06.622 07.647 00.760 00.813 00.739 00.656
15 07.325 08.525 00.760 00.813 00.739 00.656
16 08.028 09.403 00.508 00.573 00.533 00.655
17 08.754 10.289 00.508 00.573 00.533 00.655
18 09.480 11.176 01.103 00.863 00.940 00.895
19 10.183 12.072 01.103 00.863 00.940 00.895
20 10.886 12.968 00.847 00.778 00.830 00.892
21 11.566 13.857 00.847 00.778 00.830 00.892
22 12.247 14.746 00.776 00.931 00.787 00.644
23 12.950 15.576 00.776 00.931 00.787 00.644
24 13.653 16.406 00.776 00.931 00.787 00.644
 00.083 00.102 00.161 00.145
```

```
******************************************************************
*                                                                *
*                          INPUT FILE 4                          *
*                                                                *
******************************************************************
```

```
06 01.542 01.560 00.395 00.368 00.409 00.403
07 01.996 02.046 00.395 00.368 00.409 00.403
08 02.449 02.531 00.431 00.467 00.458 00.434
09 02.926 03.096 00.430 00.467 00.458 00.434
10 03.402 03.661 00.431 00.417 00.376 00.336
11 03.901 04.237 00.431 00.417 00.376 00.336
12 04.400 04.813 00.474 00.440 00.417 00.402
13 04.899 05.326 00.474 00.440 00.417 00.402
14 05.398 05.738 00.402 00.395 00.387 00.336
15 05.874 06.162 00.402 00.395 00.387 00.336
16 06.350 06.586 00.372 00.324 00.307 00.265
17 06.622 06.944 00.372 00.324 00.307 00.265
18 06.895 07.303 00.293 00.231 00.222 00.255
19 07.076 07.598 00.293 00.231 00.222 00.255
20 07.257 07.893 00.218 00.175 00.235 00.216
21 07.461 08.188 00.218 00.175 00.235 00.216
22 07.665 08.393 00.218 00.175 00.235 00.216
 00.135 00.118 00.142 00.096
```

```
*************************************************************
*                                                           *
*                      INPUT FILE 5                         *
*                                                           *
*************************************************************
```

```
01 01.94 -3.22
02 03.28 -2.33
03 07.83 01.83
04 13.50 06.83
05 18.17 11.67
06 22.00 15.61
07 24.27 18.11
08 23.72 17.67
09 20.11 13.88
10 13.77 07.17
11 08.27 02.39
12 03.50 -2.39
```

Appendix D. Program Output

AGE DAYS	AVERAGE BIRD WEIGHT MEAN KG	STDEV KG	CUMULATIVE ENERGY CONSUMPTION/BIRD SINCE AGE= 49 DAYS MEAN KCAL	STDEV KCAL	DAILY FEED CONSUMPTION KG/DAY/BIRD MEAN	STDEV	
50	2.387	0.010	571.6	5.7	0.190	0.002	
51	2.506	0.018	1214.2	10.1	0.214	0.002	
52	2.625	0.026	1873.7	15.6	0.219	0.003	
53	2.743	0.036	2548.0	22.1	0.224	0.003	
54	2.863	0.044	3238.9	30.0	0.230	0.003	
55	2.983	0.052	3945.4	37.8	0.235	0.003	
56	3.119	0.059	4689.3	45.3	0.247	0.003	
57	3.235	0.062	5426.7	54.7	0.245	0.003	
58	3.352	0.067	6179.1	63.1	0.250	0.004	
59	3.471	0.070	6946.6	71.0	0.255	0.003	
60	3.589	0.071	7726.8	79.3	0.259	0.004	
61	3.703	0.072	8519.4	87.6	0.263	0.003	
62	3.818	0.075	9325.2	96.4	0.268	0.003	
63	4.097	0.081	10348.9	110.4	0.326	0.005	FEED MIX CHANGED
64	4.218	0.082	11206.1	119.2	0.273	0.003	
65	4.339	0.083	12077.1	127.9	0.277	0.003	
66	4.459	0.088	12960.5	137.1	0.281	0.003	
67	4.579	0.091	13856.9	145.5	0.285	0.003	
68	4.696	0.096	14766.4	155.1	0.290	0.003	
69	4.814	0.102	15687.5	163.7	0.293	0.004	
70	4.921	0.106	16604.5	174.3	0.292	0.004	
71	5.043	0.109	17550.1	182.0	0.301	0.003	
72	5.166	0.112	18508.5	193.3	0.305	0.004	
73	5.286	0.117	19481.3	204.5	0.310	0.004	
74	5.408	0.121	20463.8	215.5	0.313	0.005	
75	5.531	0.127	21459.5	228.9	0.317	0.006	
76	5.653	0.133	22467.3	243.4	0.321	0.007	
77	5.762	0.136	23470.9	254.3	0.320	0.004	
78	5.889	0.142	24505.5	265.8	0.329	0.005	
79	6.017	0.147	25552.9	277.7	0.333	0.005	
80	6.143	0.150	26615.1	290.7	0.338	0.005	
81	6.269	0.152	27689.7	304.4	0.342	0.005	
82	6.395	0.158	28772.3	319.7	0.345	0.006	
83	6.524	0.162	29867.1	334.6	0.349	0.007	
84	7.127	0.177	31569.7	359.0	0.505	0.009	FEED MIX CHANGED
85	7.265	0.178	32748.9	372.7	0.350	0.005	
86	7.409	0.181	33940.0	387.5	0.353	0.005	
87	7.551	0.183	35147.2	399.0	0.358	0.005	
88	7.697	0.183	36362.1	413.9	0.360	0.005	
89	7.846	0.180	37588.7	431.5	0.364	0.007	
90	7.996	0.182	38827.2	449.1	0.367	0.006	
91	8.123	0.185	40043.5	466.1	0.361	0.009	
92	8.271	0.189	41306.0	479.5	0.374	0.007	

93	8.421	0.193	42579.9	489.2	0.378	0.008	
94	8.569	0.195	43869.6	499.7	0.382	0.007	
95	8.717	0.199	45176.0	511.2	0.387	0.006	
96	8.864	0.202	46495.5	524.7	0.391	0.006	
97	9.015	0.208	47825.0	530.5	0.394	0.006	
98	9.453	0.220	49530.8	551.0	0.491	0.007	FEED MIX CHANGED
99	9.607	0.225	50920.5	563.1	0.400	0.006	
100	9.761	0.227	52323.1	574.1	0.404	0.007	
101	9.917	0.228	53735.4	586.6	0.407	0.007	
102	10.073	0.231	55157.4	593.5	0.410	0.007	
103	10.233	0.234	56585.8	598.1	0.412	0.009	
104	10.396	0.237	58016.5	624.9	0.412	0.013	
105	10.504	0.238	59388.7	650.6	0.395	0.015	
106	10.664	0.240	60845.2	665.1	0.420	0.011	
107	10.823	0.242	62311.6	679.3	0.422	0.012	
108	10.988	0.241	63796.6	706.9	0.428	0.010	
109	11.151	0.245	65286.0	731.6	0.429	0.013	
110	11.311	0.250	66801.8	739.0	0.437	0.007	
111	11.473	0.251	68330.6	739.0	0.440	0.007	
112	11.618	0.254	69849.1	751.8	0.437	0.009	
113	11.781	0.255	71398.2	778.6	0.446	0.010	
114	11.945	0.257	72950.4	802.8	0.447	0.012	
115	12.108	0.260	74518.9	834.5	0.452	0.014	
116	12.274	0.264	76099.5	849.1	0.455	0.010	
117	12.440	0.268	77686.0	876.0	0.457	0.011	
118	12.608	0.268	79279.9	894.5	0.459	0.012	
119	12.778	0.270	80889.5	914.1	0.464	0.012	
120	12.947	0.269	82501.9	930.4	0.465	0.013	
121	13.116	0.271	84123.5	949.3	0.467	0.014	
122	13.285	0.270	85765.1	944.9	0.473	0.011	
123	13.455	0.270	87411.6	979.0	0.474	0.013	
124	13.624	0.269	89053.6	987.3	0.473	0.019	
125	13.795	0.268	90716.6	1010.6	0.479	0.017	
126	13.965	0.265	92383.7	1034.6	0.480	0.016	
127	14.137	0.265	94073.4	1055.5	0.487	0.016	
128	14.311	0.266	95769.7	1077.3	0.489	0.012	
129	14.484	0.269	97472.7	1083.6	0.491	0.013	
130	14.657	0.266	99174.7	1114.7	0.490	0.016	
131	14.828	0.265	100888.2	1134.1	0.494	0.017	
132	14.998	0.265	102606.4	1153.2	0.495	0.017	
133	15.169	0.262	104343.1	1172.0	0.500	0.018	
134	15.340	0.264	106099.9	1200.7	0.506	0.014	
135	15.512	0.262	107865.1	1207.5	0.508	0.016	
136	15.683	0.261	109622.5	1235.5	0.506	0.019	
137	15.855	0.257	111403.4	1260.7	0.513	0.018	
138	16.028	0.257	113192.4	1284.3	0.515	0.022	
139	16.199	0.254	114997.9	1302.2	0.520	0.018	
140	16.372	0.253	116817.2	1334.3	0.524	0.019	
141	16.542	0.250	118627.0	1341.5	0.521	0.022	
142	16.713	0.247	120437.4	1344.5	0.522	0.020	

143	16.886	0.245	122269.3	1375.6	0.528	0.016
144	17.057	0.245	124117.5	1411.9	0.532	0.022
145	17.226	0.245	125944.5	1455.7	0.526	0.024
146	17.395	0.241	127786.9	1479.9	0.531	0.022
147	17.565	0.241	129639.4	1496.4	0.534	0.020
148	17.734	0.241	131496.8	1515.4	0.535	0.022
149	17.900	0.238	133331.4	1537.8	0.528	0.021
150	18.065	0.242	135158.2	1566.8	0.526	0.022
151	18.227	0.241	136984.6	1579.0	0.526	0.016
152	18.390	0.240	138825.6	1582.4	0.530	0.018
153	18.554	0.243	140684.3	1592.7	0.535	0.018
154	18.720	0.242	142548.0	1600.4	0.537	0.019
155	18.881	0.244	144394.2	1608.1	0.532	0.014
156	19.042	0.245	146244.5	1640.0	0.533	0.018
157	19.200	0.247	148120.7	1653.3	0.540	0.018
158	19.359	0.247	149996.1	1660.7	0.540	0.016
159	19.515	0.250	151871.7	1670.6	0.540	0.013
160	19.671	0.249	153758.2	1680.3	0.543	0.013
161	19.828	0.251	155649.7	1694.9	0.545	0.013
162	19.983	0.252	157548.2	1698.1	0.547	0.014
163	20.140	0.248	159465.7	1720.5	0.552	0.016
164	20.296	0.250	161391.3	1746.5	0.555	0.017
165	20.453	0.250	163326.3	1762.0	0.557	0.016
166	20.606	0.250	165260.9	1765.1	0.557	0.010
167	20.759	0.249	167214.4	1779.8	0.563	0.017

AVERAGE BIRD WEIGHT ON EACH DAY OF BIRDS LIFE IS NORMALLY DISTRIBUTED WITH MEAN AND STANDARD DEVIATIONS SHOWN ABOVE.

SIMILARLY CUMULATIVE ENERGY CONSUMPTION PER BIRD ON EACH DAY IS NORMALLY DISTRIBUTED WITH MEAN AND STANDARD DEVIATIONS SHOWN ABOVE.

FEED CONSUMPTION PER DAY PER BIRD IS ALSO NORMALLY DISTRIBUTED WITH MEANS AND STANDARD DEVIATIONS SHOWN ABOVE

ENERGY CONSUMPTION VALUES SHOWN ABOVE ARE FOR BIRDS REARED IN CAGES, FOR BIRDS REARED ON FLOOR, ENERGY CONSUMPTION VALUES WILL BE 10 TO 20 PERCENT HIGHER.

Appendix E. Feed Energy density and weight gain data

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**********************************************************************
*                                                                    *
*   DEFINITION OF SYMBOLS:                                           *
*    OBS     -  OBSERVATION NUMBER                                   *
*    SEX     -  SEX OF BIRDS                                         *
*               =  H    FOR FEMALES                                  *
*               =  T    FOR MALES                                    *
*    AGE     -  AGE OF BIRDS AT THE TIME OF MARKETING                *
*    WT      -  AVERAGE WEIGHT OF BIRDS AT THE TIME OF MARKETING     *
*    FDCN    -  FEED CONVERSION RATIO KG FEED/KG TURKEY              *
*    FEED    -  TOTAL FEED CONSUMED PER BIRD UNTIL MARKETING, KG     *
*    FDCONC  -  AVERAGE FEED ENERGY CONCENTRATION, KCAL/KG           *
*               =  CAL/FEED                                          *
*                                                                    *
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OBS	SEX	AGE	WT	FEED	FDCONC
1	H	91	6.40926	14.6510	3134.93
2	H	91	6.46823	14.4696	3123.03
3	H	91	6.18700	14.0160	3108.30
4	H	91	6.32762	13.6531	3138.84
5	H	92	6.30947	14.3335	3123.66
6	H	92	6.19607	14.4696	3137.20
7	H	92	6.05546	13.9253	3128.55
8	H	93	6.54534	15.0593	3126.71
9	H	93	6.44101	14.8778	3123.64
10	H	93	6.52266	15.0593	3164.23
11	H	93	6.46369	14.6964	3158.80
12	H	93	6.51359	14.6964	3131.99
13	H	94	6.39565	15.3314	3144.91
14	H	94	6.45009	14.6057	3131.52
15	H	95	6.68595	15.3314	3140.93
16	H	95	6.53627	14.7871	3163.63
17	H	95	6.32308	14.6964	3158.26
18	H	96	6.50452	15.1953	3135.76
19	H	96	6.83564	15.6036	3174.78
20	H	96	6.65420	15.3768	3171.27
21	H	96	6.52266	15.2861	3165.37
22	H	97	6.55895	15.3768	3141.55
23	H	97	6.54988	15.8757	3141.40
24	H	97	6.76306	15.8757	3164.20
25	H	97	6.74038	16.3747	3173.43
26	H	97	6.78121	14.7418	3143.25
27	H	97	6.50452	14.9686	3147.33
28	H	97	6.29586	15.0593	3167.82
29	H	97	6.41833	15.3314	3153.59
30	H	97	6.54534	15.4221	3159.48
31	H	97	6.93089	16.5561	3173.87
32	H	97	6.95357	16.1025	3169.81

33	H	98	6.58163	15.6943	3016.57
34	H	98	6.65420	16.1025	3148.82
35	H	98	6.34576	15.4675	3130.37
36	H	98	7.11687	16.6922	3177.23
37	H	98	6.51812	15.0593	3147.36
38	H	98	6.73131	15.6943	3118.20
39	H	99	6.62699	15.6943	3145.60
40	H	99	6.71770	15.6943	3125.85
41	H	99	6.59523	15.7397	3119.89
42	H	99	6.90368	16.9644	3141.41
43	H	99	7.23026	17.2819	3185.24
44	H	99	6.89914	16.7829	3179.90
45	H	99	7.04429	17.5540	3210.03
46	H	99	6.61791	16.0572	3145.76
47	H	99	6.68142	15.9665	3177.41
48	H	99	6.68142	16.2840	3159.55
49	H	99	6.85832	16.1479	3160.41
50	H	99	6.37297	14.9686	3124.48
51	H	99	6.48637	15.7850	3182.64
52	H	99	6.91729	17.2819	3166.44
53	H	99	6.89461	15.8757	3124.45
54	H	99	7.04883	16.9644	3147.25
55	H	99	6.81750	16.1025	3164.60
56	H	100	6.7585	17.1004	3172.38
57	H	100	6.3458	15.5582	3142.26
58	H	100	7.0171	16.8283	3167.76
59	H	100	6.9536	17.1004	3140.15
60	H	100	6.6542	16.1479	3166.17
61	H	100	6.6179	16.1025	3152.98
62	H	100	6.9989	16.2386	3140.35
63	H	100	7.0307	16.5108	3168.36
64	H	100	6.7177	15.9211	3148.34
65	H	101	7.2393	16.9644	3161.39
66	H	101	7.2620	18.0076	3186.04
67	H	101	6.7903	16.6015	3148.57
68	H	101	6.9989	16.6468	3180.90
69	H	101	6.7767	16.7829	3183.24
70	H	101	6.9309	16.3293	3141.34
71	H	101	6.5091	15.5129	3134.95
72	H	101	6.9989	17.8715	3166.77
73	H	101	6.6769	16.3293	3159.59
74	H	101	6.5227	16.7376	3137.67
75	H	101	6.6950	15.9665	3151.92
76	H	101	6.8084	16.0572	3168.49
77	H	101	6.7449	16.0118	3195.64
78	H	101	6.4455	15.6036	3152.67
79	H	101	7.0035	17.2819	3172.80
80	H	102	7.3301	17.3726	3159.46
81	H	102	7.0216	17.0097	3199.52
82	H	102	6.9400	16.1479	3175.03

83	H	102	6.6723	16.3747	3143.63
84	H	102	6.4410	15.6036	3142.61
85	H	102	6.2959	14.5603	3101.58
86	H	102	6.7948	16.1933	3174.22
87	H	103	7.7564	18.5066	3229.61
88	H	103	6.8492	17.0097	3181.95
89	H	103	7.1940	18.1891	3179.44
90	H	104	7.2983	17.8715	3173.65
91	H	104	6.7721	17.2819	3193.75
92	H	104	7.0670	17.9623	3196.65
93	H	104	7.3890	18.3705	3216.52
94	H	104	7.3437	18.2344	3204.65
95	H	105	7.2847	17.3272	3130.62
96	T	110	10.0879	25.3105	3174.62
97	T	112	10.1786	26.6259	3193.17
98	T	113	9.5753	22.3621	3166.34
99	T	119	10.5687	26.5805	3203.25
100	T	119	11.6437	30.0278	3238.16
101	T	119	12.1517	31.3432	3261.95
102	T	119	11.7889	29.7557	3251.72
103	T	120	12.1926	31.2979	3263.89
104	T	120	12.3014	31.0711	3256.37
105	T	121	11.8115	30.0732	3229.26
106	T	121	12.1472	31.1618	3262.55
107	T	121	12.4148	32.3411	3273.97
108	T	122	12.9954	33.2030	3288.77
109	T	122	11.3489	30.4361	3239.05
110	T	122	11.8932	30.7536	3222.62
111	T	122	12.2152	31.0711	3232.33
112	T	122	12.1563	31.0257	3243.70
113	T	122	11.1947	29.8917	3196.13
114	T	122	12.5237	32.4772	3265.77
115	T	122	13.2993	33.5205	3281.58
116	T	123	11.8614	30.7082	3223.37
117	T	123	11.7934	31.0257	3251.17
118	T	123	11.6755	30.3000	3253.17
119	T	123	12.2833	31.3886	3282.37
120	T	123	13.2767	33.2937	3282.51
121	T	123	12.4556	31.2072	3239.48
122	T	123	12.3150	31.9329	3232.62
123	T	123	12.2515	31.3886	3265.77
124	T	123	11.8478	30.4361	3250.09
125	T	123	12.2515	31.0711	3244.46
126	T	123	11.7707	32.4772	3278.11
127	T	123	13.0816	32.2504	3214.19
128	T	123	11.7390	30.9804	3239.89
129	T	123	11.2990	29.9371	3219.42
130	T	123	12.6824	32.2051	3243.22
131	T	123	12.9365	32.6133	3264.96
132	T	123	12.0021	31.8422	3276.47

133	T	124	12.1926	31.7968	3268.88
134	T	124	12.3196	31.1618	3247.92
135	T	124	12.7777	34.4277	3243.64
136	T	124	12.5917	31.9783	3264.81
137	T	124	12.5373	33.0215	3245.76
138	T	124	12.4284	32.1143	3285.42
139	T	124	11.6982	31.0257	3229.64
140	T	124	12.5237	33.3390	3288.55
141	T	124	12.0520	33.6566	3297.90
142	T	124	13.4127	34.9720	3255.23
143	T	124	12.7142	32.6587	3269.12
144	T	125	11.1085	27.7145	3203.56
145	T	125	12.6870	34.4730	3242.85
146	T	125	12.2198	32.4772	3260.75
147	T	125	13.1406	34.7905	3309.29
148	T	125	11.4124	30.1185	3258.13
149	T	125	12.0474	30.6175	3243.96
150	T	125	11.5167	29.1660	3197.18
151	T	125	12.3468	33.2483	3273.97
152	T	125	12.1835	32.1143	3276.14
153	T	125	12.1245	30.6629	3258.01
154	T	125	12.5055	31.9783	3261.25
155	T	125	11.7254	31.7061	3229.79
156	T	125	12.8866	32.2958	3271.60
157	T	125	12.6144	32.6587	3279.10
158	T	125	12.3150	32.3865	3254.23
159	T	125	12.3513	31.7515	3276.89
160	T	125	12.7505	33.6566	3291.57
161	T	126	13.2222	34.1102	3275.15
162	T	126	12.3423	34.4277	3249.86
163	T	126	12.6779	31.7061	3257.70
164	T	126	12.5146	31.7515	3270.18
165	T	126	12.7822	33.5658	3275.38
166	T	126	12.6099	32.4319	3272.37
167	T	126	12.2152	31.7061	3278.86
168	T	126	12.4058	31.3886	3259.78
169	T	126	13.2222	34.6545	3247.03
170	T	126	12.4965	32.2958	3247.39
171	T	126	11.7390	31.4793	3207.06
172	T	126	12.6961	34.4277	3258.25
173	T	126	12.3423	31.5700	3264.08
174	T	126	12.5328	31.9783	3260.53
175	T	126	12.5645	31.0257	3252.85
176	T	126	13.4490	34.2462	3279.37
177	T	126	12.8866	32.4772	3238.85
178	T	126	11.8206	30.7082	3251.54
179	T	127	13.3084	34.1555	3274.93
180	T	127	12.0520	31.4340	3266.02
181	T	127	12.7323	33.4298	3254.82
182	T	127	12.3468	32.0236	3276.42

183	T	127	11.2219	29.3928	3236.03
184	T	127	11.6120	29.3021	3217.28
185	T	127	11.8388	32.1143	3244.72
186	T	128	13.3855	34.4730	3272.91
187	T	128	12.9546	34.1555	3246.65
188	T	128	12.8820	35.1534	3255.44
189	T	128	12.7187	35.3349	3256.05
190	T	128	12.1835	32.0236	3254.25
191	T	128	12.6371	34.0648	3282.13
192	T	128	12.9229	34.6091	3289.57
193	T	129	13.7620	35.1534	3265.03
194	T	129	13.4037	35.7884	3244.09
195	T	129	12.6099	32.2051	3247.38
196	T	129	12.9501	34.2009	3294.36
197	T	129	12.8730	32.6587	3265.54
198	T	129	13.4127	32.3411	3264.82
199	T	129	13.1678	33.8380	3266.92
200	T	130	12.5146	33.6566	3283.43
201	T	130	11.7208	31.4793	3264.65
202	T	130	12.9138	32.7947	3269.52
203	T	130	13.4989	34.7905	3297.19
204	T	132	13.2903	35.5163	3301.61
205	T	132	12.9818	34.6545	3302.20

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