World's Poultry Science Journal

ISSN: 0043-9339 (Print) 1743-4777 (Online) Journal homepage: www.tandfonline.com/journals/twps20

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To cite this article: A.A. Al-Saffar & S.P. Rose (2002) Ambient temperature and the egg laying characteristics of laying fowl, World's Poultry Science Journal, 58:3, 317-331, DOI: 10.1079/WPS20020025

To link to this article: https://doi.org/10.1079/WPS20020025

Published online: 23 Sep 2019.

Ambient temperature and the egg laying characteristics of laying fowl

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Laying hens have physiological responses that affect their productive performance when given different ambient temperatures. The objectives of this study were, first, to quantitatively describe the relationship between different constant environmental temperatures and egg production characteristics of laying hens by a statistical analysis and assessment of the published literature. Second, to compare the effect of different cycling environmental temperatures on the egg production characteristics of laying hens. Twenty-nine experiments were selected that had compared different constant temperatures and that included 21°C within their range. Differences in egg production were expressed as a proportion of the treatment group given 21°C within that experiment. An exponential curve with the addition of a linear trend gave the best ($P<0.001$) description of egg numbers, weight and mass, feed intakes and egg composition variables. There was a linear decrease ($P<0.001$) in measures of shell strength with increasing temperature. A second statistical analysis compared eight published experiments that had described the egg laying responses of laying hens kept in daily fluctuating temperatures and had been compared to a treatment group kept at 21°C within the same experiment. The results indicated that the egg laying responses of the hens were best predicted by computing the mean of the predicted responses to each of the temperatures that occurred during the day. However, information on the low temperature, the proportion of the day at the low temperature and the amplitude of the temperature cycle were required to give a precise prediction of the egg laying responses.

Keywords: temperature; cycling temperature; laying hens; egg production; egg composition; egg quality

Introduction

Temperature is the most pervasive environmental factor that influences livestock and poultry. Domestic fowl are homeotherms and they must maintain a constant body temperature by biochemical, physiological and behavioural responses.

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Birds moved to cold environments respond by increasing metabolic thermogenesis (Freeman, 1965; McDonald *et al.*, 1966; Smith and Oliver, 1971), reducing blood flow to body extremities (Sturkie, 1970), and huddling to other individuals in the flock (Baldwin, 1974; Esmay, 1978). Birds moved to hot environments respond by panting to increase evaporate heat loss (Freeman, 1965; Sturkie, 1965; Romijn and Lokhorst, 1966; Hafez, 1968), they will increase blood flow to body extremities (Sturkie, 1970) and have behavioural and postural changes that increase body heat loss (Freeman, 1969; Wathes, 1978).

The general model of thermogenesis of farm animals' responses to temperatures is that there is a thermoneutral zone where changing ambient temperatures do not change the metabolic rate of the animal and that all body temperature regulation is achieved by physiological and behavioural means (van Kampen, 1981). However, there is evidence that, in poultry, throughout the whole range of environmental temperatures there are physiological responses that affect their productive performance and efficiency of feed utilisation (Howlider and Rose, 1987; Marsden and Morris, 1987).

Emmans and Charles (1977) and Charles (1985) stated that 21°C is the optimum house temperature for laying hens. However, because laying performance changes continuously with ambient temperature, the optimum economic temperature may change depending on the economic conditions that prevail for a specific egg unit. There is a need for a precise description of the relative changes in the egg laying characteristics of laying hens with changing ambient temperatures to enable individual egg producers to decide upon their ideal house temperature. One previous study has examined this subject (Marsden and Morris, 1987). However it used a limited data set that examined experiments mostly published prior to 1980. There is now a need to re-evaluate and include the large amount of recent published information that has been generated on the production responses of hens kept under different environmental temperatures.

Birds kept in cold climates are predominantly kept in controlled environmental housing where there will be only a relatively small diurnal variation in ambient temperature. However the growing importance of free-range egg production in parts of Europe results in large diurnal temperature variations for this class of poultry. Birds kept in hot climates frequently will experience large diurnal variations in their ambient temperature. Open-sided housing may be used in hot climates and this gives little environmental control. Controlled environment housing may still not be able to reduce the high amplitude of the diurnal variation in ambient temperature in these climates.

There is a practical need to understand and quantify the egg laying responses of hens to these diurnal temperature effects. De Andrade *et al.* (1977) suggested that the response of birds could be calculated from the mean daily temperature. However, no quantitative data has yet been examined to statistically test this conclusion. There is a need to examine the responses of birds kept in diurnally cycling ambient temperatures to evaluate the effect on their egg laying performance.

The objectives of this study were, first, to quantitatively describe the relationship between different constant environmental temperatures and the egg production characteristics of laying hens by a statistical analysis and assessment of the published literature. Second, to compare the effect of different cycling environmental temperatures on the egg production characteristics of laying hens.

Methods of selection and analysis of data

A detailed literature search was conducted for all published experiments in which two or more constant temperatures had been maintained for at least 3 weeks. The experiments selected had to include 21°C within their temperature treatment range and at least one temperature had to be within ± 3°C of 21°C. Twenty-nine experiments were found that had used white feathered birds (a total of 27487 birds) and ten experiments were found that used brown feathered birds (a total of 24594 birds). Twenty-three experiments used birds that were kept in groups in cages (a total of 50873 birds) and sixteen experiments used birds caged singly (a total of 1208 birds) (*Table 1*).

Table 1 Sources of data used in computation of equations of egg production, egg composition and shell strength of laying hens kept under different environmental temperatures.

Reference	Number of birds in experiment	Experiment duration (weeks)	Experimental temperatures °C	Bird details		Data availability		
				Single (S) or Group (P) housed birds	White (W) or Brown (B)	Laying egg performance	Egg composition	Shell strength
Ahmad *et al.* (1974)	64	22	21, 30	S	W	✓	✓	✓
Ahvar *et al.* (1982)	837	50	21, 32	G	W		✓	✓
Blake *et al.* (1984)	16	4	21, 30	S	W	✓		
Carmon *et al.* (1965)#1	40	8	19, 30	S	W		✓	
Carmon *et al.* (1965)#2	75	3	8, 19, 30	S	W		✓	
Cheng *et al.* (1990)	248	12	23.9, 31.1	G	W	✓	✓	✓
Cowan and Michie (1980)	480	24	21, 27	G	B	✓		
De Andrade *et al.* (1976)	216	18	21, 32	S	W	✓	✓	✓
De Andrade *et al.* (1977)	216	12	21, 31	S	W	✓	✓	✓
Emery *et al.* (1984)#1	54	15	23.9, 26.7, 29.4	S	W	✓		✓
Emery *et al.* (1984)#2	36	14	23.9, 26.4	S	W	✓		✓
Emmans *et al.* (1977)#1	4560	56	19, 24	G	W	✓		
Emmans *et al.* (1977)#2	3648	56	19, 24	G	B	✓		
Emmans *et al.* (1977)#3	4560	52	18, 20, 22, 24	G	W	✓		
Emmans *et al.* (1977)#4	3648	52	18, 20, 22, 24	G	B	✓		
Emmans *et al.* (1977)#5	4560	52	18, 20, 22, 24	G	W	✓		
Emmans *et al.* (1977)#6	3648	52	18, 20, 22, 24	G	B	✓		
Goto *et al.* (1982)	50	3	21, 32	S	W			✓
Hill *et al.* (1988)	7680	40	18, 21	G	B	✓		
Huston *et al.* (1972)#1	90	24	8, 19, 30	S	W	✓		
Huston *et al.* (1972)#2	90	24	8, 19, 30	S	B	✓		
Hvidsten *et al.* (1976)#1	1260	56	10, 16, 22, 28	G	W	✓		✓
Hvidsten *et al.* (1976)#2	1260	60	10, 16, 22, 28	G	W	✓		✓
Jones *et al.* (1976)	45	3	4.5, 21, 35	S	W	✓		
Lillie *et al.* (1976)	1620	24	13, 21.5, 29.5	G	W	✓		✓
Marsden *et al.* (1981)#1	2160	23	15, 18, 21, 24, 27, 30	G	W	✓	✓	✓
Marsden *et al.* (1981)#2	2160	34	15, 18, 21, 24, 27, 30	G	B	✓	✓	✓
Marsden *et al.* (1987)#1	2160	34	15, 18, 21, 24, 27, 30	G	W	✓		
Marsden *et al.* (1987)#2	2160	34	15, 18, 21, 24, 27, 30	G	B	✓		
Marsden *et al.* (1987)#3	1080	61	18, 22.5, 27	G	W	✓		
Marsden *et al.* (1987)#4	1080	61	18, 22.5, 27	G	B	✓		
Miller and Sunde (1975)#1	12	12	10, 21	S	W	✓		✓
Miller and Sunde (1975)#2	162	13	10, 21, 32	S	W	✓	✓	
Ota (1960)[+]	*	*	-5[a], 3, 8, 13, 18, 24, 29	S	B	✓		
Payne (1966a)	72	16	18, 24, 30	G	W	✓	✓	
Peguri and Coon (1985)	1440	16	16.1, 18.9, 22.2, 24.4, 27.8, 31.1	G	W	✓		
Smith (1970)	42	14	21, 32, 38[a]	S	W	✓	✓	✓
Stockland and Blaylock (1974)	432	26	18.3, 29.4	G	W	✓		✓
Wilson *et al.* (1972)	120	24	10, 23, 34	G	W	✓		✓

[+] Information not available.
[a] Data available but were not used in the statistical analysis.

The selected experiments spanned 30 years and included a large number of production methods and different strains of laying hen kept under varied management conditions. There were, therefore, large variations between experiments in the egg production characteristics of the laying hens, so the temperature treatment differences were described as a proportion of the treatment group within that experiment that were kept at 21°C. This temperature has been suggested to be the optimum ambient temperature for caged laying hens (Emmans and Charles, 1977; Charles, 1985). All the reported egg production variables of the treatment group were expressed as a proportion (%) of the values obtained from the layers kept at 21°C in that experiment. If the experiment did not contain a treatment exactly at 21°C then a predicted performance was estimated linearly using the nearest treatment groups above and below 21°C. As one of these treatment groups was within 3°C of 21°C, any inaccuracies of this method were considered to be only relatively small. Only the reported temperatures were used in the analysis and no adjustments were made for stocking rate, humidity, air speeds or any other factors that may affect the response to temperature.

Regression analyses were conducted on these data using temperature as the explanatory variable. Linear, quadratic and exponential models were fitted to the data sets and the model that gave the lowest residual standard deviation was selected to describe the temperature responses. The two classifications of white and brown feathered birds and multiple or singly caged birds were included in the regression analyses as grouping factors and tests of whether these factors significantly reduced the residual standard deviation were conducted.

A second statistical analysis examined the egg laying performance of hens kept under fluctuating temperature regimens. Data were available from eight published experiments (a total of 1032 birds) in which a constant temperature of 21°C (± 3°C) was used and compared to cyclic temperature regimens (*Table 2*). A number of calculations were made to describe the responses of the birds to the diurnally fluctuating temperatures. First, the mean of the daily cycling temperatures was calculated,

Equation 1: mean temperature = (low temperature x hours at this temperature + high temperature x hours at this temperature)/24

A second calculation was used to test the hypothesis that the responses of birds given two diurnally fluctuating temperatures were equivalent to the predicted response of birds in each of the temperatures multiplied by the proportion of the day spent at that temperature. The response of the birds to the high and low temperatures were separately predicted using the equations previously derived in this paper for the birds given different constant temperatures. The predicted responses of the birds at each temperature were then multiplied by the proportion of the day (number of hours/24) that the high and low temperatures were given.

Equation 2: Predicted response to a diurnally cycling temperature regimen with two temperatures = (proportion of time at high temperature each day x predicted response of birds kept constantly at this high temperature) + (proportion of time at low temperature each day x predicted response of birds kept constantly at this low temperature).

The cycling temperature regimen was further described by recording the proportions of time at the high and low temperatures and the amplitude of the high and low temperatures (high temperature minus low temperature).

A regression technique was used to compare the closeness of fit of the responses of the birds given the cycling temperature regimens to that of the birds given the equivalent

Table 2 Relationship between experimentally determined egg laying performance of hens given cycling temperature regimens with their predicted response (weighted according to the proportion of time spent at each temperature) and three characteristics of the cycling temperature regimen.

Dependent variable observed experimental response (% of constant 21°C)	Independent variables (± SE) Predicted response (% of constant 21°C) [s]	Low temperature (°C) [§]	Proportion of time at low temperature [†]	Temperature amplitude (°C) [‡]	Residual standard deviation	% Variance accounted for
Food intake	0.4364 (0.0870)	1.163 (0.454)	30.1 (20.9)	1.582 (0.736)	6.04	45.1***
Food conversion ratio	1.00752 (0.00561)	-0.0055 (0.0126)	- 0.051 (0.565)	- 0.1559 (0.0211)	0.140	99.5***
Egg number	0.7434 (0.0797)	0.800 (0.211)	5.6 (10.7)	0.820 (0.371)	2.82	4.9***
Egg weight	0.8699 (0.0391)	0.3852 (0.0980)	2.70 (4.95)	0.502 (0.171)	1.28	89.6***
Egg mass	0.5340 (0.0739)	1.160 (0.391)	18.9 (17.7)	1.407 (0.641)	5.26	75.4***

Sources of data used in multiple regression analysis: Cowan and Michie (1980) , De Andrade *et al.* (1976), Emery *et al.* (1984), Miller and Sunde (1975) #1, Miller and Sunde (1975) #2, Payne (1966a) #1, Payne (1966a) #2, Payne (1966a) #3.

Where:
[s] Predicted response (% of constant 21°C) = proportion of time at high temperature x predicted response of birds at this constant temperature + proportion of time at low temperature x predicted response of birds at this constant temperature.
[§] Lowest temperature in cycling regimen.
[†] Proportion of 24 hours at low temperature.
[‡] Temperature amplitude = high temperature – low temperature.
*** P<0.001

mean temperature constantly. Equation 1 was used to describe the mean single temperature given to the birds.

The poor correlation between the egg laying performance of the birds given cycling temperatures and their predicted response using the mean daily temperature (equation1) resulted in the second equation being devised. A multiple regression analysis was used to examine the characteristics of the diurnal cycling temperature regimens that significantly explained the variation in the egg production responses. The following explanatory variables were used to describe the responses relative to the birds kept at a constant 21°C; the mean predicted response to different temperatures each day (equation 2), the mean temperature (equation 1), the high temperature, the proportion of time at the high temperature (number of hours/24), the low temperature, the proportion of time at the low temperature (number of hours/24) and the temperature amplitude (high temperature minus low temperature).

Results

CONSTANT TEMPERATURE

None of the responses to temperature of any of the measured variables of egg production, egg composition and quality were affected (P>0.05) by bird strain (brown or white feathered) or caging method (group or single caged). Therefore, no further references to these possible causes of variation are made in describing the results.

Egg laying performance

The data for the effect of constant temperature on egg laying performance are shown in *Figures 1 and 2*. The results obtained show that increases in environmental temperature gave relatively small decreases in all measured variables (except feed conversion ratio) of the laying hens until a critical temperature was reached. Thereafter, there were large decreases in these egg production variables. The lowest residual standard deviations for these relationships were obtained using a curvilinear exponential model with the addition of a linear trend;

$$y = a + (b \times r^{(T + (c \times T))})$$

Where y = egg laying response (% of birds kept at a constant 21°C), T = ambient temperature (°C) and b, r and c are constants.

Increasing temperature decreased feed conversion ratios, although there was evidence that a minimum value was reached at high ambient temperatures. The lowest residual standard deviation for this relationship was obtained using a quadratic model;

$$y = a + (b \times T) + (c \times T^2)$$

Where y = feed conversion ratio response (% of birds kept at a constant 21°C), T = ambient temperature (°C) and b and c are constants.

Egg composition

The data for egg composition (egg yolk, egg shell and egg albumen) as functions of temperature are shown in *Figure 3*. The results obtained show that increases in environmental temperature gave relatively small decreases in the egg yolk and egg shell of laying hens until a critical temperature was reduced. Thereafter, there were large decreases in these egg composition variables. There was no statistically significant relationship ($P>0.05$) of egg albumen with increasing temperature. The lowest residual standard deviations for the relationships of the proportions of yolk and shell with different temperatures were again obtained using a curvilinear exponential model with the addition of a linear trend.

Egg quality

The data for egg laying for egg shell strength (egg shell thickness, egg deformation and specific weight) and Haugh unit as functions of temperature are shown in *Figure 4*. There were negative linear regressions between egg shell thickness and specific weight of the eggs and increasing environmental temperatures, and a positive linear response with egg deformation;

$$y = a + (b \times T)$$

Where y = egg shell thickness, egg deformation or specific weight responses (% of birds kept at a constant 21°C), T = ambient temperature (°C) and a and b are constants.

There was no statistically significant effect ($p>0.05$) of temperature on Haugh units.

FLUCTUATING TEMPERATURE

A first hypothesis was tested that the egg laying responses of layers given a cycling temperature regimen was equivalent to the response of layers kept at a constant temperature that was the mean of the fluctuating temperatures. The results indicated that, apart from feed conversion ratio, this approach consistently over-estimated the reduction in egg laying performance of high diurnally fluctuating temperatures compared to high constant temperatures (*Figure 5*).

A second hypothesis was tested that the egg laying responses of layers given a cycling temperature regimen was equivalent to the sum of the two predicted responses of the high and low diurnal temperatures multiplied by the proportion of the day at these temperatures (Equation 2). The results similarly indicated that this approach consistently over-estimated the reduction in egg laying performance at the diurnally cycling temperatures. The third hypothesis tested that the egg laying responses were explained by a number of explanatory variables that included the predicted responses equation and a number of measurable characteristics of the diurnally varying temperature regimen. The multiple regression analysis indicated that four variables explained ($P<0.05$) the variation in egg production; these were the predicted response (Equation 2), the low temperature, proportion of time at the low temperature and amplitude of the temperature regimen (*Table 2*).

Discussion

Temperature is a major environmental variable that can affect the profitability of a commercial egg laying enterprise due to its effects on the egg production characteristics and egg quality of laying hens. Caged laying hen egg production in hot climates can be conducted in low-cost, open-sided houses where the birds can be subjected to high ambient temperatures. Controlled environment buildings can reduce the heat load on caged laying hens but these houses are more expensive and so their use increases the fixed capital costs of an egg production enterprise. Cooling systems within controlled environment buildings can reduce internal ambient temperatures but their installation costs are high and the running costs are expensive. The choice of building type and the possibility of installing cooling equipment are thus important economic decisions that can only be correctly made if the improvement of egg production characteristics can be accurately quantified for a proposed reduction in ambient temperature for the layers.

Caged egg production in cold climates is frequently conducted in controlled environment buildings that, if suitable building construction and material and ventilation design are implemented, can use bird heat to maintain a wide range of possible temperatures. The actual set temperature that is used in these situations is an economic decision that also depends on accurately quantifying the comparison of increased egg production characteristics against the increased cost of higher feed intakes.

The objective of this study was to review published literature to give a precise description of the effect of changing temperatures on the egg production, egg quality and feed intakes of laying hens. The curves used to describe these egg laying response not only mathematically explain the high proportion of the observed variation but also give models that are biologically relevant: The fitted curve shows a rapid fall in egg production, feed intakes and shell strength at approximately 28 to 30°C and this is the temperature where panting and the acute effects of heat stress would begin to occur. Decreasing temperature below this critical point gave a relatively small, linear increase in most egg production variables, shell strength and feed intakes. Increasing heat loss to the environment would increase the energy requirements of the birds for thermogenesis and so they would increase their feed intakes to meet their increased energy requirements. The increased feed intakes also increase their intakes of other essential nutrients and so this may cause a relatively small increase in egg mass output and shell strength.

The equations derived from this approach to reviewing the literature on temperature have given practically consistent results. For example, Payne (1964) estimated that a one degree decrease in ambient temperature below the point of heat stress would give a 0.90% increase in feed intake. The feed intake equation derived from the present study indicates that a one degree decrease in temperature in this zone would result in a 0.95% increase in feed intakes. The regression equations indicate that, below the point of heat stress, the weight of increased feed intake is approximately three times greater than the weight of egg output. These regression equations therefore give the egg production industry the quantitative information that they require to make economic decisions about the cost-effectiveness of temperature reduction costs.

Although the effects of cycling temperatures on laying hens has often been examined, no general model has been proposed that would enable their responses to be predicted. De Andrade *et al.* (1977) observed that there was a poor relationship if the mean daily temperature was computed and the predicted response was considered to be equivalent to birds given this temperature constantly. The present study has confirmed the poor prediction using this approach in determining the egg laying responses of birds kept in daily fluctuating temperatures. In general, the reduction in egg laying performance and feed intakes of birds kept at high average temperatures was over-estimated by this approach. Birds change their eating behaviour to be more active during cooler parts of the day (de Andrade *et al.*, 1977). This study indicates that birds are able to tolerate periods of high temperature during the day without markedly affecting their productive performance.

A second approach used to predict the responses to cycling temperatures was to consider that there were separate responses to each of the temperatures that occur during the day. It was proposed that the response to each temperature could be predicted from the response of birds kept at constant temperatures and that their overall daily responses were the sum of these individual responses weighted for the proportion of the day at each temperature. The results of the statistical analysis showed that this method gave an improved accuracy in predicting the response compared to the first method, but there was still relatively poor precision.

The multiple regression approach considered a large number of explanatory variables but only four were significantly significant in explaining the variation in the egg laying responses of laying hens in fluctuating temperatures. The results indicate that the mean of the responses to the individual temperatures must be computed but also the responses are affected by the characteristics of the daily fluctuating temperature; information on the lowest temperature, the amount of time at this temperature and the amplitude of the cycling temperature are required to effectively describe the birds' responses. These results therefore give a model for egg producers to predict the egg laying responses of hens kept in hot, diurnally fluctuating temperatures when changes in housing construction or design or investments in cooling equipment are being contemplated.

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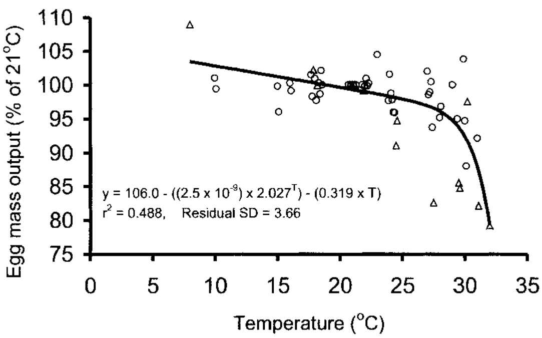
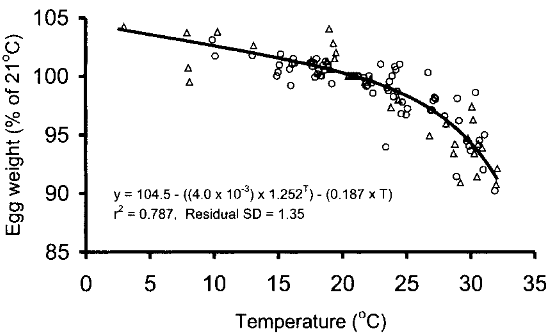
Figure 1 The effect of ambient temperature for laying hens on their egg laying performance (expressed as a % response relative to 21°C); egg mass, egg weight and egg number. Data given for single caged birds (△) and group caged birds (O) but regression equations are given for the combined data.





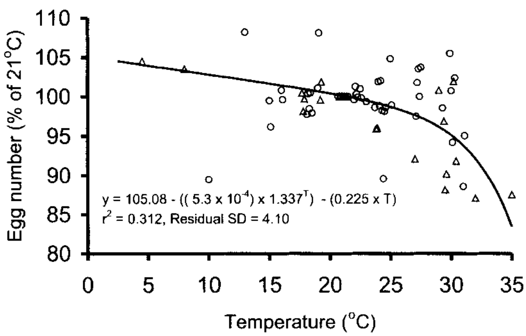
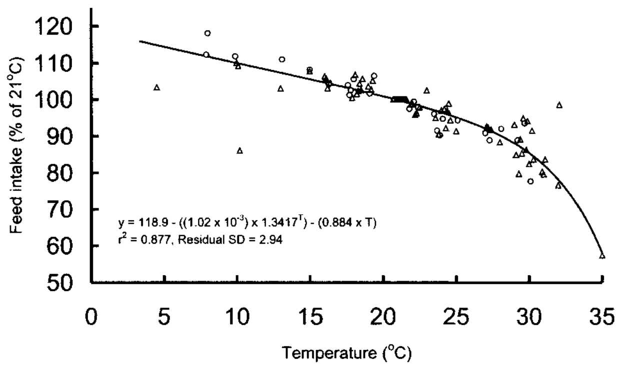
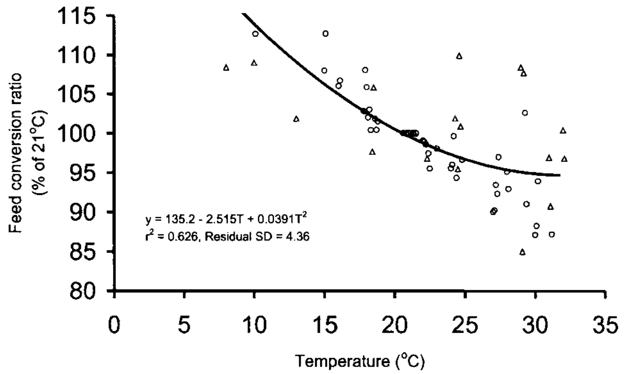


Figure 2 The effect of ambient temperature for laying hens on their egg laying performance (expressed as a % response relative to 21°C); feed intake, feed conversion ratio and body weight change. Data given for single caged birds (△) and group caged birds (O) but regression equations are given for the combined data.





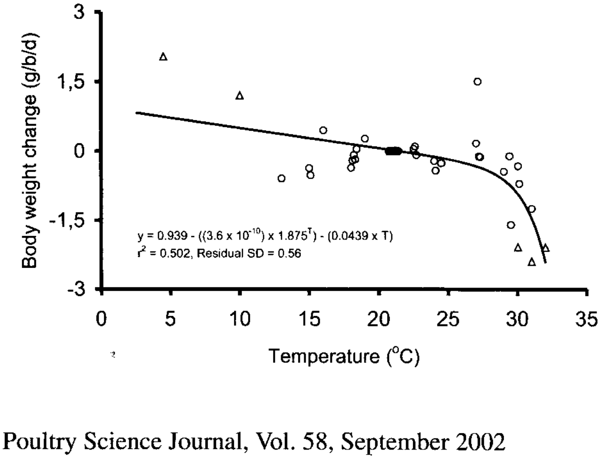


Figure 3 The effect of ambient temperature for laying hens on their egg laying performance (expressed as a % response relative to 21°C); egg shell, egg yolk and egg albumen.

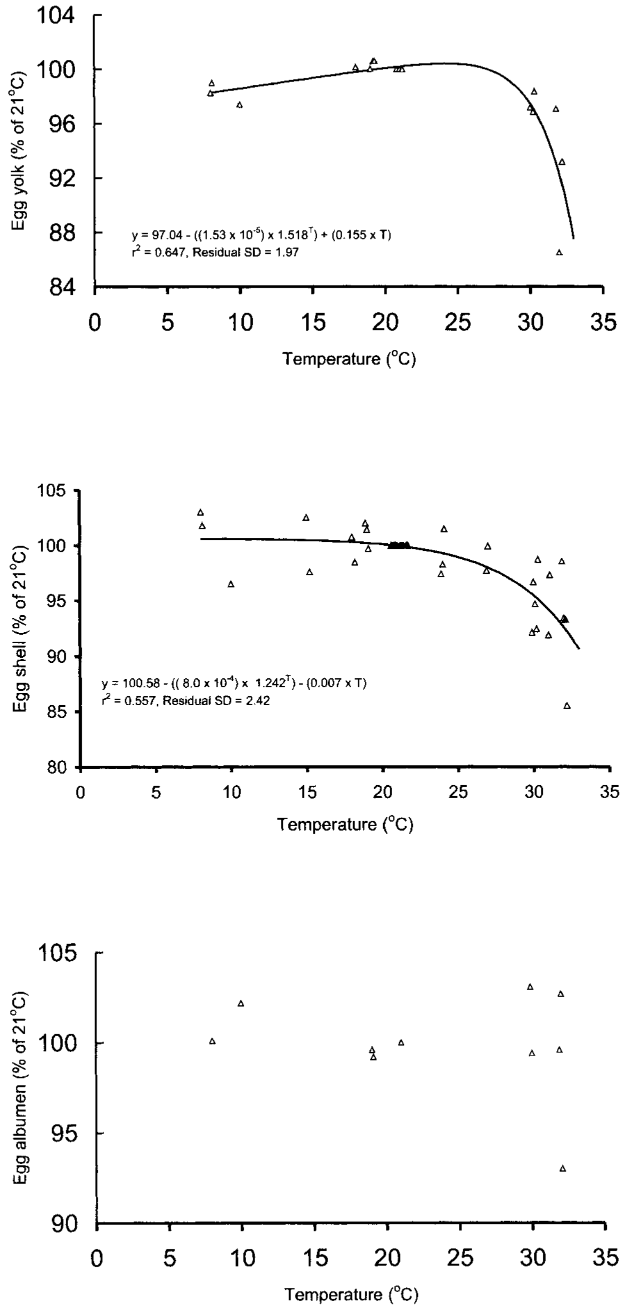


Figure 4 The effect of ambient temperature for laying hens on their egg laying performance (expressed as a % response relative to 21°C); egg shell thickness, egg deformation, specific weight and Haugh unit.

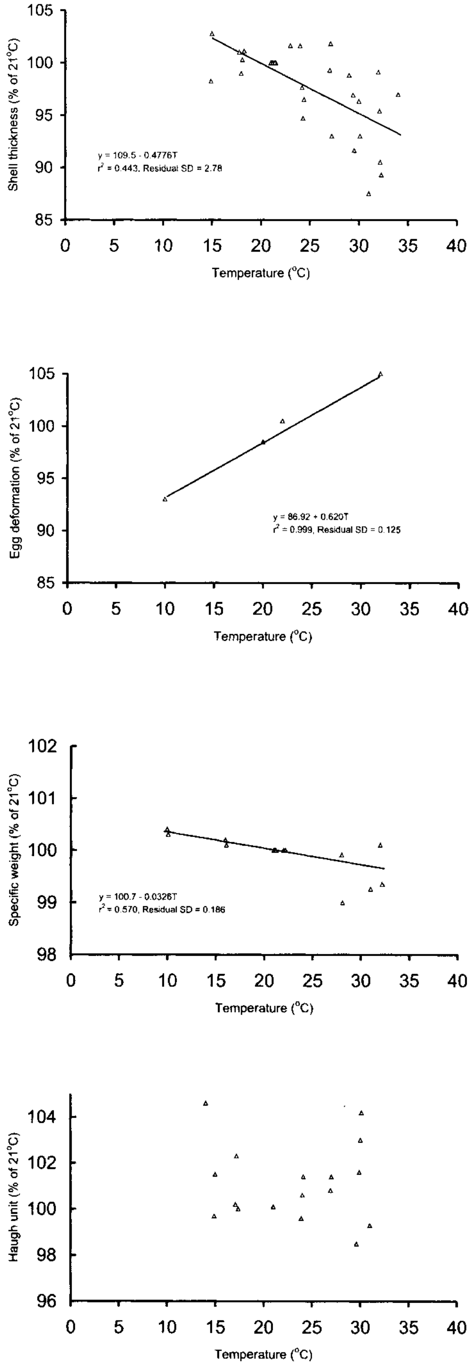


Figure 5 Comparison of the predicted and actual responses of laying birds to different ambient temperatures when kept either in constant or diurnally fluctuating temperature regimens. The predicted responses were calculated using the equations previously determined in this paper for birds kept under constant temperatures. A single ambient temperature was determined for the diurnally fluctuating temperatures by calculating the mean daily temperature.