578 Beretning fra
Statens Husdyrbrugsforsøg

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Studies on Energy Metabolism in Laying Hens

Studier over energiomsætning hos æglæggende høner

Med dansk sammendrag

Statens Husdyrbrugsforsøg
Afdeling for Dyrefysiologi og Biokemi

København 1985

I kommission hos Landhusholdningsselskabets forlag,
Rolighedsvej 26, 1958 København V.

Trykt i Frederiksberg Bogtrykkeri 1985

Denne afhandling er af Den kgl.
Veterinær- og Landbohøjskoles fagråd
for landbrugsvidenskab antaget til
offentligt at forsvares for den
jordbrugsvidenskabelige doktorgrad.

København, den 27. november 1984

Brian Dennis
Formand for fagrådet for landbrugsvidenskab

Acknowledgements

The present work was carried out at the National Institute of Animal Science, Department of Animal Physiology and Biochmistry, Copenhagen.

The report is the result of a collaboration between myself and numerous persons who each assisted me in their own particular way. I wish to express my sincere thanks to *Professor P. E. Jakobsen,* the former Head of the Department, for placing research facilities at my disposal, *Dr. agro. A. Just,* Head of the Department, for helpful advice and the drafting of this manuscript, *Dr. agro. h.c. G. Thorbek* for her great support, encouragement and most prolific guidance in carring out the project, *Dr. agro. B. O. Eggum* for his never failing interest in the project, *Cand. stat. S. Henckel* for his inspiring cooperation in regard to the statistical analyses, *Mr. H. B. Keldman Hansen, Ms. B. Mathiasen, Ms. V. Nielsen* and *Ms. L. Jarchow* for the extensive work of chemical analyses carried out with skillfulness and great precision, *Mr. J. Lind* for technical supervision of the respiration plant and the analytical work with CO_2 and O_2 determinations, *Ms. A. Tommerup* for the preparation of the drawings, *Ms. M. Wilstrup* and *Ms. R. Ibsen* for the carefully executed revision of the experimental data, the stable staff, represented by *Mr. H. Laursen* for the great accuracy in sampling of droppings and eggs and the careful managment of the animals.

I am most indebted to the Danish Agricultural and Veterinary Research Council for financial support.

Copenhagen, April 1984

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I. Introduction

Egg production is influenced by several factors which can be divided in two main groups described as internal and external factors. The internal factors are connected with the genetical structure of the bird and its ability to transform the intake of nutrients into eggs. The external factors may be called the environmental factors including food compounds and their composition and such characteristics as ambient temperature and housing system. The knowledge about egg production during the laying period in respect to the environmental and genetical factors is well established from a numerous of practical trials. However relatively little is known about the physiological aspects of egg production concerning energy metabolism and the energetic efficiency of egg production.

It is generally accepted that food intake and egg production increase during the first part of the laying period as it is well known that the hens produce bigger eggs in the last part of the laying period. It is still a matter of discussion whether the increase in egg size is combined with a constant proportion between albumen and yolk or whether the amount of albumen or yolk in relation to egg size will increase, *Fletcher et al. (1981)*. The chemical composition of eggs concerning fat and energy content seems to increase during the laying period and thereby being related to the egg size as shown by *Sibbald (1979)* and *Fletcher et al. (1981)*.

The influence of ambient temperature, origin and housing system on laying performance has been investigated by several authors. Food intake and thereby intake of nutrients and energy decline with increasing temperature as reviewed by *Sykes (1977)*, which for a broader range of temperature may result in reduced egg production, *Payne (1967)*, *Cowan & Michie (1980)*, and in decreased egg size, *Fletcher et al. (1981)*. However in a narrow range of temperature the changes in food intake, egg production and egg size were rather small, *Petersen (1977)*, and temperature per se might not have any effect on laying performance when hens are fed with equal quantities and qualities of food as discussed by *Emmans (1974)*. Different breeds and strains have different laying performance, in White Leghorns commonly used in Denmark a hybrid called Shaver St. 288 has shown a higher egg production and a better food conversion rate than other White Leghorns as demonstrated by *Neergaard (1983)*. The effect of housing system on laying performance has been investigated in a number

of practical experiments especially concerning hens kept in battery cages with different density and space per hen. It has been demonstrated from experiments in which the density was 300–500 cm^2/hen with groups from 2 to 7 hens/cage that decreasing area per bird reduces food intake, depresses egg production and increases mortality, *Robinson (1979), Cunningham & Ostrander (1982), Hughes (1983).* However comparing singly kept hens with 2 hens per cage giving areas of 1520 cm^2 and 760 cm^2 respectively, no significant reduction in egg production was found by *Eskeland et al. (1977).* As suggested by *Hughes & Black (1974 a)* the presence of a second bird has a socially facilitating effect on eating which in the long term leads to an increased food intake but without any influence on the egg production. It has also been demonstrated that hens kept in groups are more active than single birds, *Bessei (1981).*

The differences obtained from practical experiments concerning laying performance owing to genetical and environmental factors have to be connected to differences in physiological processes. Since energy metabolism can be defined as a function of numerous catabolic and anabolic interchanges of different nutrients, the physiological explanation may be sought first at all on basis on energy metabolism and more specific by estimating the energetic efficiency of egg production. Measurements of energy metabolism can be based on slaugther techniques or on calorimetric experiments carried out by means of respiration units and balance methods. The energy metabolism in laying hens has usually been measured in short term experiments giving only few information about an influence of the laying period and the age of hens on nitrogen and energy retention in body and in eggs. From slaughter experiments, *Davis et al. (1973), Neill et al. (1977), Kirchgessner (1982)* demonstrated negative or close to zero nitrogen and energy retention in body at the beginning of the laying period and their results are in accordance with balance experiments indicating very low values of nitrogen or energy retention in the body of young hens, *Hoffmann & Schiemann (1973), Grimbergen (1974), Sykes (1979), Chwalibog et al. (1984).* However no attention has been drawn to separate the amount of nitrogen and energy retained in body from the deposition in eggs under development in the ovarian system.

It has been demonstrated from short term experiments by *Hoffman & Schiemann (1973)* and *Voreck & Kirchgessner (1980 a)* that nitrogen deposition in eggs (ON) and the utilization of nitrogen for egg production (ON/IN) are fairly constant during the laying period. Contrary energy deposition in eggs (OE) seems to increase during the laying period caused by an increased egg production combined with an increament of energy in the eggs, but the proportions of OE/GE or OE/ME seems to be constant, *MacLeod et al. (1979).* However more evidence is necessary to estabalish this hypothesis.

Information in the literature about the effect of temperature on energy

metabolism is mostly concerned with heat production as reviewed by *Sibbald (1982)* and *MacLeod (1984)*. It has been demonstrated that heat production increases with decreasing temperature, *O'Neill et al. (1971), Kampen van (1981),* but in a limited range the differences are usually not significant, *Balnave (1974), Strøm (1978)*. Furthermore the recent findings of *Tzschentke & Nichelmann (1984)* demonstrated that the so called biological optimum temperature (BOT) for White Leghorns was between 17–22°C which indicates a constant heat production in this range of temperature. Assuming that the small changes in temperature (about 5°C) have no influence on energy intake and energy expenditure the amount of energy deposited in eggs and the gross utilization of energy might then be identical.

Some breeds or strains of layers have a better laying performance than others but it is a question whether a higher egg production is caused only by a higher food intake and/or a better food conversion ratio or whether the heat production and the gross utilization of nitrogen and energy for egg production are different. The literature does not give many information on this matter although there are some indications of differences in heat production between races and strains of layers, however, from experiments carried out under fasting conditions or in short periods, as reviewed by *MacLeod (1984)*. Results from such experiments are difficult to transform into farming conditions in which hens are fed ad libitum during the whole period of laying.

Concerning housing systems the differences in eating pattern and locomotor activity between single hens and hens kept in groups are likely to change the energy metabolism as hens kept together often have a higher energy intake but at the same time they might be more active. The locomotor activity account for about 10–20% of total energy expenditure as reviewed by *MacLeod et al. (1982)* and if the »crowding« of birds inreases activity the energy expenditure inreases as suggested by *Madrid et al. (1981)*. Thereby the energy retention in body and in eggs or the utilization of energy for egg production might be changed.

In order to evaluate the influence of environmental and genetical factors on the energetic efficiency of utilization of metabolizable energy (ME) for egg production it is necessary to have a knowledge about the requirement of ME for maintenance (ME_m). In adult animals maintenance requirement is often expressed as $ME_m = a\ W,kg^b$ in which W,kg^b indicates the metabolic body weight being related to the surface of the animals and it is generally accepted to use the value of 0.75 for the exponent b as discussed in detail by *Kleiber (1961), Blaxter (1972)* and *Es van (1972)*. The values of ME_m and efficiency of ME utilization for egg production reported in the literature are often controversial showing a range of ME_m between 300–600 $kJ/W,kg^{0.75}$ and the efficiency between 0.5–0.8 depending on the way of calculation as well as on environmental and genetical conditions, *Hoffmann & Schiemann (1973), Grimbergen (1974), McDonald*

(1977), Byerly (1979), Voreck & Kirchgessner (1980 c), Kirchgessner (1982). In a number of papers ME_m has been calculated from one-dimensional regression by regressing energy in produced eggs or total energy retention on ME values. The equation predict ME_m as the intercept on the x-axis while the slope of the regression line estimates the efficiency of ME utilization for energy deposition in eggs (k_o) or for total energy retention i.e. in body and eggs (k_{go}). Another method to estimate ME_m and energetic efficiency of egg production is to use multiple regression models which gives the possibility to estimate ME_m and to separate between the efficiency for energy deposition in eggs and in body. Different models of calculation can be applied as shown by *Hoffmann & Schiemann (1973)* and *Voreck & Kirchgessner (1980 c).*

It is generally accepted that ME_m decreases with increasing temperature, *Kampen van (1974),* and significantly different values of ME_m and efficiency of ME utilization for egg production have been demonstrated for a broad range of temperature as reviewed by *Balnave et al. (1978)* and *Byerly (1979).* However in a narrow temperature range as from 16 to 23°C the differences were negligible as demonstrated by *O'Neill & Jackson (1974).* Genetical differences can influence the values of ME_m and efficiency of ME utilization for egg production as shown by *Farrell (1975), McDonald (1977), MacLeod & Shannon (1978),* for different breeds, however there is not a priori evidence of such an influence within White Leghorn origins. Concerning the housing system *Madrid et al. (1981)* demonstrated increasing ME_m and the efficiency of ME utilization for egg production with increasing density from 3 to 7 hens per cage, but no reports have been found in respect to differences between hens kept singly and in groups.

The present experiment was designed as a systematic investigation on energy metabolism in hens during their laying period in order to estimate the effect of age of hens, temperature, origin and housing on energetic efficiency of egg production.

In practical farming in Denmark the temperatures are usually about 21°C but sesonal it can decrease to 17°C and these two temperatures were applied in the present studies. In order to investigate the influence of origin on energy metabolism and energetic efficiency of egg production White Leghorns from the Test Station for Egg Layers in Favrholm called origin A were compared with the hybrids Shavers St. 288, called origin B. Concerning the influence of housing 3 different systems were chosen in which the hens were kept singly in cages with an area of 2100 cm^2/hen, another in which groups of 3 hens were kept in battery cages with 700 cm^2/hen and a third system in which 6 hens were kept freely on the floor of the respration chambers giving an area of 2100 cm^2/hen.

The studies were performed with a total of 204 balances and respiration experiments from which the laying performance, size and chemical composition

of eggs, gas exchange, nitrogen metabolism, energy metabolism and energetic efficiency of egg production have been investigated during the laying period of 22 weeks in respect to the influence of temperature, origin and housing. The data are collected in the Main Tables and the results are demonstrated and based on statistical analyses, discussed in the respective chapters. The measurements of laying performance included the data of food intake, egg production, laying rate and the values of food conversion ratio. The results concerning egg size and chemical composition of eggs are based on the individual measurements of egg size and content of dry matter, ash, nitrogen, fat and energy in eggs. The respiration measurements included the data of CO_2 production and O_2 comsumption and the results have been used to predict the gas exchange in relation to metabolic body weight and metabolizable energy. The measurements of nitrogen metabolism included the data of nitrogen intake, nitrogen in droppings, nitrogen balance, nitrogen deposited in eggs from which the nitrogen utilization for egg production have been estimated. The measurements of energy metabolism included the data of gross energy, metabolizable energy, heat energy and heat production units, energy balance and energy deposited in eggs. The values of metabolizability of energy and gross utilization of energy for egg production have been estimated.

An attempt was made to define the maintenance requirement of energy and the efficiency of ME utilization for egg production. In order to calculate ME_m and the efficiency of ME utilization different models of calculations have been applied and the results are discussed. On the basis of the measurements of energy metabolism and the performed calculations of maintenance and efficiency of ME utilization the partition of ME has been demonstrated. The obtained values of efficiency of ME utilization for egg production have been presented and compared in respect to the age of hens and between the temperatures, origins and housing systems.

The main characteristics of the present studies can be described by the following key words:

CO_2 and O_2 exchange,
Nitrogen balance,
Nitrogen deposition in eggs,
Utilization of nitrogen for egg production,
Heat production,
Energy balance,
Energy deposition in eggs,
Gross utilization of energy for egg production,
Maintenance requirement of energy,
Efficiency of metabolizable energy utilization for egg production.

II. Materials and methods

2.1 Outline of experiment

The main purpose of the present studies was to investigate energy metabolism during the laying period and to measure the influence of age of hens, ambient temperature, origin and housing on energetic efficiency of egg production. The experiment included the measurements of laying performance, size and chemical composition of eggs, gas exchange, nitrogen metabolism, energy metabolism and energetic efficiency of egg production. The measurements were carried out in 4 series (G, H, K, J) during the laying period from 26 to 47 weeks of age. The allocation of the experimental animals to the different series and treatments is shown in Table 2.1.

Table 2.1 Survey of experiments
Tabel 2.1 Forsøgsoversigt

Series		G	H		K		J	
Origin		A	A		B		B	
Housing		Battery cages	Battery cages		Battery cages		Respiration chambers	
Density		1 hen/cage	3 hens/cage		3 hens/cage		6 hens/chamber	
Area	cm^2/hen	2100	700	700	700	700	2100	2100
Temp.	°C	21	17	21	17	21	17	21
Hens	n	12	12	12	12	12	6	6

Temperature. The hens in series G were kept at a constant ambient temperature of 21°C, while the hens in series H, K and J were kept either at 17 or 21°C.

Origin. White Leghorn hens from the Danish Test Station for Egg Layers in Favrholm (origin A) were distributed at random with 12 hens in series G and with 24 hens in series H. Shaver St. 288 from »Nørgård Hønseri« (origin B) were distributed at random with 24 hens in series K and with 12 hens in series J.

Housing. The hens in series G, H and K were kept in battery cages with 1 or 3 hens per cage, giving an area of 2100 or 700 cm^2 per hen respectively. The hens in series J were kept in the respiration chambers with 6 birds in each chamber, giving an area of 2100 cm^2 per hen.

All hens were fed ad libitum with a food compound of the same composition during the experimental time. For each hen or group of hens, 8 consecutive balance periods of 7 days duration with a 24 hours respiration experiment were carried out. The experimental work was concluded in October 1980 for series G and H and in December 1981 for series K and J.

2.2 Experimental animals and journals

Animals. Thirty-six White Leghorns were delivered to the laboratory by an age of 20 weeks from the Test Station for Egg Layers in Favrholm (origin A). The hens were chosen at random from the so-called »experimental groups« (nos. 27 and 28) being tested at the Station, *Neergaard (1983).* At the laboratory they were allocated at random to series G and H (Table 2.1). The other 36 hens were delivered by an age of 20 weeks from »Nørgård Hønseri« in Havstrup (origin B). These hens were chosen at random from a stock of White Leghorn hybrids Shaver Starcross 288 and they were allocated at random to series K and J. The management and feeding of all pullets in the rearing period prior to the delivery was in accordance to the principles described by *Neergaard (1980, 1983).*

Journal of animals in series G. Hen no. 2 refused to eat and had very loose droppings in period I, therefore no measurements were carried out in this period but after a treatment for 3 days with tetracycline it was fully recovered. Hens no. 3 and 7 produced normal eggs in periods I-II and I-I-III respectively but then they started to lay a great amount of eggs with soft shells and for that reason the results from these hens were excluded in the following periods. For technical reasons no respiration experiment was carried out with hen no. 12. in period IV. Caused by an error in analysing the outgoing air from the respiration chambers the results from hens no. 9 in period VI and from no. 1 in period VII were omitted as well.

Journal of animals in series H. In group no. 4 (17°C) one hen was physically damaged in period IV and the results from periods IV-VIII were excluded for this group. In group no. 8 (21°C) one hen was not in laying at the beginning of the experiment and for that reason all results from this group were omitted from the final calculations.

Journal of animals in series K. In group no. 6 (21°C) caused by inaccuracy in collection of droppings in period I the results from this period were omitted. In group no. 5 (21°C) one hen started to moult in period V and the results from periods V-VIII were excluded. In group no. 7 (21°C) one hen was physically damaged in period VI and the results from periods VI-VIII were omitted from the final calculations.

Journal of animals in series J. The hens were healthy and no data were omitted from the calculations. As discussed later some of the hens went into the habit of laying their eggs on the floor thereby causing an inaccuracy in the collection of eggs.

2.3 Experimental techniques

2.3.1 Housing and environmental conditions

Series G, H and K. The hens were kept in battery cages either singly in series

G or in groups of 3 in series H and K (Table 2.1). The battery cages were of the same type; Oli-Standard 201 (Swedish), commonly used in practice, but adjusted for separate feeding and collection of droppings and eggs. The cages measured 47 cm wide × 45 cm deep (2100 cm^2 floor area) and had a sloping floor giving a height of 43 cm at the cage front and of 37 cm at the back side. The cages were combined in sections of 4 cages separated by plastic walls. Each section was equipped with an external food trough traversing the width of the section and separated for each cage by inserted plastic divisions. The hens were supplied with water from nipple drinkers (2 per cage) positioned along a pipe at the back of of the cages. Droppings were falling through a wire floor (2.5 mm) to a plastic collection tray placed 10 cm below the floor. Eggs were rolling out in a frontal (external) wire trough.

Series G. The battery cages were placed in an insulated room equipped with heating, ventilation and water evaporation system in order to keep a constant ambient temperature of 21°C and a relative humidity from 60–70%. A constant 17 hours lighting was applied.

Series H and K. The battery cages were placed in climatically controlled respiration chambers designed for cattle. The ambient temperature was either 17 or 21°C and the relative humidity was 60–70%. A constant 17 hours lighting was applied.

Series J. The hens were kept in groups of 6 birds on a wire floor in the respiration chambers designed for pigs. The net area was 1.26 m^2 corresponding to 2100 cm^2/hen, allowing some free movement of the hens. An automatic feeding device (40 cm wide) was hanged up close to the chamber's door, water was supplied from 4 nipple drinkers placed on the back side of the chamber. Droppings were falling through a wire floor (3.5 mm) on a plastic collection tray placed 20 cm below the floor. Eggs were collected in two wooden nests (30 × 40 cm) placed closed to the chamber's door. Temperature, humidity and lighting were the same as in series H and K.

2.3.2 Technique applied in balance experiments

The balances started after a preliminary period of 5–7 weeks in which the hens were kept under the same conditions as during the experimental time. Each balance consisted of a 7 days period of collection and was followed by a 14 days intermediate period, and a total 8 balance periods were carried out for each hen or group of hens.

Food intake. The food was weighed out for each animal or group of hens for 7 days periods and aliquote samples were taken for chemical analyses. The hens were fed ad libitum every morning at 9^{00} a.m. after the food residuals from the day before were collected and stored in a refrigerator (5°C) until the end of a collection period.

Collection of droppings. The droppings were collected daily before feeding and stored in closed boxes in a deepfreezer (–20°C) until the end of a collection period.

Collection of eggs. The eggs were collected at 8^{00} a.m., weighed and stored in a refrigerator (5°C) until the end of a collection period.

2.3.3 Technique applied in respiration experiments

The respiration plant working according to the indirect calorimetry principle with open air circulation was used to measure the gas exchange. The plant consists of 3 respiration units, each with 2 independently controlled climatic chambers. In all units the air flow is measured by the differential pressure principle and the composition of outgoing air is measured in accordance to the infrared principle for CO_2 and the paramagnetic principle for O_2. The unit for small animals (chambers E and F), described by *Chwalibog et al. (1979),* was used in series G, the unit for cattle (chambers A and B), *Thorbek & Neergaard (1970),* was used in series H and K and the unit for pigs (chambers C and D), *Thorbek (1969),* was used in series J. The main parameters of the respiration plant are shown in Table 2.2.

Table 2.2 Survey of respiration parameters in the different chambers
Tabel 2.2 Oversigt vedrørende respirationsparametre i de forskellige kamre

Chambers Series	No. No.	A H-K	B H-K	C J	D J	E G	F G
Volume of chambers	m^3	10	10	3	3	1	1
Air flow	m^3/h	6	6	4	4	0.6	0.6
Internal air circulation	m^3/h	800	800	720	720	150	150
Temperature	°C	17	21	17	21	21	21
CO_2-conc. max.	%	0.4	0.4	0.3	0.3	0.3	0.3

A high internal ventilation is necessary to obtain a homogenous mixture of outgoing air. Due to different volumes of the chambers and density of animals in the chambers the internal ventilation expressed per animal was 67 m^3/h in chambers A and B, 120 m^3/h in chambers C and D and 150 m^3/h in chambers E and F. However, it was assumed that these differences had no effect on the results as the hens were not exposed to any draft, owing to the false ceiling in the chambers. The preferable concentration of CO_2 in poultry houses is about 0.3%, *Pedersen & Pedersen (1979),* and in order to keep such a concentration in the respiration chambers different flow rates were applied depending on the volume and number of hens in the chamber.

Series G. The hens were measured individually in the respiration chambers E and F. In order to accomodate animals to the chambers and to reach an equilibrium of CO_2 concentration the hens were placed in the chambers 2 hours before start of an experiment. Temperature and humidity were the same as in the experimental room.

Series H and K. Four battery cages with 3 hens/cage were placed permanently in the respiration chamber A at 17°C and B at 21°C. Before starting a respiration experiment, one hour was necessary to achieve an equilibrium of CO_2 concentration. The measurements of gas exchange included the values for 12 hens and were divided between the groups (3 hens/cage) in proportion to metabolic body weight ($W,kg^{0.75}$).

Series J. The hens were kept permanently in the respiration chamber C at 17°C and D at 21°C with 6 hens/chamber. Before starting a respiration experiment, one hour was necessary to achieve an equilibrium of CO_2 concentration. The measurements of gas exchange included the values for 6 hens.

2.3.3.1 Calculations of gas exchange

Gas exchange was calculated from differences between the concentration of atmospheric air entering the chamber and the gas leaving the chamber, multiplied per rate of flow at which gas is withdrawn from the chamber. The composition of atmospheric air was constant with 20.946% O_2 and 0.034% CO_2 being in agreement with the values tabulated by *Mitrov (1964)* and *Machta & Hughes (1970)*. Assuming that N_2 volume is constant in ingoing and outgoing air from the chambers the following calculations were applied:

Outgoing air

V = volume of air (flow × time), litres

$O_2,l = (V \times O_2,\%)/100$, $CO_2,l = (V \times CO_2,\%)/100$

$N_2,\% = 100\% - (O_2,\% + CO_2,\%)$, $N_2,l = (V \times N_2,\%)/100$

Ingoing air

$N_2,\% = 100\% - (20.946 + 0.034)$

$O_2,l = (20.946 \times N_2,1)/N_2,\%$, $CO_2,l = (0.034 \times N_2,l)/N_2,\%$

Correction for chamber's equilibrium

O_2 correction,l = (O_2,% initial – O_2,% final) × (chamber volume/100)

CO_2 correction,l = (CO_2,% final – CO_2,% initial) × (chamber volume/100)

Gas exchange

O_2,l consumed = O_2 ingoing – O_2 outgoing + O_2 correction

CO_2,l produced = CO_2 outgoing – CO_2 ingoing + CO_2 correction

2.3.3.2 Calibration of the respiration units

Calibrations of the respiration units were carried out by measuring the

amount of ingoing and outgoing CO_2. A mixture of pure nitrogen and 10% CO_2 was passing into the chamber through an oil gas meter. The volume of CO_2 which entered the chamber was then compared with the volume of CO_2 in outgoing air registred by the flow meter and CO_2 analysator, (Table 2.3).

Table 2.3 Calibration experiments in the different chambers. Mean values of difference in volume between in and outgoing CO_2

Tabel 2.3 Kalibreringsforsøg i de forskellige kamre. Middelværdier af volumen differencer mellem ind- og udgående CO_2

Chambers Series	No. No.	A H-K	B H-K	C J	D J	E G	F G
Calibration experiments	n	11	11	5	5	3	7
Diff. CO_2	%	1.07	1.65	0.82	1.36	0.60	0.33
	SD	0.88	1.07	0.08	1.02	0.44	0.19

Chambers A and B gave in average differences between the volume of ingoing and outgoing CO_2 of 1.07% and 1.65% respectively which are of the same magnitude as in earlier experiments, *Thorbek (1980)*. Satisfactory results were also obtained for the other units with mean values of deviations between ingoing and ougoing CO_2 being 0.82% and 1.36% for chambers C and D, and 0.60% and 0.33% for chambers E and F. The values were were not significantly ($P > 0.05$) different and the mean for all 6 chambers was 1.07% indicating a high accuracy of the respiration plant.

2.3.3.3 Analytical precision of gas analyses

Precision of CO_2 and O_2 analyses was evaluated according to the same method as described for chemical analyses (cf. Chapter 2.5.1). Using duplicate or triplicate analyses the following results were obtained as shown in Table 2.4.

Table 2.4 Precision of multiple analyses in determination of CO_2 and O_2 concentration in outgoing air. Mean values from the different series

Tabel 2.4 Analytisk nøjagtighed ved multiple bestemmelser af CO_2- og O_2-koncentration i udgående luft. Middelværdier fra de forskellige serier

Series Chambers		G E-F	H A-B	K A-B	J C-D
Analyses	n	81	16	16	16
CO_2	CV %	0.56	0.58	0.48	0.80
O_2	CV %	0.81	0.63	0.48	1.48

The coefficient of variation (CV) values for CO_2 determination were in the range from 0.5 to 0.8% and for O_2 determination from 0.5 to 1.5%. As the carbon loss in CO_2 is about 40–50% of the carbon intake it is necessary to work with a high precision of CO_2 analyses, hence the precision of CO_2 analyses was considered to be satisfactory being in accordance with a high precision obtained in the determination of carbon in food, droppings and eggs (Table 2.7). The higher CV values for O_2 analyses are probably due to a high sensitivity of O_2-analysator to changes in barometric pressure.

2.4 Experimental diets

The hens were fed ad libitum with the same food compound in all series during the experiment and with free access to water. Oyster shells were available in the intermediate periods but not during the balance periods. A commercial food compound used at the Test Station in Favrholm (diet C) was delivered to the Laboratory in two batches, one in 1980 for series G and H and one in 1981 for series K and J. The composition of the food compound is shown in Table 2.5.

Table 2.5 Composition of food compound (g/kg)
Tabel 2.5 Sammensætning af foderblanding (g/kg)

Barley	608
Oats	100
Maize	50
Lucerne greenmeal	70
Meatbonemeal	57
Fishmeal	40
Fat, animal	30
$CaCO_3$	35
NaCl	4.4
$MnSO_4$	0.5
ZnO	0.1
Ethoxyquin	0.2
Vitamin mixture[1)]	4.8

[1)] Vitamin mixture mg/kg food
[1)] Vitaminblanding mg/kg foder

Retinol	4.61
Chlolecalciferol	0.048
α-tocopherol	13.44
Thiamin	0.24
Rifboflavin	8.16
Nicotinamid	12.00
Pteroylmonø glutamic acid	0.77
Pyridoxine	4.56
Cyanocobalamin	0.015
Panthothenic acid	16.56
Biotin	0.072
Choline	192.0

The diet contained 19.6 g calcium and 6.6 g phosphorus per kg food according to *Neergaard (1983)*. Chemical analyses of the food compound (cf. Chapter 2.5) were performed 8 times for each series and the mean values are demonstrated in Table 2.6.

Table 2.6 Chemical composition of food compound
Tabel 2.6 Kemisk sammensætning af foderblanding

Series No.	G–H		K–J	
	as fed %	DM %	as fed %	DM %
Dry matter	86.64	–	89.72	–
Organic matter	79.70	91.99	81.39	90.72
Crude protein (N×6.25)	14.75	17.02	15.06	16.79
Crude fat (Stoldt)	6.14	7.09	6.55	7.30
Crude fibre	5.48	6.33	6.11	6.81
Crude ash	6.95	8.02	8.33	9.28
Nitrogen-free extracts	53.99	61.55	53.67	59.82
Energy (MJ/kg)	16.32	18.84	16.63	18.54

The chemical analyses of the two batches showed that the food supplied in 1981 had about 2% higher content of dry matter, organic matter and energy but the differences were considered to be negligible and were not a matter of further attention.

2.5 Chemical analyses

Food. The aliquote samples of food were analysed for dry matter (DM), ash, nitrogen (N), fat, crude fibre (CF), carbon (C) and energy (E). The food residuals were weighed, mixed and used for DM determination in order to correct for differences in moisture content between food and food residuals.

Droppings. After concluding a collection period, droppings were thawed (24 hours), weighed and mixed in 10 minutes. A sample was taken for determination of DM in »fresh« material while a part was freeze-dried, milled and used for analyses of DM, N, C and E.

Eggs. In series G all eggs (but no more than 6) from each hen were used for chemical analyses while in the other series 6 at random chosen eggs from maximum 21 collected in each group in series H and K or from 42 in series J were sampled for chemical analyses. Eggs were weighed and boiled for 12 minutes. After cooling (15 minutes in cold water) they were peeled and shells, and the content of eggs was weighed. Additionally in series K, yolks and whites from boiled eggs were separated and weighed. Egg's content was mixed (10 minutes) and samples were taken for DM determination and for freeze-drying. The freeze-dried material was grinded in mortars and distributed for chemical analyses of DM, ash, N, fat, C and E. The shells were air-dried during 4 days then grinded in mortars, milled and used for N and C analyses.

For the purpose of calculation the DM content in droppings and eggs was determined both in »fresh« droppings and boiled eggs as well as in the freeze-dried

materials. The chemical analyses of DM, ash, N, CF and E were done according to methods described by *Weidner & Jakobsen (1962)*. Crude fat was determined according to Stoldt-method *(Stoldt, 1957)* by HCL-hydrolysis prior to diethyl-ether extraction (HCL + EE) as this method extracts more fat and fatty acids than ether extraction alone, *Thomsen (1972)* and *Thorbek & Henckel (1977)*. Carbon was determined according to the principle of electric conductivity, by means of Wästhoff-apparatus, *Neergaard et al. (1969)*.

2.5.1 Analytical precison of chemical analyses

The term precision can be considered as repeatibility of analyses, describing the closeness of agreement between successive results obtained with the same method on identical materials under the same operational conditions. As balance experiments are based on analyses of N, C and E in food, droppings and eggs, errors attached to those analyses are a potential source of shortcoming results. In order to measure the analytical repeatibility, the method described by *Rasch et al. (1958)* was applied, using duplicate, triplicate or quadruplicate analyses to estimate the coefficients of variation, CV% (SD × 100/mean). This method presumes that the errors of multiple analyses are independent of concentration (or if they are not, data may be grouped according to concentrations) so there is a linear relationship between log SD plotted against log mean. It follows that SD is proportional to a mean value, which again means, that the relative standard deviation is constant. The precision of multiplicate analyses for N, C and E in food, dropping and eggs is presented in Table 2.7.

The precision obtained for N, C and E determination in food was of the same magnitude as in earlier results from the experiments with pigs and calves, *Thor-*

Table 2.7 Precision of multiple analyses in determination of nitrogen, carbon and energy in food, droppings and eggs. Mean values from the different series

Tabel 2.7 Analytisk nøjagtighed ved multiple bestemmelser af kvælstof, kulstof og energi i foder, gødning+urin og æg. Middelværdier fra de forskellige serier

Materials	Series No.	Sampl. n	Nitrogen CV %	Carbon CV %	Energy CV %
Food	G-H	8	0.61	0.30	0.48
Food	K-J	8	0.39	0.23	0.23
Droppings	G	81	1.46	0.59	0.46
Droppings	H	51	0.83	1.14	0.48
Droppings	K	56	2.04	0.81	0.34
Droppings	J	16	0.78	0.87	0.30
Eggs	G	81	1.04	1.09	0.66
Eggs	H	51	0.86	0.87	0.46
Eggs	K	56	1.10	0.81	0.40
Eggs	J	16	0.75	0.89	0.37

bek (1975, 1980). The CV values indicated very small error attached to these analyses. Determination of N and C in droppings was carried out with CV in the range from 0.6 to 2.0% being higher than for faeces in experiments with pigs and calves and indicating difficulties in homogenous mixing of faeces and urine in droppings. The CV values for N and C analyses in eggs were fairly constant of about 1% indicating a high precision of the analyses and a good homogeneity of the samples. Concerning the precision of energy determination in droppings and eggs, a low CV value of about 0.4% demonstrates a very good repeatability of the multiple analyses. Keeping in mind that errors attached to the analyses of droppings and eggs are not directly comparable with errors associated to the analyses of food, as the impact of different materials on final results from balance experiments is not equal, the precision obtained in all analyses can be considered satisfactory.

2.6 Methods of calculation

Energy balance and heat energy were calculated by means of carbon and nitrogen balances (C-N method) measured over a 7 days period of collection with a 24 hours respiration experiment placed in the middle of the period. The values of N intake, N in droppings, N in eggs, C intake, C in droppings and C in eggs were determined in chemical analyses. The values of gross energy, energy in droppings and energy in eggs were obtained by means of calorimetric bombs and the values of CO_2 production from respiration measurements. The set of constants and factors accepted at the 3rd Symposium on Energy Metabolism, *Brouwer (1965),* was used for all calculations. The calculations were performed in the following way:

N balance,g = N intake,g – (N in droppings, g + N in eggs,g)
Protein balance,kJ = N balance,g × 6.25 × 23.86

C in CO_2 production,g = CO_2 production, litres × 0.536
C in Protein balance,g = N balance,g × 3.25
C balance,g = C intake,g – (C in droppings, g + C in eggs,g + C in CO_2 production,g)
C in Fat balance,g = C balance,g – C in Protein balance,g
Fat balance,kJ = C in Fat balance,g × 1.304 × 39.76

Energy balance,kJ = Protein balance,kJ + Fat balance,kJ

Heat energy,kJ = Gross energy,kJ – (Energy in droppings,kJ + Energy balance,kJ + Energy in eggs,kJ).

The quantity of Protein balance,kJ was calculated by multiplying N balance,g by 6.25 and by 23.86 assuming that protein tissue contains 16% N and the energy factor for 1g protein is 23.86 kJ. Fat balance,kJ was calculated by multiplying C in Fat balance,g by 1.304 and by 39.76 assuming that C not being stored in protein was solely stored as saturated fat (C_{16} or C_{18}) which contains 76.7% C (100/76.7=1.304) and the energy factor for 1g fat is 39.76 kJ.

All results presented in tables and figures were calculated per hen in 24 hours.

2.7 Statistical analyses

The hens were allocated to the experimental treatments in an allotment of a continous trial in which an animal, once placed on a given treatment, remains on that treatment until the end of experiment. Therefore if any time trends exists, they would affect all treatments equally and do not need to be considered in between treatments comparisons. A completely randomized design was used, as the hens were simply allotted to the treatments in a random fashion and thus no attention was given to the matter of whether or not the groups were alike with respect to various characteristics as live weight or egg production in the preliminary period. The design of the present experiment allowed to use simple statistical analyses with a high sensitivity associated with a resonable number of degrees of freedom (df) for error as discussed by *Lucas (1975)*. The experiment involved 3 factors namely the ambient temperature, origin and housing system.

In series H and K the hens with different origins were allocated to the similar housing system and were measured at corresponding temperatures and the results were tested by means of two way analysis of variance (ANOVA) according to the following model.

$$Y_{ijk} = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{(ij)k}$$

The value of μ is the common level, α_i and β_j represent the effects of i-th level of temperature and j-th level of origin, respectively. The value of $(\alpha\beta)_{ij}$ is the effect of interaction between temperature and origin and with mean 0($E\{\varepsilon_{(ij)k} = 0$)is the random effect of unspecified variables (error). The measurements for each fixed combination of factors were mostly normally distributed and the homogeneity of variance among replicates was proved by Brown and Forsythe-test, *Gill (1978)*. The generally accepted method of weighed squares of means, *Snedecor (1956)*, was used to perform ANOVA for the unbalanced 2 factor model with fixed effects. The following hypotheses (H) were tested:

H.1: $(\alpha\beta)_{ij} = 0$ about inconsistent response between factors i.e insignificance of interaction in relation to the main effects. If the hypothesis was accepted the

not significant ($P > 0.05$) interaction was not pooled with error as the df for error was more than the df for interaction, *Mead et al. (1975)*.
H.2: $\alpha_i = 0$ and H.3: $\beta_j = 0$ about inconsequential effects of factors i.e that the effects of factors temperature and origin were not significant.

The effect of temperature in series J and the effect of housing for series G versus H were analysed by using t-test of the mean values. The application of the different statistical tests is shown in Figure 2.1.

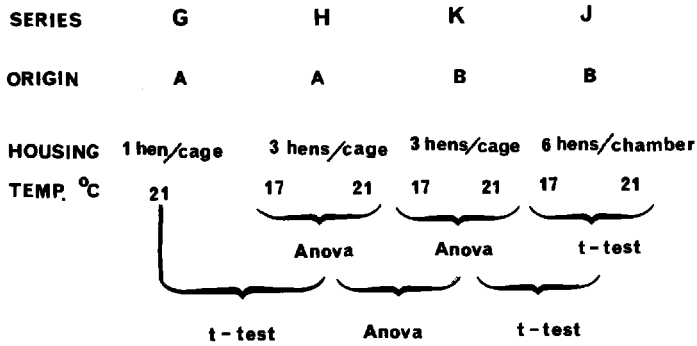


Figure 2.1. Survey of statistical analyses.
Oversigt vedrørende statistiske analyser.

An effect of the age of hens (periods) on the measurements was inspected for most of the parameters by means of one way analysis of variance for all periods or by t-test if only two periods were compared.

The regression analyses were performed according to the following model:

$$Y_i = \alpha + \beta_o x_{io} + \beta_1 x_i \ldots . \beta_p x_{ip} + \varepsilon_i$$

where Y_i = observed value of the dependent variate for i-th unit, α is the common level of the dependent variate, x_{ij} = value of jth independent variate for ith unit, β = the parameters to be estimated for $j = 0,1\ldots,p$, ε_i = an error associated with the ith unit of Y, ε_i is assumed to be mutually independent, identically and normally distributed with mean value 0.

The calculations were made according to *Henckel (1973)* using a programme developed at A/S Regnecentralen. The programme performs one-dimensional or multi-dimensional regression analyses with possibility for comparison of several regression planes according to models with or without intercepts. The equations with intercept (model 1) and without intercept (model 2) can be written as follows:

Model 1. $Y = a + \sum_{i=1}^{p} b\,(x_i - \bar{x}_i)$ with Var., (Y) = constant

Model 2. $Y = \sum_{i=1}^{p} b_i x_i$ with Var., (Y) = constant

All estimates were calculated by the least squares error method (LSE). Comparing different groups of observations (sets of linear regressions) the best regression coefficiencts were determined by LSE-method, which graphically means minimization of the sum of squares of vertical distances between the observed values and fitted hyperplanes. In the within-group analyses the normal distribution of Y_i was assumed and the homogeneity of variance was proved by means of Bartlett's test, *Gill (1978)*. The following hypotheses, depending on the regression model were tested.

Model 1.
H.1.1: about parallel regression planes through the groupwise center of gravity,
H.1.2: about identity of the groupwise regression planes i.e one common regression plane through the center of gravity in the total data material,
H.1.3: that all regression coefficients under H.1.2 are not significantly different from 0.

Model 2.
H.2.1: about identity of the groupwise regression planes i.e one common regression plane through the origin,
H.2.2: that all regression coefficients under H.2.1 are not significantly different from 0.

The degree of significance was expressed in terms of a significance level 1-α with the generally used values of α = 0.95, 0.99 and 0.999 corresponding to 0.05, 0.01 and 0.001 significance level and in the tables denoted as *, **, ***, respectively.

III. Performance

The mean values of age, live weight, food intake, egg production and laying rate for 8 balance periods (per. I-VIII) are shown for each series in the Main Tables. In series G with hens kept singly the values are means of the individual observations while in series H, K and J, with groups of hens, the measurements are divided with the number of hens in the group in order to obtain comparable individual values. All series were started by an age of 26 weeks and were concluded by an age of 47 weeks. The data were partly used to describe the course of performance including live weight, food intake and egg production during the experimental time and partly to evaluate the effect of temperature, origin and housing on the performance.

3.1 The course of live weight, food intake and egg production

Mean values of the initial live weight ranged between 1.5–1.7 kg and for the final live weight between 1.7–2.0 kg. The mean live weight gain for the whole experimental time was 117 g in series G and 217 g, 162 g, 168 g in series H, K, J at 17°C and 291 g, 267 g, 196 g in the same series at 21°C. The daily body gain varied from –5 to 2 g in series G and from –2 to 5 g in series H, K and J.

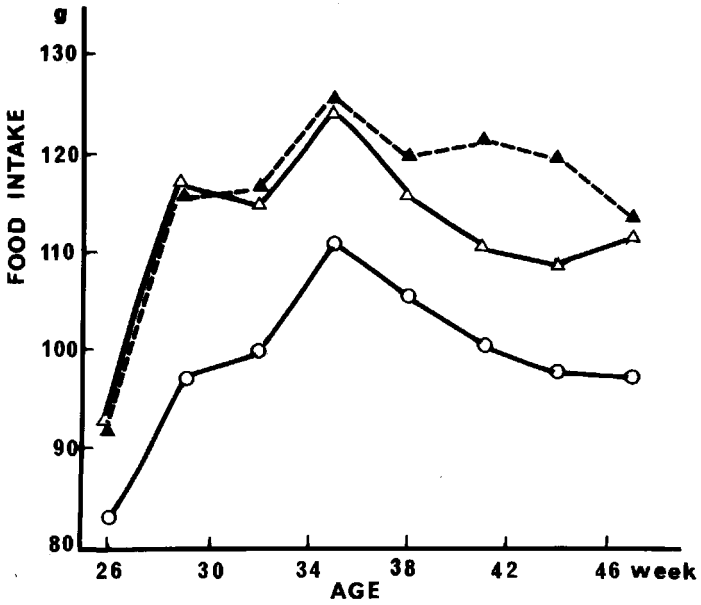


Figure 3.1. Mean values of food intake in relation to age. Series G and H. o Ser. G 21°C, ▲ Ser. H 17°C, △ Ser. H 21°C.
Middelværdier for foderoptagelse i relation til alder. Serie G og H.

The course of food intake, being ad libitum in all series is shown in Fig. 3.1 for series G and H and in Fig. 3.2 for series K and J. All series showed generally the same pattern for food intake starting with mean daily values of 83 g, 93 g, 116 g and 109 g independent of temperature for series G, H, K and J, respectively. Then the food intake increased to maxima of 111 g, 126 g and 135 g in series G, H and K by an age of 35 weeks while in series J a maximum of 120 g was reached at 32 weeks. In the later part of the experiment a relative constant plateau was obtained in all series.

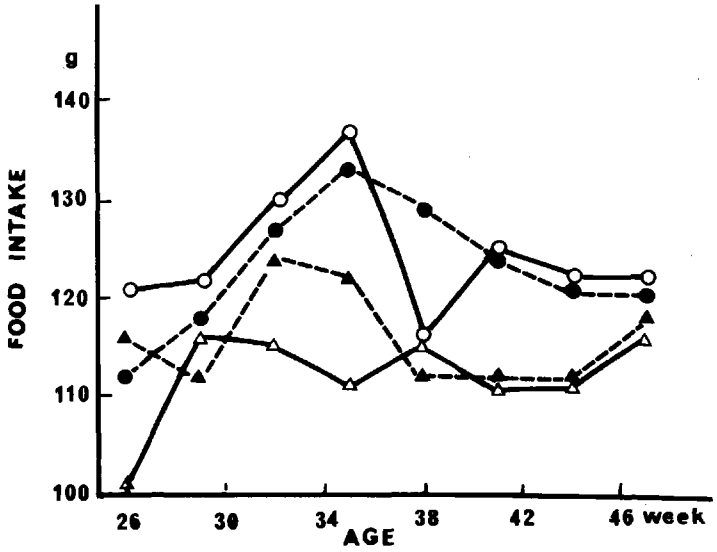


Figure 3.2. Mean values of food intake in relation to age. Series K and J. • Ser. K 17°C, o Ser. K 21°C, ▲ Ser. J 17°C, △ Ser. J 21°C.
Middelværdier for foderoptagelse i relation til alder. Serie K og J.

The course of egg production being demonstrated in Fig. 3.3 and 3.4 followed the same pattern for series G, H and K in reaching maxima at an age of about 38–41 weeks.

The daily egg production in period I (26 weeks) was 41 g, 42 g and 49 g for series G, H and K being significantly ($P < 0.001$) different from the maxima of 49 g, 49 g and 58 g in the respective series. Caused by some hens in series J laying their eggs on the floor the collection of eggs was incomplete, giving a very irregular picture of the egg production in this series as shown in Fig. 3.4.

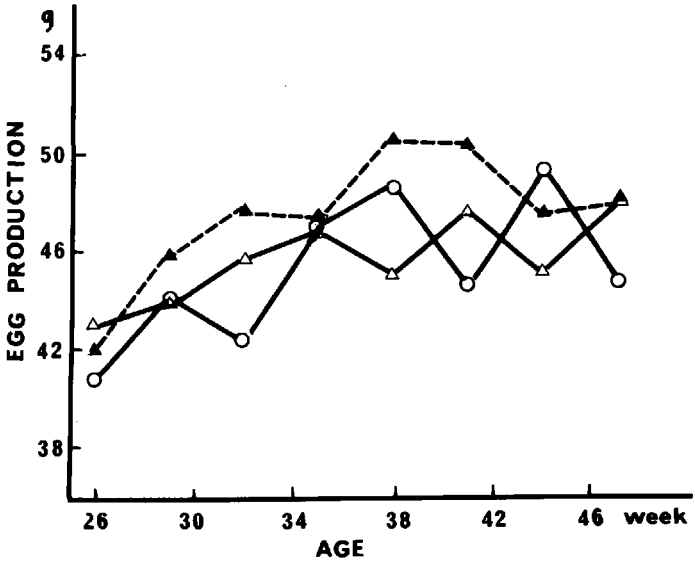


Figure 3.3. Mean values of egg procuction in relation to age. Series G and H. o Ser. G 21°C, ▲ Ser. H 17°C, △ Ser. H 21°C.
Middelværdier for ægproduktion i relation til alder. Serie G og H.

The laying rate was calculated as the number of eggs divided with the number of days in the collection period (No. eggs/7 × 100) and it varied from 76 to 85% in series G, from 78 to 89% in series H and from 87 to 99% in series K and no maxima were observed. The differences between periods were not significant ($P > 0.05$). In series J the laying rate started about 96%, but then caused by the laying habits it showed a great variation from 57 to 95%.

3.2 The effect of temperature, origin and housing on performance

The total material consisted of 204 balances with 81 individual measurements with single hens in series G and with 51 and 56 balances of groups (3 hens/cage) in the battery cages in series H and K respectively and with 16 group balances (6 hens/chamber) with the hens kept freely in the respiration chambers in series J (cf. Chapter 2.3.1). The grand means of all observations of live weight, food intake, egg production, laying ratio and food conversion rate (FCR) in each experimental series for the two ambient temperatures (17°C and 21°C) are presented in Table 3.1.

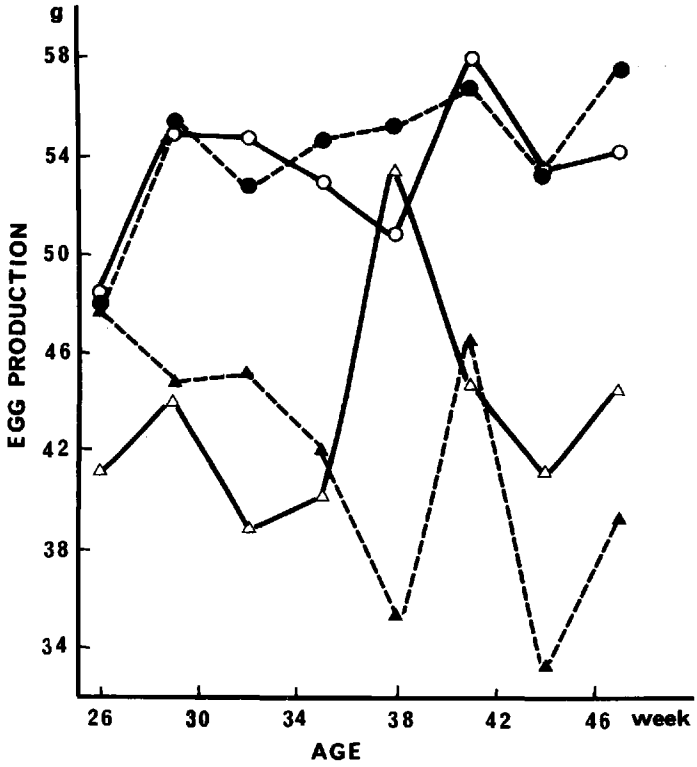


Figure 3.4. Mean values of egg production in relation to age. Series K and J. • Ser. K 17°C, o Ser. K 21°C, ▲ Ser. J 17°C, △ Ser. J 21°C.
Middelværdier for ægproduktion i relation til alder. Serie K og J.

All hens were weighed individually before and after each balance period. The mean initial live weight was 1560 g for origin A (series G and H) and 1630 g for origin B (series K and J). At both temperatures the mean daily ad libitum food intake was highest in series K with 124 g and lowest in series G with 99 g, with standard errors of means (SEM) varying from 1.4 to 2.2 and corresponding to the coefficient of variation (CV) between 6–10%.

The mean daily egg production was 45 g, 47 and 54 g in series G, H and K, respectively with SEM varying from 0.7 to 1.1. The mean value of 43 g with SEM from 1.6 to 1.9 in series J may be caused by insufficient egg collection. The mean laying rate was 82%, 84% and 94% in series G, H and K with SEM between 1.0 and 2.6. The average laying rate in series J was 78% with SEM from 3.7 to 4.4.

Table 3.1 Performance. Mean values of initial and final live weight (LW), food intake, egg production, laying rate and food conversion ratio (FCR) from 26 to 47 weeks of age

Tabel 3.1 Ydelse. Middelværdier for start og slut legemsvægt (LW), foderoptagelse, ægproduktion, æglægningsprocent og foderudnyttelse (FCR) i alderen fra 26 til 47 uger

Series	No.	G	H		K		J	
Temp.	°C	21	17	21	17	21	17	21
Balances	n	81	27	24	32	24	8	8
LW, initial	g	1555	1600	1531	1658	1704	1656	1511
final	g	1672	1815	1822	1820	1971	1824	1707
Food	g	99	115	112	123	125	116	112
SEM		1.5	2.2	2.1	1.4	1.7	1.7	1.8
EGG	g	45.3	47.5	45.8	54.2	53.5	41.7	43.5
SEM		0.78	0.74	0.67	0.78	1.07	1.90	1.62
Laying	%	81.5	85.3	82.1	94.6	92.4	74.7	80.9
SEM		1.16	1.03	1.23	1.70	2.62	4.39	3.65
FCR	g/g	2.19	2.42	2.45	2.27	2.34	2.78	2.57
SEM		0.033	0.039	0.052	0.033	0.053	0.128	0.085

The mean food conversion ratio (FCR = food,g/eggs,g) was 2.19, 2.43 and 2.30 in series G, H and K with SEM from 0.03 to 0.05, while the high values of 2.78 and 2.57 with SEM 0.13 and 0.09 in series J are related to the difficulties in collecting all eggs.

The data from the different series were used in statistical analyses in order to test the significance of differences observed in relation to the ambient temperatures, origins and housing. The statistical analyses were performed by means of 2 factor analysis of variance (ANOVA) by which the factors were compared simultaneously or by t-tests (cf. Chapter 2.7). The ANOVA was carried out with series H and K for hens being of different origins but kept in the identical housing systems in order to measure the effect of temperature and origin on the performance. The t-test was carried out in series J, in order to compare the effect of temperature on the mean performance. Furthermore the t-test was used to compare the effect of housing system on the mean performance using the results from series G and H. In series G all hens were kept at 21°C and were compared with the pooled observations in series H (17°C + 21°C) as there were no significant differences between the applied temperatures. The hens kept freely in series J were not compared with other housing systems as the results from this series are uncertain owing to the difficulties in egg collection, (Table 3.2).

Table 3.2 Statistical analyses of performance
Tabel 3.2 Statistiske analyser af ydelse

Methods		Analyses of variance				t-test	
Series		H versus K				J	G vs. H
Variables		Origin (H–K)	Temp. (17–21)	Inter-action	Error (ms)	Temp. (17–21)	Housing[1] (S–Gr)
df		1	1	1	103	14	130
Food	dif. g	–10.3	0.8			4.0	–14.6
	f	32.3***	0.06	2.03	265.8	1.62	6.68***
Egg	dif. g	–7.2	1.5			–1.8	–1.4
	f	76.5***	2.04	0.11	54.25	0.71	1.38
Laying	dif. %	–9.9	3.1			–6.2	–2.3
	f	9.02**	3.53	0.00	0.018	1.10	1.45
FCR	dif.	0.13	–0.06			0.21	–0.24
	f	8.15**	1.40	0.71	0.051	1.50	4.65***

[1] S = Single hens in battery cages, Series G
Gr = Group of hens in battery cages, Series H
) P<0.01, *) P<0.001

The statistical analyses (ANOVA) for series H and K indicated that there were no significant ($P > 0.05$) interactions between temperature and origin. The temperatures 17°C and 21°C had no significant ($P > 0.05$) effect on the tested performance parameters. The differences in the performance owing to the origins were all highly significant ($P < 0.01$ or 0.001). The hens from origin A (series H) had in average 10 g lower food intake, 7 g lower egg production, 10% lower laying rate and 0.13 higher FCR than origin B (series K). In series J the differences owing to the temperatures were not significant ($P > 0.05$) as found in series H and K. The single hens in series G and the groups in series H, kept in the battery cages showed highly significant ($P < 0.001$) differences concerning food intake and FCR. The mean food intake was 15 g lower while FCR was 0.24 better in series G than in H. There were no significant ($P > 0.05$) differences in egg production and laying rate.

3.3 Discussion

3.3.1 The course of performance

Live weight. In the present experiment the balances started with the hens sexually matured being 26 weeks old and weighing between 1.5–1.7 kg. The final live weight was between 1.7–2.0 kg and average body gain was in the range from 100 to 300 g during 22 weeks of the laying period. In all series the pattern of body gain was similar, increasing during experimental time and with relatively

high variation between individuals. In series G (hens kept singly) nearly 30% of all observations showed body losses up to –5 g daily. Observations with negative body gain were also noted in series H and K, however to a smaller extend. Negative body gain was primarly measured at the beginning of the experiment as it also was observed by *Neill et al. (1977)*. This may be caused by a markedly decrease in fat retention by body tissue at the beginning of laying as noted by *Chwalibog et al. (1984)*. The present results are in agreement with a number of balance trials with single hens where measurements of body gain or energy gain were usually attached to a big variation often with negative body gain depending on several environmental and nutritional factors, *Waring & Brown (1965, 1967), Grimbergen (1970), Es van et al. (1970), Es van et al. (1973)* and *Hoffmann & Schiemann (1973)*.

Food intake. Daily ad libitum food intake followed nearly the same pattern for all series. The food intake increased during the first 4 balance periods and reached a maximum in period IV by an age of 35 weeks then it varied around a constant level (Fig. 3.1 and 3.2). The mean food intake in series G increased from about 80 to 110 g, in series H from 90 to 125 g, in series K from 115 to 135 g and in series J from 110 to 115 g, at both temperatures. The mean values of food intake in the present investigation were of the same magnitude as the average food intake tabulated on basis of about 1 million data collected from Danish egg producers from 1981–82 by *»Landsudvalget for Fjerkræ«* (National Council for Poultry); *Report (1983)*. In this report the mean food intake increased from 110 g by an age of 25–28 weeks to 122 g in weeks 33–36 and then it was almost constant with about 124 g in weeks 37–48. An increasing food intake within the first months of laying was also demonstrated in the report from the Test Station for Laying Hens in Favrholm from where the hens in series G and H were delivered, *Neergaard (1980, 1983)*.

Egg production. The lower egg yield at the beginning of the laying period and then an increase during the first months of laying is a typical course of egg production. Daily egg production in series G, H and K was lower at the beginning of the experiment than in the following periods (Fig. 3.3 and 3.4) and it was significantly different from the maximum egg production reached by an age of 36 weeks or for older hens with about 49–58 g eggs. The measurements of egg production in series J showed higher variation than in other series, probably caused by difficulties in collecting all eggs as some eggs were damaged and eaten by the hens.

The laying rate was not significantly different between periods and it was varing between 76–89% in series G and H and from 87% to nearly 100% in series K. In series J the range was 57–98%, caused by incomplete egg collection. The data from *»Landsudvalget for Fjerkræ«, Report (1983)*, showed that the average laying pct. in the same age interval was 79–87% i.e. about the level in

series G and H and lower from series K. The average figures from the Test Station for Laying Hens in Favrholm for years 1979–80 were at 26 weeks of age about 80% while the maximum laying pct. of 92% was measured by an age of 33 weeks, *Neergaard (1980)*. In the recent report from the Test Station a lower laying pct. of about 70% and maximum of 88% was observed, *Neergaard (1983)*.

3.3.2 The effect of temperature, origin and housing on performance

Temperature. The statistical analysses showed no differences in performance between the applied temperatures. The hens kept at 17°C or 21°C had almost the same food consumption, egg production, laying ratio and food conversion rate (Table 3.2). As found by *Benedict et al. (1932), Sturkie (1954), King & Farner (1964)* the temperatures of 17°C and 21°C are inside the thermoneutral zone of domestic fowl. Both temperatures are also very close to the range of so-called optimum temperature suggested by *Kampen van & Romijn (1970)* to be between 15°C and 20°C with regard to food utilization and by *Es van et al. (1973)* between 10°C and 25°C described on basis of heat production. A biological optimum temperature (BOT) according to *Nichelmann (1983)* constitutes an ambient temperature at which an animal is exposed to minimum thermal stress so that on average the highest overall performance can be expected to occur at this temperature. Recently *Tzschentke & Nichelmann (1984)* reported that BOT for White Leghorns is about 19°C.

In general, it is accepted that food intake declines when ambient temperature increases as reviewed by *Sykes (1977), Kampen van (1981)* and *MacLeod (1984)*. As a result of the reduced intake of food and caused by the thermoregulatory response, *Cowan & Michie (1980)* at higher temperature, laying performance and body gain will be reduced. The changes in food intake can be observed even in the range 10–30°C but not always combined with reduced laying performance. A number of investigations dealing with temperatures between 10°C and 30°C, demonstrate that laying performance is not necessarily influenced by temperatures in this range, *Payne (1967), Ahmad et al. (1974), Haugen (1976)* and *Vohra et al. (1979)*.

The allocation to 17°C and 21°C in the present experiment is close to the temperatures (17.7°C and 21.4°C) applied in the »field trials« performed by *Petersen (1977)* on a large number of layers kept on sloping wire. His results showed lower food intake and slightly higher egg production at 21.4°C which was not the case in the present investigation. It is however questionable to what extent the egg output depends on temperature when food intake is not equal. As discussed by *Emmans (1974)*, an effect of temperature per se on laying performance can only be evaluated when intake of nutrients is similar and he concluded that the laying rate for White Leghorns at equal nutrient intake is inde-

pendent of temperatures from 5 to 25°C. Thus in the present experiment in which the food consumption was identical at both temperatures the egg production and the laying rate were similar at 17°C and 21°C.

Origin. Comparison between the two origins of White Leghorns (series H vs. K) kept in similar housing system and temperatures showed that all performance parameters were highly significant different (Table 3.2). The hens from origin B (series K) had about 10 g higher food intake, 7 g higher egg production, 10% higher laying rate and 0.13 g/g better FCR than origin A (series H). The results are in accordance with the data from the Test Station for Laying Hens in Favrholm (for hens in deep-litter system) demonstrating a higher food consumption, egg production and laying pct. and a better FCR for Shaver St. 288 than for the test groups (no. 27, 28) belonging to the same origin as in series H, *Neergaard (1983).*

Housing. In the present experiment the hens kept singly in the battery cages (series G) with the floor area of 2100 cm^2/hen had a significantly lower food intake but better FCR than groups of hens kept in the battery cages with 3 hens/cage and the area of 700 cm^2/hen (series H). However, the egg production and laying rate were not significantly different (Table 3.2). The differences in food intake can be related to the number of hens per cage and to the area per bird. It is likely that the lower food intake of single hens is combined with so-called social facilitation by eating. The term was originally proposed by *Tolman (1964)* in his studies on growing chickens where the birds reared in pairs ate significantly more than the isolated chickens. Apparently, the presence of the second bird serves as a stimulus for eating, whether this stimulus is simply a companion or more specifically a companion who is eating is not clear. Thus *Savory (1975)* and *Savory & MacLeod (1980)* reported that groups of growing birds gain more rapidly than the isolated individuals, however, the improved gain was due to the better food conversion ratio but food intake was not increased. However, *Chwalibog et al. (1978)* demonstrated that chickens kept in individual cages had a lower food consumption and a higher FCR than chickens kept in groups, probably caused by a lack of competition. For laying hens *Hughes & Black (1974 a)* suggested that the presence of a second bird has a socially facilitating effect on eating pattern causing an increased food intake.

The number of hens in a cage is a controlling factor appearing mostly in combination with the area per bird and feeding space *(Robinson, 1979)* as well as with the locomotor activity, *Hughes & Black (1974 b).* In the present investigation activity was not measured but it was observed that the hens kept in groups in series H were more active than the hens kept singly in series G. Locomotor activity has often been cited as at least a partial explanation of different performance as reviewed by *MacLeod et al. (1982),* and it is likely to influence food intake, *Süs (1976)* and *Eskeland (1977).* In the present experiment by increas-

ing the number from 1 to 3 hens per cage (series G and H) the area per hen and the feeding space were proportionally diminished. Each cage had a food trough of 47 cm and the feeding space was big enough to allow all hens to eat at the same time, therefore the factor »feeding space« seems to be negligible for the present studies. Laying performance may be independent of number of birds in colonies if floor area per bird is constant, *Wells (1971)* and *Robinson (1979)*. However, after reviewing several experiments *Hughes & Black (1974a)* and *Hughes (1983)* concluded that egg production decreases with increasing colony size. This is most noticeable for small colonies on an area below 400 cm^2/hen as reported by *Hill & Binns (1973), Carpena (1973), Purkiss & Perry (1974)* and *Robinson (1979)*. Moreover no reduction in laying pct. was found between 1 and 2 hens/cage on area 1520 cm^2 and 760 cm^2 by *Eskeland et al. (1977)*. Consequently the lack of differences in egg production and laying rate betweens series G (2100 cm^2/hen) and H (700 cm^2/hen) could be explained by the relatively big area/hen in both housing systems.

Resuming the above discussion it can be suggested that, at both temperatures for the hens kept together, the increase in food intake may be called a »luxury consumption« as the egg production did not increase and thus the FCR was higher than in single hens. This leads to the conclusion that from a nutritional point of view the egg production from single hens is less expensive than from hens kept in groups. However the question remains whether the phenomenon can be explained on basis of energy metabolism.

IV. Size and chemical composition of eggs

The mean values of egg size and chemical composition of eggs in the different balance periods are shown in the Main Tables. The values are either means of individual or group measurements. The data were used partly to describe the size of eggs and chemical composition in relation to the laying period (age) and partly to evaluate the effect of temperature, origin and housing on these two parameters.

4.1 Size and chemical composition of eggs during laying period

Size. The relations between egg size and age are shown graphically in Fig. 4.1 for series G and H and in Fig. 4.2 for series K and J.

The mean size of eggs at the beginning of the experiment, by an age of 26 weeks was 51 g, 50 g, 54 g and 46 g for series G, H, K and J at both temperatures (17°C and 21°C). The egg size increased during the laying period and the final

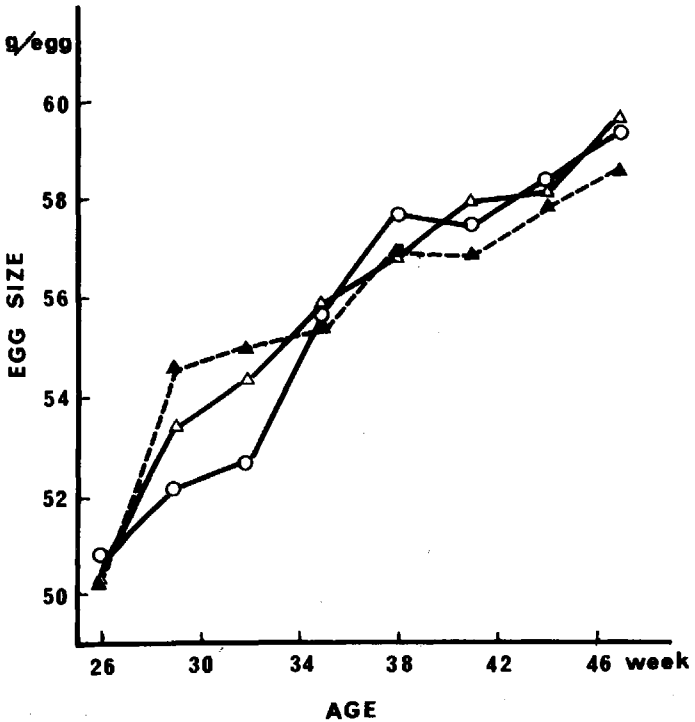


Figure 4.1. Mean values of egg size in relation to age. Series G and H. o Ser. G 21°C, ▲ Ser. H 17°C, △ Ser. H 21°C.
Middelværdier for ægstørrelse i relation til alder. Serie G og H.

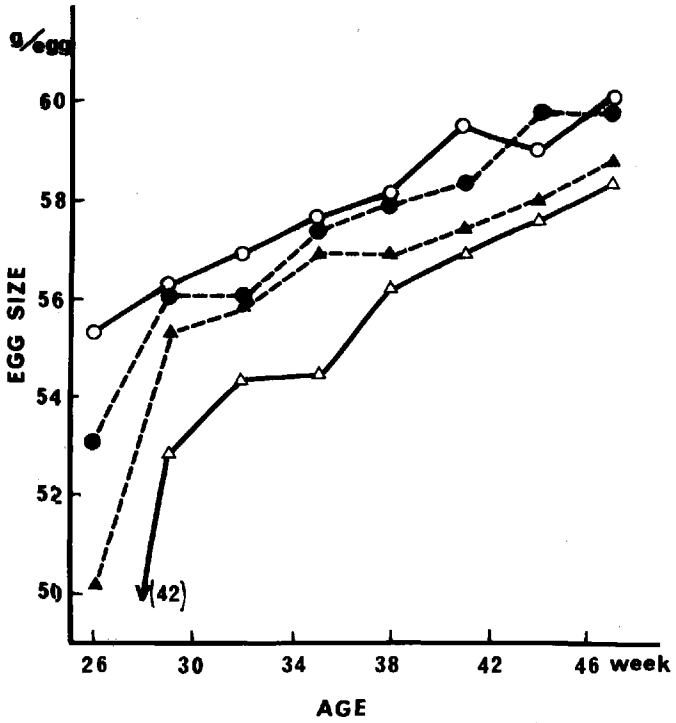


Figure 4.2. Mean values of egg size in relation to age. Series K and J. • Ser. K 17°C, ○ Ser. K 21°C, ▲ Ser. J 17°C, △ Ser. J 21°C.
Middelværdier for ægstørrelse i relation til alder. Serie K og J.

size was about 59 g for all series. The differences between the initial and final egg size were in all series highly significant ($P < 0.001$). Yolks and albumen were separated and weighed in series K (cf. Chapter 2.5). The amount of yolk increased from 14.5 to 17.5 g in periods I-VIII.

The ratio between the weight of yolks and the total weight of eggs content showed a significant ($P < 0.01$) increase from 28.8 to 32.6% in periods I-VIII corresponding to a decrease in albumen/eggs content from 71.2 to 67.4%. The ratio between the weight of yolks and albumen increased from 41.0 to 48.0%, being highly significant ($P < 0.001$).

Chemical composition. The mean values of the chemical composition of eggs content (eggs without shells) in relation to age are shown graphically in Fig. 4.3 for series G and H and in Fig. 4.4 for series K and J. With no significant ($P > 0.05$) influence of the temperatures on the chemical composition, the curves indicate mean values from both temperatures.

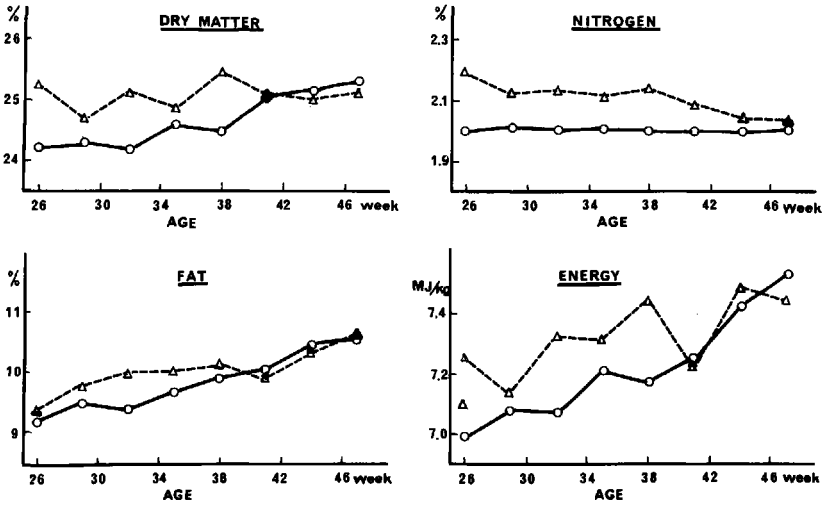


Figure 4.3. Mean values of dry matter, nitrogen, fat and energy in eggs in relation to age. Series G and H. o Ser. G 21°C, △ Ser. H (17°C + 21°C).
Middelværdier for indhold at tørstof, kvælstof, fedt og energi i æg i relation til alder. Serie G og H.

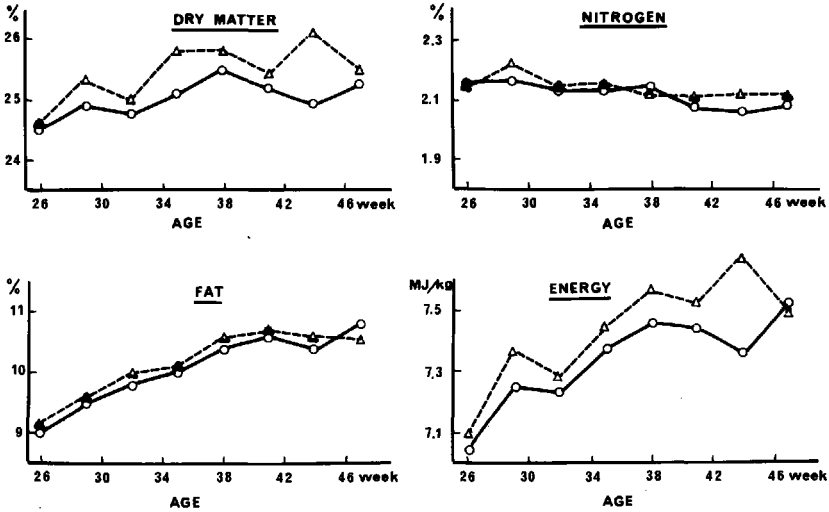


Figure 4.4. Mean values of dry matter, nitrogen, fat and energy in eggs in relation to age. Series K and J. o Ser. K (17°C + 21°C), △ Ser. J (17°C + 21°C).
Middelværdier for indhold af tørstof, kvælstof, fedt og energi i æg i relation til alder. Serie K og J.

The dry matter content ranged between 24–26% and nitrogen between 2.0–2.2% for all series with no significant ($P > 0.05$) differences between periods. The mean fat content increased from 9% in period I to 10.5% in period VIII and the difference was highly significant ($P < 0.001$). The mean energy content, except series H at 17°C, was about 7.1 MJ/kg eggs (without shells) in period I and increased to 7.5 MJ/kg in period VIII. The differences between period I and VIII in series G and H at 21°C were »nearly« significant ($0.05 < P < 0.10$) while in series K the difference was highly significant ($P < 0.01$).

4.2 The effect of temperature, origin and housing on the size and chemical composition of eggs

The grand means of all observations of egg size and chemical composition of eggs content in each experimental series for the temperatures 17°C and 21°C are presented in Table 4.1.

The mean dry matter content varied between 25–26%, nitrogen 2.1–2.2%, fat 9.9–10.3% and ash 0.93–0.96%. The content of energy was about 7.2 MJ/kg eggs content in series G, 7.3 MJ/kg in series H and K and 7.4 MJ/kg in series J. All means were estimated with small standard errors (SEM) being of the same magnitude for all series and corresponding to CV between 2–5% for dry matter, 2–4% for nitrogen, 6–9% for fat, 3–11% for ash and 2–5% for energy. The small differences found in the chemical analyses of egg content (Table 4.1) be-

Table 4.1 Mean values of size, chemical composition and energy content of eggs from 26 to 47 weeks of age

Tabel 4.1 Middelværdier for størrelse, kemisk sammensætning og energi-indhold i æg i alderen fra 26 til 47 uger

Series	No.	G	H		K		J	
Temp.	°C	21	17	21	17	21	17	21
Balances	n	81	27	24	32	24	8	8
Size	g/egg	55.3	55.4	55.8	57.3	57.5	56.2	54.1
SEM		0.49	0.76	0.63	0.49	0.44	0.93	1.83
DM	%	24.6	25.2	24.9	25.1	25.0	25.5	25.4
SEM		0.13	0.18	0.12	0.11	0.12	0.16	0.25
N	%	2.08	2.12	2.11	2.12	2.12	2.17	2.11
SEM		0.010	0.017	0.017	0.011	0.015	0.014	0.017
FAT	%	9.86	10.13	9.98	10.02	10.06	10.10	10.33
SEM		0.095	0.127	0.135	0.125	0.116	0.200	0.260
ASH	%	0.93	0.95	0.93	0.94	0.95	0.95	0.96
SEM		0.011	0.021	0.013	0.008	0.011	0.011	0.023
OE	kJ/kg	7215	7378	7285	7333	7344	7432	7440
SEM		43.1	60.7	59.3	40.5	41.2	58.6	81.6

tween series, indicated no influence of temperature, origin and housing on the chemical composition of eggs.

The mean egg size was highest in series K with about 57 g for both temperatures and lowest in series G and H with 55 g, with CV values from about 4 to 10% for all series. The individual data of egg size from different series were used in the statistical analyses (cf. Chapter 2.7) in order to test the effect of temperature, origin and housing on this parameter. The comparisons were made by means of 2 factor analysis of variance (ANOVA) and t-tests as described in the previous chapter (cf. Chapter 3.2). The analysis of variance between series H and K indicated that there was no significant ($P > 0.05$) interaction between temperature and origin. The analysis showed that the difference in egg size of 0.2 g between 17°C and 21°C was not significant ($P > 0.05$) in series H and K. Neither showed the t-test in series J any significant ($P > 0.05$) difference owing to the temperatures. The origin A (series H) had in average 1.8 g smaller eggs than origin B (series K) and the difference was highly significant ($P < 0.001$). The eggs from the hens kept singly (series G) were in average 0.3 g smaller than from the groups (series H) but the difference was not significant ($P > 0.05$).

4.3 Discussion

4.3.1 Size and chemical composition of eggs during laying period

Size. The egg size in the present experiment increased from 50 g, 51 g, 54 g and 46 g by an age of 26 weeks in series G, H, K and J respectively, to about 59 g by an age of 47 weeks for all observations and the differences were highly significant. It has early been documented that egg size increases with age of the hen, *Clark (1940)* and *Jeffery (1941),* lately being confirmed by many authors as reviewed by *Fletcher et al. (1981).* At the Test Station for Egg Layers in Favrholm, *Neergaard (1980),* the egg size increased form 50 to 60 g as in the present investiation while the average values from Danish egg producers tabulated by *»Landsudvalget for Fjerkræ«, Report (1983),* were placed on a higher niveau i.e. from 53 to 62 g. A linear increase of egg size has been observed in several other reports although the maximum egg weight was reached at different age, *Anderson et al. (1978), Hurnik et al. (1977)* and *Ambrosen & Rotenberg (1981).* In the present experiment the increase in size was joint with increasing weight of yolks which constituted a greater part of the egg content at the end of the experimental period. By the same time the proportion between yolk and albumen was also increasing. Since the work of *Jull (1924)* who observed high correlations between weight of egg components and egg size a number of workers ascribed the differences in egg size to changes in weight of yolk and albumen. That hens produced more albumen by increasing egg size was shown by *Chung & Stadelman (1961), Skala & Swanson (1962)* and *Ajjam et al. (1977).* In contrast to the present results an increase in procent of albumen and a decrease in

percent of yolk with increasing egg size was reported by *Cunningham et al. (1960), Jenkins and Tyler (1960), Cotteril et al. (1962), Kline et al. (1965)* and *Ambrosen & Rotenberg (1981)*. However, the present results are in full agreement with findings of *Fletcher et al. (1981)* who showed that with increase of age, yolk in percent of egg content increased from 29 to 33% but percent of albumen decreased from 71 to 67%.

Chemical composition. The chemical analyses of eggs content showed no significant differences in dry matter and nitrogen content within age while significant increase in fat content from 9 to 10.5% and in consequence an increase in energy content from 7.1 to 7.5 MJ/kg was found. These results agree with *Anderson et al. (1978)* who reported that protein content did not vary with age, but they are in disagreement with the results from *Fisher (1983a)* who reported that protein content is declining over the first laying year. The increase in energy content in the present experiment is in contrast to *Hoffmann & Schiemann (1973)* who found decreasing energy content with increase in egg size, however, the differences in egg size were not related to the age of hen (the hens were more than 62 weeks old) but were probably caused by individual variation. The present findings are in accordance with *Sibbald (1979)* who calculated the linear regression of energy in eggs (with shells) in relation to egg weight (OE,kJ = –82.5 + 7.58 × egg weight) for eggs with different size, indicating lower energy content in smaller eggs and and thereby lower energetic value of eggs from younger hens. There is a number of measurements of energetic value of eggs demonstrating that the only one value can be used, independent of age of the hen *Tasaki & Sasa (1970), Davis et al. (1972), Hoffmann & Schiemann (1973)* and *Kirchgessner & Voreck (1980 b)*. However on the basis of the present investigation showing significantly increasing energy content in eggs from 26 to 47 week of laying, it may be suggested to use different energetic values of eggs within the laying period.

4.3.2 The effect of temperature, origin and housing on size and chemical composition of eggs

The present results showed that egg size was independent of the temperature (17°C or 21°C) and housing system while significant differences were found between the origins. Since the work of *Jeffery (1941)* temperature was considered as a factor which can influence egg weight. By temperatures above 25°C egg size tended to be depressed as reviewed by *Emmans (1974)* and *Fletcher et al. (1981)*. It was suggested that the depression in egg size at higher temperatures was due to a shortage of energy, *Payne (1967)*. However, *Smith & Oliver (1972)* and *Vohra et al. (1979)* showed that even on the same energy level egg size decreases by high temperatures. The not significant difference in egg size between 17°C and 21°C in the present investigation disagree with the results

presented by *Petersen (1977)* who measured 2.5% lighter eggs at 21.4°C than at 17.7°C but this was combined with reduced food intake and reduced egg production which was not the case in the present experiment (cf. Chapter 3.2).

The effect of the origin on egg size was significant in the present experiment being in agreement with many authors as discussed in detail by *Cunningham & Ostrander (1982)*. The differences in egg size between White Leghorn lines (or groups) were also noted at the Test Station in Favrholm where Shaver St. 288 in 28 weeks period of laying had an average egg size of 57 g while the control groups of the same origin as in series G and H produced eggs weighing 54 g, *Neergaard (1983)*.

The influence of housing on egg size is reviewed and discussed by *Bareham (1972)* for deep-litter versus battery cages, by *Petersen (1977)* for sloping wire versus deep-litter, by *Eskeland et al. (1977)* for different density in battery cages and by *Lee et al. (1978), Cunningham & Ostrander (1982)* and *Hughes (1983)* for an effect of cage shape. Results are often controversial as many associated factors as temperature, origin, feeding condition etc. are not specified. However the present results are in agreement with the experiment of *Eskeland et al. (1977)* who measured that the egg size was not significantly different between 1 hen/cage (1520 cm^2/hen) and 3 hens/cage (507 cm^2/hen), comparable with housing in series G and H.

Chemical composition and energy content of eggs (without shells) were almost the same in all series and thereby independent of the temperature, origin and housing. In average the eggs content consisted of 25% dry matter, 2.1% nitrogen (13% protein), 10% fat, 0.9% ash and 7.3 MJ/kg eggs. These values are in agreement with the literature as reviewed by *Siewert & Bronsch (1972), Hoffmann & Schiemann (1973)* and *Kirchgessner & Voreck (1980b)*.

V. Gas exchange

The mean values of daily carbondioxide production and oxygen consumption in the different balance periods are shown for each period in the Main Tables. The values are either means of the individual measurements (series G) or means of groups (series H, K and J) expressed per one hen. In series H and K, 4 battery cages with 3 hens/cage were placed in each respiration chamber while in series J, 6 hens were placed freely in each respiration chamber. The gas exchange was measured totally for all hens in the chamber and then it was divided between groups (series H and K) or between individuals (series J) in relation to their metabolic body weight ($W,kg^{0.75}$). In order to describe the course of gas exchange during the laying period from 26 to 47 weeks of age, the CO_2 production was related to age of the hens in each series. An attempt was made to calculate functions of CO_2 production and O_2 consumption in relation to $W,kg^{0.75}$, metabolizable energy (ME) and egg production using the individual observations from series G. Finally the effect of temperature, origin and housing on the gas exchange was inspected.

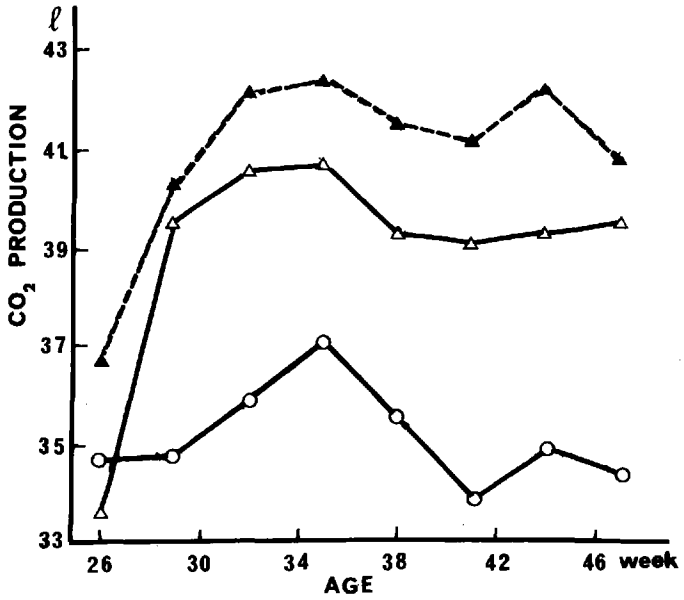


Figure 5.1. Mean values of CO_2 production in relation to age. Series G and H. o Ser. G 21°C, ▲ Ser. H 17°C, △ Ser. H 21°C.
Middelværdier for CO_2 i relation til alder. Serie G og H.

5.1 The course of CO_2 production and the predictions of gas exchange

Course. The relations between mean daily CO_2 production and the age of hens are shown graphically in Fig. 5.1 for series G and H and in Fig. 5.2 for series K and J.

The CO_2 production in series G in which the hens were kept at 21°C increased from 35 to a maximum of 37 l by an age of 35 weeks and then it decreased to about 35. The hens in series H, kept at 17°C or 21°C showed the same pattern with increasing CO_2 production from 37 to 42 (17°C) and from 34 to 41 (21°C) by an age of 35 weeks and then levels of about 41 and 40 l were maintained in the following weeks. In series K in which the highest CO_2 production was observed, levels of about 43 and 45 l were kept from 33 weeks of age and during the whole experimental time. In series J increments from 41 to 42 (17°C) and from 37 to 41 l (21°C) were measured.

Predictions. In order to establish functions for gas exchange in laying hens, the individual values of CO_2 production and O_2 consumption from series G were related to W,$kg^{0.75}$, ME and egg production. The multiple regressions of gas exchange were calculated according to the following model:

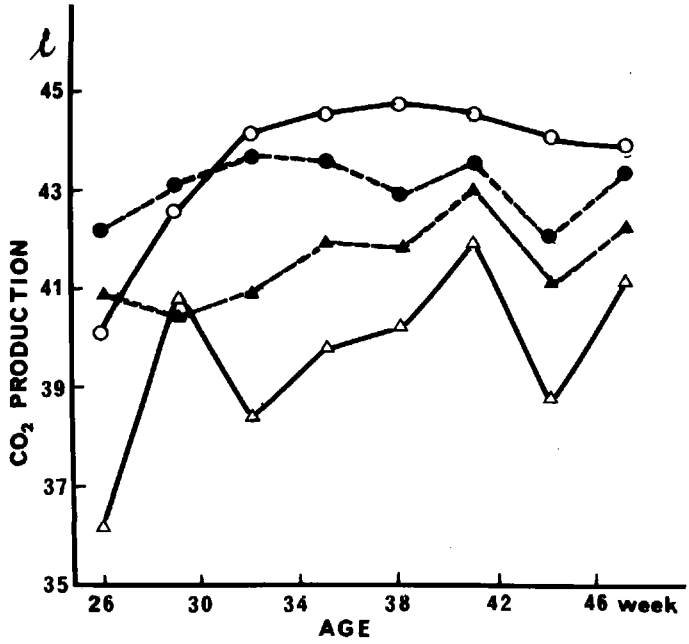


Figure 5.2. Mean values of CO_2 production in relation to age. Series K and J. • Ser. K 17°C, o Ser. K 21°C, ▲ Ser. J 17°C, △ Ser. J 21°C.
Middelværdier for CO_2 i relation til alder. Serie K og J.

CO_2 or O_2,l = a + b_1 × W,$kg^{0.75}$ + b_2 × ME,kJ + b_3 × Eggs,g
Where a is an intercept and b_1,b_2,b_3 are the regression coefficients. The following equations were obtained:

(1)	CO_2,l =	5.56 +	12.7 × W,$kg^{0.75}$ +	0.0084 × ME,kJ +	0.047 × Eggs,g
	se:	3.218	2.94	0.00214	0.0539
	t-test:	1.73	4.32***	3.92***	0.87

n = 81, RSD = 2.49, CV = 7.08%, R^2 = 0.564

(2)	O_2,l =	3.54 +	18.3 × W,$kg^{0.75}$ +	0.0048 × ME,kJ +	0.095 × Eggs,g
	se:	3.616	3.31	0.00241	0.0605
	t-test:	0.98	5.54***	2.01*	1.57

n = 81, RSD = 2.80, CV = 7.11%, R^2 = 0.584

A t-test for the »null« hypothesis of the intercepts and regression coefficients showed that the intercepts and the regression coefficients for egg production were not significant (P > 0.05). Consequently the variable egg production was excluded from the further calculations and multiple regressions of CO_2 and O_2 were calculated in relation to W,$kg^{0.75}$ and ME. The intercepts were not significant and the following equations through the origin (cf. Chapter 2.7) for CO_2 production and O_2 consumption in series G were obtained:

(3)	CO_2,l =	17.3 × W,$kg^{0.75}$ +	0.0094 × ME,kJ
	se:	1.61	0.00200
	t-test:	10.6***	5.00**

n = 81, RSD = 2.51, CV = 7.15%

(4)	O_2,l =	22.7 × W,$kg^{0.75}$ +	0.0063 × ME,kJ
	se:	1.80	0.00231
	t-test:	12.5***	2.95**

n = 81, RSD = 2.82, CV = 7.17%

Compared with the first set of equations (1,2) the residual standard deviation (RSD) and the coefficient of variation (CV = RSD/y × 100) increased only slightly but the values of R^2 from the regressions with intercept were markedly improved ((3) R^2 = 0.682, (4) R^2 = 0.720) when the information about egg production was excluded. Thereby indicating that daily CO_2 production and O_2

consumption in series G could be predicted with a satisfactory accuracy when based on metabolic body weight and metabolizable energy.

5.2 Gas exchange in different series

The grand means of all measurements of daily gas exchange in each experimental series for 17°C and 21°C are presented in Table 5.1. As the values of CO_2 production and O_2 comsumption in series H, K and J were obtained with corrections for metabolic body weights and number of hens, no statistical comparison was carried out between the series but only the magnitude of the means was inspected. The mean gas exchange was lowest in series G with in average 35 l CO_2 and 39 l O_2. The highest mean values were measured in series K with 43 l CO_2 and 47 l O_2 for both temperatures. The RQ values (CO_2/O_2) were 0.90, 0.86 and 0.92 in series G, H and K at both temperatures. In series J, RQ was 0.99 which may be caused by the O_2-analysator giving too low values (cf. Table 2.4) in this series.

Table 5.1 Gas exchange. Mean values of carbondioxide production (CO_2) and oxygen consumption (O_2) from 26 to 47 weeks of age

Tabel 5.1 Luftstofskifte. Middelværdier for kuldioxydproduktion (CO_2) og iltoptagelse (O_2) i alderen fra 26 til 47 uger

Series	No.	G	H		K		J	
Temp.	°C	21	17	21	17	21	17	21
Balances	n	81	27	24	32	24	8	8
CO_2	Litres	35.2	40.8	38.9	43.0	43.5	41.5	39.6
SEM		0.41	0.44	0.49	0.26	0.37	0.30	0.64
O_2	Litres	39.3	47.1	45.6	47.1	46.9	42.1	39.7
SEM		0.47	0.44	0.52	0.31	0.35	0.33	0.60

The differences caused by the temperatures were only 1.5 l of CO_2 and O_2 in series H and there were no differences between 17°C and 21°C in series K and J. Comparing the hens with different origins and allocated to the same housing (series H and K) the differences were small, about 3 l CO_2 and 1 l O_2. Greater differences in gas exchange were noted between housing systems in which the hens kept singly (series G) had about 6 l lower CO_2 and 7 l lower O_2 than the groups in the battery cages (series H and K). The hens kept freely (series J) had 2 l lower CO_2 and 6 l lower O_2 than in series H and K.

The equations of CO_2 production and O_2 consumption were estimated for series H and K at each temperature with gas exchange regressed on the $W,kg^{0.75}$ and ME as in series G. The functions of gas exchange in series J were not calculated as the determinations were uncertain. The performed multiple regres-

sions gave the possibility to test the effect of the temperature and origin and to inspect the influence of housing on gas exchange. Statistical analyses between the regressions at 17°C and 21°C, separately in series H and K showed no significant ($P > 0.05$) differences in gas exchange for the two temperatures. Consequently the regressions on the pooled observations (17°C + 21°C) in series H were compared with series K as in both series the hens were in the same housing and the gas exchange of each group (3 hens) was calculated in the same way (cf. Chapter 2.3.3). The regressions for the two origins of White Leghorns (series H vs. K) were not significant ($P > 0.05$). Finally the total regressions of gas exchange were calculated for all measurements in series H + K. The results are tabulated below together with the values for series G, and the equations for each housing system are inspected.

Model: CO_2 or O_2,l = $b_1 \times W,kg^{0.75} + b_2 \times ME,kJ$

		$W,kg^{0.75}$		ME,kJ			
		b_1	se	b_2	se	RSD	CV,%
CO_2 production, litres							
G	(n = 81)	17.3	1.61	0.0094	0.0020	2.51	7.15
H+K	(n = 107)	18.0	0.92	0.0120	0.0010	1.33	3.20
O_2 consumption, litres							
G	(n = 81)	22.7	1.80	0.0063	0.0023	2.82	7.17
H+K	(n = 107)	24.1	1.12	0.0072	0.0012	1.62	3.48

All regressions of gas exchange showed satisfactory residual standard deviations (RSD) in the rangae 1.3–2.8 corresponding to the relative RSD (CV) between 3.2–7.2%. Due to the different method of calculation the gas exchange in each housing system, no statistical analyses were carried out between the regressions but in order to compare the influence of the housing systems an attempt was made to preedict the gas exchange in each housing by means of the obtained regression equations. By assuming daily food intake of 100 g i.e. about 1130 kJ ME and live weight of 1.8 kg i.e. 1.55 $W,kg^{0.75}$ the following values of CO_2 production and O_2 consumption were obtained:

Series	Housing	CO_2,l	O_2,l
G	1 hen/cage	37	42
H+K	3 hens/cage	41	46

The results indicated that the groups of hens in the battery cages (series H, K) would have had about 11% higher CO_2 production and 8% higher O_2 consumption than the single hens (series G) under the given assumptions.

5.3 Discussion

Respiratory studies on the domestic fowl are few and generally carried out with fasting hens, kept isolated in the respiration chambers and measured in relatively short experiments as reviewed by *Misson (1974)* and *Boshouwers & Nicaise (1981)*. Under practical conditions laying hens are rarely fasted or kept on low feeding level and therefore it is of greater interest to obtain values for gas exchange from hens fed ad libitum, kept in conditions close to practical farming and measured over a longer period of laying as it was done in the present investigation. The gas exchange in the present experiment was either measured in hens kept singly (series G) or in groups permanently placed in the respiration chambers in the battery cages with 3 hens/cage or kept freely with 6 hens/chamber. In all series CO_2 production was lower at the beginning of the laying period than in the later periods and the curves of CO_2 production (Fig. 5.1 and 5.2) were parallel to the curves of food intake (cf. Fig. 3.1 and 3.2) thereby indicating a close relationship between CO_2 production and food intake during laying period.

The CO_2 production and O_2 consumption are close related to metabolism of the animal, and the levels of CO_2 and O_2 are directly dependent on animal size including body mass and surface. It is generally agreed that the power of live weight to which gas exchange is related is between 0.6–1.0 as reviewed by *Blaxter (1972)*. It has been agreed at a conference on energy metabolism in 1964, *Kleiber (1965)*, that for the sake of simplicity in calculations and for between species and interspecies comparisons the power of weight to which metabolism is proportional should be 3/4 and the metabolic body weight may be defined as $W,kg^{0.75}$. The linear relation between gas exchange and metabolic body weight can be obtained as long as there is a relatively big variation in live weight, for example for growing chickens, *Chwalibog et al. (1978)*, however, in laying hens the variation might be too small to give any reasonable function of gas exchange, *Geers et al. (1982)*, and in order to predict gas exchange other variables should be included. In the present experiment an attempt has been made to predict gas exchange by means of multiple regressions of CO_2 and O_2 in relation to $W,kg^{0.75}$, metabolizable energy and egg production. As it was mentioned before the curves of CO_2 production were similar to the curves of food intake and thereby to ME, furthermore it was assumed that gas exchange is dependent on egg production, hence non laying hens have lower heat production than layers, *Waring & Brown (1965)*, *Tasaki & Sasa (1970)* and *O'Neill & Jackson (1974)*. The multiple regressions were performed on the individual measurements in series G where the data of gas exchange were not divided between hens (cf. Chapter 2.3.3). The calculations showed that egg production could be excluded from the equations as its regression coefficients were not significantly different from zero and the following predictions of gas exchange were obtained:

CO_2,l = 17.3 × W,kg$^{0.75}$ + 0.0094 × ME,kJ,

O_2,l = 22.7 × W,kg$^{0.75}$ + 0.063 × ME,kJ.

The gas exchange was lowest for single hens (series G) and it was highest for the groups in the battery cages (Table 5.1). The valus of RQ were between 0.86–0.92 for series G, H and K being in accordance with the results obtained in experiments with poultry fed ad libitum or near ad. libitum, *Shannon & Brown (1969)* for cockerels, *Lundy et al. (1978)* for laying hens, *Johnson & Farrell (1982)* for broiler breeders and *Thorbek & Chwalibog (1984)* for chickens.

Considering that gas exchange can be satisfactory predicted from metabolic body weight and metabolizable energy as it was demonstrated for individual measurements in series G, the same regression model was applied in the other series. The regression equations were not significantly different between the applied temperatures and the origins indicating that independent on the origin the decrease in temperature from 21°C to 17°C did not cause an increase in the gas exchange and thereby no changes in heat production should be expected. However, the functions of gas exchange demonstrated that CO_2 production and O_2 consumption in the hens kept in groups (series H+K) was higher than for single hens (series G) when assuming an equal live weight and food intake. Since it is difficult to accept that differences in gas exchange were caused by different metabolic processes for hens in the two housing systems, the result may be explained by differences in the locomotor activity *(MacLeod et al. 1982)*. It has been previously discussed (cf. Chapter 3.3.2) that the hens kept in groups caused by the social facilitation by eating had a higher activity which can be the exclusive reason for the higher level of gas exchange indicating an extra energy expenditure and heat production. The fact may be considered both in nutritional cost and in design of environmental control system in poultry houses.

VI. Nitrogen metabolism

The mean daily nitrogen intake, nitrogen in droppings, nitrogen balance and nitrogen deposition in eggs for 8 balance periods are shown for each series in the Main Tables. The measurements of nitrogen balance include the part of nitrogen retained in eggs being under development in the ovarian system and the part retained in body. In series G with hens kept singly the values are means of individual observations while in series H, K and J, with groups of hens, the measurements are divided with the number of hens in the group in order to obtain comparable individual values. All series were started by an age of 26 weeks and concluded by an age of 47 weeks. The data was partly used to

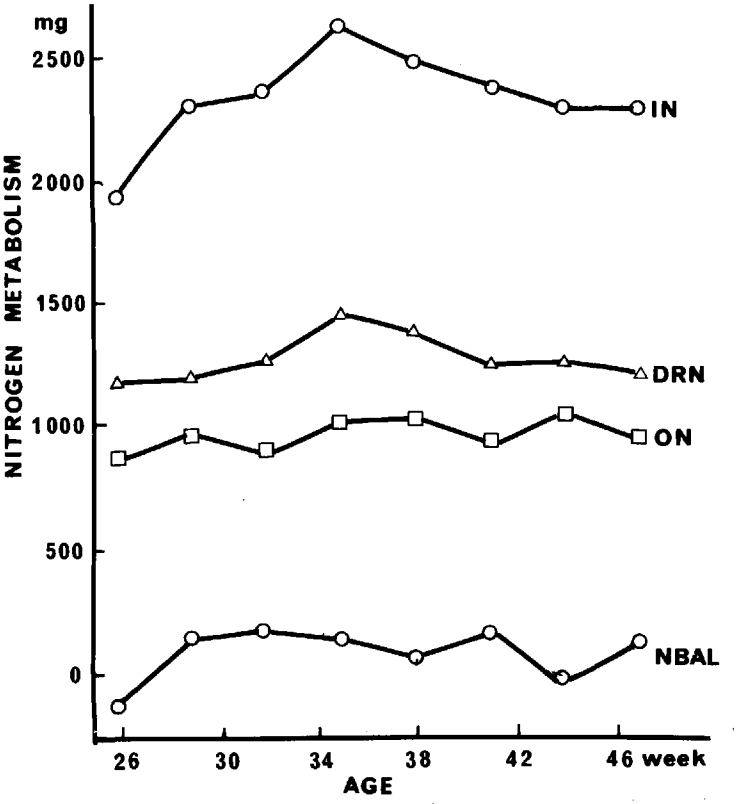


Figure 6.1. Mean values of nitrogen metabolism in relation to age. Series G. o Intake of nitrogen (IN), △ Droppings nitrogen (DRN), □ Nitrogen in eggs (ON), o Nitrogen balance (NBAL).

Middelværdier for kvælstofomsætning i relation til alder. Serie G.

describe the course of nitrogen intake, nitrogen in droppings, nitrogen balance, nitrogen in eggs and the utilization of nitrogen for deposition in eggs and partly to evaluate the effect of temperature, origin and housing on the nitrogen metabolism.

6.1 The course of nitrogen metabolism

The course of nitrogen metabolism is shown in Figures 6.1, 6.2, 6.3 and 6.4. for series G, H, K and J respectively. All series showed generally the same pattern for nitrogen intake (IN) starting with mean values of 1944 mg, 2194 mg, 2711 mg and 2535 mg independent of temperatures for series G, H, K and J.

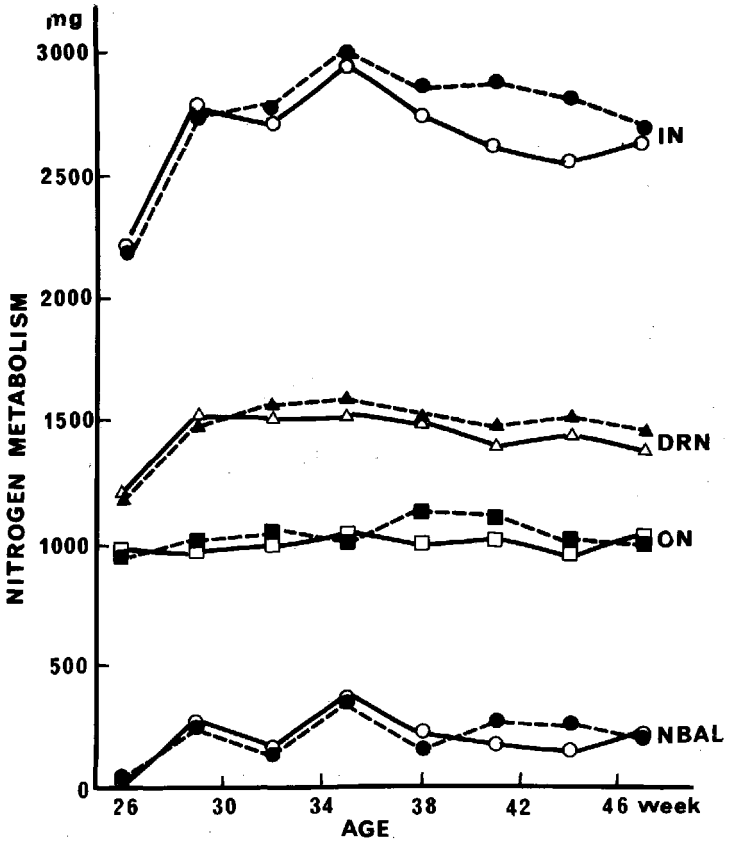


Figure 6.2. Mean values of nitrogen metabolism in relation to age. Series H. • 17°C Intake of nitrogen (IN), ▲ 17°C Droppings nitrogen (DRN), ■ 17°C Nitrogen in eggs (ON), • 17°C Nitrogen balance (NBAL), o 21°C IN, △ 21°C DRN, □ 21°C ON, o 21°C NBAL.
Middelværdier for kvælstofomsætning i relation til alder. Serie H.

Then it increased to maxima of 2633 mg, 2974 mg and 3222 mg by an age of 35 weeks except in series J in which the maximum was reached at 32 weeks. In the last part of the experiment a relative constant plateau was obtained in all series.

Nitrogen in droppings (DRN) was in the range of 1175–1464 mg in series G, 1194–1587 mg in series H, 1490–1693 mg in series K and 1237–1634 mg in series J, following the pattern for IN. Measurements of nitrogen balance (NBAL) including the part of nitrogen retained in eggs being under development in the ovary, showed generally a big variation with the lowest values by an age of

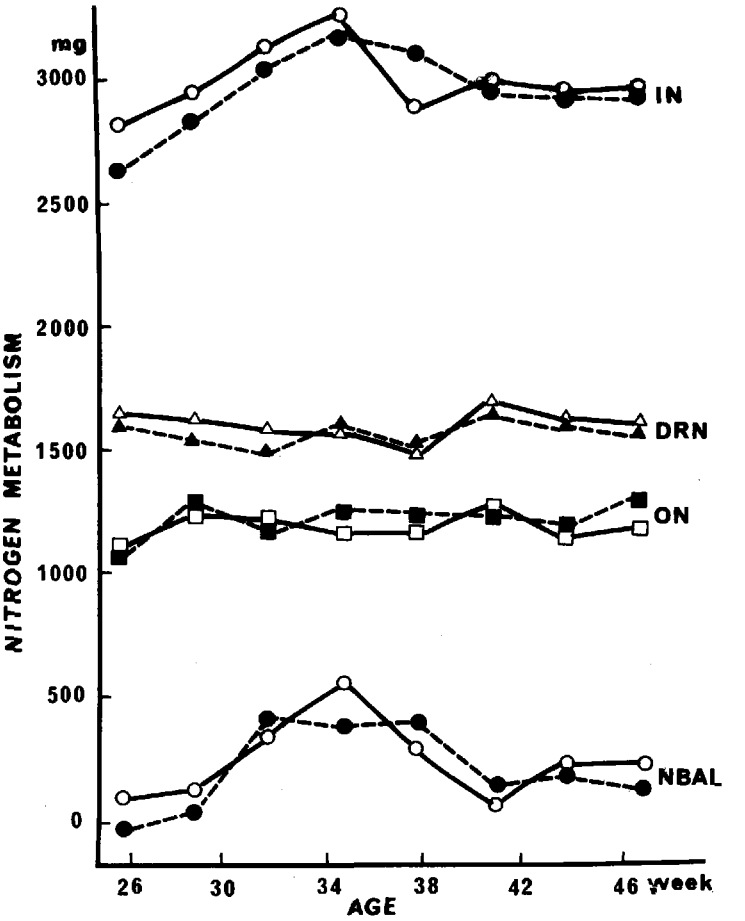


Figure 6.3. Mean values of nitrogen metabolism in relation to age. Series K. • 17°C Intake of nitrogen (IN), ▲ 17°C Droppings nitrogen (DRN), ■ 17°C Nitrogen in eggs (ON), • 17°C Nitrogen balance (NBAL), o 21°C IN, △ 21°C DRN, □ 21°C ON, o 21°C NBAL.
Middelværdier for kvælstofomsætning i relation til alder. Serie K.

26 weeks. In series G the mean values of NBAL varied from about –110 to 180 mg. In series H the NBAL was from 25 to 380 mg at both temperatures and in series K from –35 to 390 mg at 17°C and from 25 to 540 mg at 21°C. Nitrogen balance in series J was in the range 200–500 mg and 150–600 mg at 17°C and 21°C respectively. However, caused by some hens in series J laying their eggs on the floor the collection of eggs was incomplete, giving very irregular picture of nitrogen balance and nitrogen deposition in eggs in this series.

Nitrogen deposited in eggs produced (ON) was, except for the first period (26 weeks), fairly constant about the level of 1000 mg for series G and H, and about

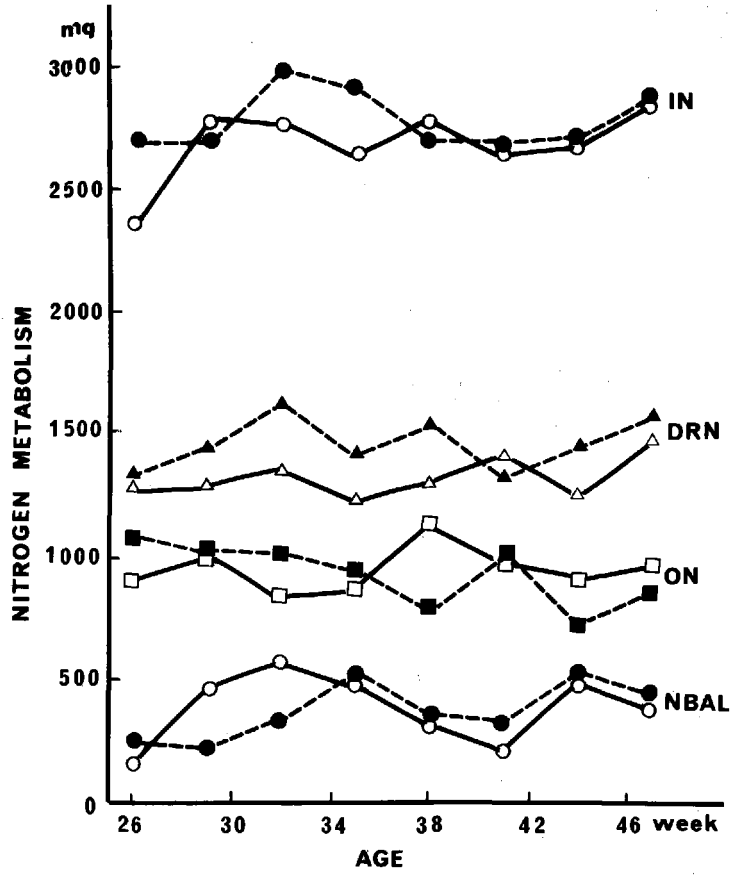


Figure 6.4. Mean values of nitrogen metabolism in relation to age. Series J. • 17°C Intake of nitrogen (IN), ▲ 17°C Droppings nitrogen (DRN), ■ 17°C Nitrogen in eggs (ON), • 17°C Nitrogen balance (NBAL), o 21°C IN, △ 21°C DRN, □ 21°C ON, o 21°C NBAL.
Middelværdier for kvælstofomsætning i relation til alder. Serie J.

1200 mg for series K at both temperatures. In series J, ON was about 950 mg with big variation caused by the difficulties in egg collection. The mean values of ON/IN varied between 39–46%, 37–45% and 36–44% in series G, H and K, respectively, with no significant ($P > 0.05$) differences between periods.

6.2 The effect of temperature, origin and housing on nitrogen metabolism

The grand means of all observations in each experimental series for the two ambient temperatures are presented in Table 6.1. The mean values of daily nitrogen intake were highest with 2984 mg, in series K (21°C) and lowest with 2346 mg in series G. The losses of nitrogen in droppings were 1281 mg, 1461 mg, 1578 mg and 1401 mg in series G, H, K and J at both temperatures. In relation to nitrogen intake (DRN/IN) the corresponding means were 55%, 54%, 53% and 51%.

Table 6.1 Nitrogen metabolism. Mean values of intake of nitrogen (IN), nitrogen in droppings (DRN) and nitrogen deposited in eggs (ON) from 26 to 47 weeks of age

Tabel 6.1 Kvælstofomsætning. Middelværdier for optagelse af kvælstof (IN), kvælstof i gødning + urin (DRN) og kvælstof aflejret i æg (ON) i alderen fra 26 til 47 uger

Series	No.	G	H		K		J	
Temp.	°C	21	17	21	17	21	17	21
Balances	n	81	27	24	32	24	8	8
IN	mg	2346	2743	2651	2954	2984	2789	2689
SEM		35	51	50	35	40	44	54
DRN	mg	1281	1481	1439	1562	1599	1470	1332
SEM		19	27	28	17	20	38	30
ON	mg	978	1041	1003	1200	1176	941	958
SEM		17	17	13	17	23	45	33
ON/IN	%	41.7	38.0	38.1	40.7	39.4	33.8	35.7
SEM		0.67	0.78	0.78	0.58	0.76	1.68	1.19

The mean of nitrogen deposition in eggs produced was highest in series K with about 1200 mg, about 1000 mg for series G and H, and 950 mg for series J. The CV values for the mean ON were 16% in series G, about 8% in series H and K and about 12% in series J. The mean ON in relation to nitrogen intake was 42% in series G while lower values were obtained in the other series, with about 38% in series H, 40% in series K and only 35% in series J caused by difficulties in egg collection.

The measurements of nitrogen balance which consists of nitrogen retained in body and in developing eggs showed a big individual variation in each series, and the extreme values were in the following range:

Series	Range of NBAL,g
G	–0.5 to 0.6
H	–0.1 to 0.5
K	–0.2 to 0.6

The statistical analyses (cf. Chapter 2.7) were carried out on individual data from different series in order to test the effect of temperature, origin and housing on nitrogen deposition in eggs (Table 6.2). The analyses were performed by means of 2 factor analysis of variance (ANOVA) and t-tests as described in chapter 3.2.

Table 6.2 Statistical analyses of nitrogen metabolism
Tabel 6.2 Statistiske analyser af kvælstofomsætning

Methods		Analyses of variance				t-test	
Series		H versus K				J	G vs. H
Variables		Origin (H–K)	Temp. (17–21)	Inter-action	Error (ms)	Temp. (17–21)	Housing[1] (S–Gr)
df		1	1	1	103	14	130
ON	dif. mg	–167	37			–17	–45
	f	88.7***	2.47	0.14	25.37	0.31	1.88
ON/IN	dif. %	–2.1	0.7			–1.9	3.7
	f	5.12*	1.02	0.46	14.16	0.94	3.90***

[1] S = Single hens in battery cages, Series G
Gr = Group of hens in battery cages, Series H
*) P<0.05, ***) P<0.001

The statistical analyses for series H and K showed no significant interaction between temperature and origin. The nitrogen deposition in eggs produced and the utilization of nitrogen for egg production (ON/IN) were not significantly ($P > 0.05$) different between the hens kept at 17°C or 21°C in series H and K as well as in series J. It was found that the origin had a significant effect on the nitrogen deposition in eggs ($P < 0.01$) and nitrogen utilization ($P < 0.05$). The origin B (series K) produced 170 mg ON more and had 2% better ON/IN than origin A (series H). The comparison between the housing systems for series G versus H showed that ON was not significantly ($P > 0.05$) different. However, ON/IN was 4% higher for the hens kept singly than in the groups, the difference being highly significant ($P < 0.001$).

6.3 Discussion

The measurements of nitrogen balance carried out in the present experiment gave basis for calculations of energy metabolism by means of C-N method (cf.

Chapter 2.6) as well as the data was used to estimate the nitrogen metabolism and thereby the protein metabolism in laying hens using the factor 6.25 for calculating protein. This factor is probably not valid for detailed consideration of protein retention in growing birds in which a considerable part of nitrogen is stored in feathers, *Håkansson et al. (1978)* and *Thorbek & Chwalibog (1984)*, however, the factor is generally accepted for egg protein, *Hoffmann & Schiemann (1973)* and *Voreck & Kirchgessner (1980 a)*, and it is commonly used in different comparisons, *Fisher (1981)*.

In order to investigate nitrogen metabolism different methods can be applied as described by *Farrell (1972)* but in the present studies only the balance technique have been used. This method includes generally, even by a very careful collection, some systematic errors by which the intake of nitrogen (IN) is overestimated while the excretion of nitrogen in droppings (DRN) is underestimated, causing an overestimation of retained nitrogen (RN), determined as RN = IN – DRN. In experiments with poultry another source of error may occur caused by mixing of feathers and plumage with the droppings, *Sørensen et al. (1983)*. Loss of nitrogen from the droppings as ammonia during the time of collection may happen if fermentation has started but this was not the case in the present experiment, being in accordance with the results from *Es van et al. (1970)* who was unable to detect ammonia during 24 hours respiration experiments with laying hens. It should also be stressed that nitrogen retention in body tissues of laying hens is relatively small and the mentioned source of errors in balance experiments might only have a minor effect on the final picture of nitrogen metabolism in the present investigation.

6.3.1 The course of nitrogen metabolism

In the present experiment with the same composition of food the intake of nitrogen followed the pattern of ad libitum food intake. The losses in droppings were related to nitrogen intake and thereby the proportion DRN/IN was almost constant (51–55%) during the experiment. The level of DRN/IN with a mean value of about 54% is lower than the value of 77% reported by *Hoffmann & Schiemann (1973)* but it is in accordance with *Harnish (1972)* who measured from 30% to 50% DRN losses depending on protein intake.

After subtraction DRN from IN the rest of nitrogen is available for retention in body and eggs. The amount of nitrogen deposited in eggs produced (ON) was measured by chemical analyses and thereby the NBAL was calculated as NBAL = IN – (DRN+ON). The NBAL included not only nitrogen retained in body tissues but also nitrogen incorporated in the eggs being under development in the ovarian system. In the present studies it was impossible to make a further experimental subdivision between the part of nitrogen retained in body and nitrogen in eggs in the ovary as the laying is not a continous process (like

milk production). It takes about 25 hours to develop and lay an egg, but the eggs are typically laid in clutches separated by daily intervals, so-called closed cycles, *Fisher (1981)*. Depending on the length of the cluthes the ovioposition takes place at different time and if the collection of eggs takes place at a fixed hour, as in the present experiment, then different amount of eggs material will be under development in the ovary by the time of collection, causing a great variation in NBAL. In fact no steady state of laying can be obtained which prevents the separate measurements of nitrogen retained in body and nitrogen which belongs to eggs being under development. Furthermore it is likely that protein deposition in eggs may be a discontinous process for egg white synthesis as well as for yolk protein synthesis, *Fisher (1981)*. Although NBAL could not be experimentally partitioned between the components, the value of nitrogen retained in body can be approximate when assuming that 15% of body gain is protein gain *(Neill et al., 1977)* as calculated below:

Series no.	G	H	K
Body gain,g	0.76	1.63	1.34
Assumed RN,mg	11	24	20
Measured NBAL,mg	90	220	200
RN/NBAL,%	12	11	10

The calculations showed that about 90% of NBAL would be nitrogen deposited in the eggs being under development in the ovary while only 10% nitrogen retained in the body (RN). However, the figures shall be treated with caution because of the very high variation in daily body gain and NBAL.

In the present experiment NBAL by an age of 26 weeks was close to zero or negative in series G, H and K. In series J, NBAL was overestimated owing to the difficulties in collection of eggs and this series will not be considered in the further discussion. The low NBAL at the beginning of laying is perhaps due to a very low nitrogen retention in body prior to laying and at the start of the laying period as found by *Chwalibog et al. (1984)*. By means of slaughter analyses, *Neill et al. (1977)* demonstrated that prior to egg laying protein content in carcass decreases. The decrease in protein retention may proceed after the offset of sexual maturity with even negative protein retention as found in several balance and slaughter experiments, *Hoffmann & Schiemann (1973), Grimbergen (1974), Farrell (1975)* and *Kirchgessner (1982)*.

Nitrogen deposition in eggs produced (ON), except at the beginning of laying period, was almost on the same level during the experimental time, about 1 g ON in series G and H and 1.2 g in series K. The values are in the range given by *Voreck & Kirchgessner (1980 a)* and correspond with the measurements of *Harnish (1972)* who also reported no influence of age on ON as in the present investigation.

The utilization of nitrogen for egg production (ON/IN) was between 39–46% in series G, 37–45% in series H and 36–44% in series K without any significant differences between balance periods. The ON/IN was higher than the range of 30–40% reported by *Reid et al. (1965), Grimbergen et al. (1968), Morris (1972), Vogt & Harnish (1978), Voreck & Kirchgessner (1980 a)* and the value of 24% noted by *Hoffmann & Schiemann (1973).* However, maxima of ON/IN in the present experiment are in agreement with the utilization of 48% measured by *Harnish (1972).*

6.3.2 The effect of temperature, origin and housing on nitrogen metabolism

In order to compare the present values of nitrogen deposition in eggs produced (ON) and the total nitrogen output (ON + NBAL) including nitrogen in body tissues and in eggs being under development in the ovary with protein retention in growing poultry and laying hens, nitrogen was recalculated to protein and expressed per metabolic body weight ($W,kg^{0.75}$). As there were no significant differences in nitrogen metabolism between 17°C and 21°C the observations were pooled in each series and the following mean values for protein deposition in eggs produced (OPROT) and total protein output (TPROT) were calculated:

Series no.	n	OPROT $g/W,kg^{0.75}$	TPROT $g/W,kg^{0.75}$
G	81	4.12	4.87
H	51	4.14	5.01
K	56	4.65	5.50

The OPROT was lower than protein retention in growing poultry (chicken, turkey„duck) being about 6 $g/W,kg^{0.75}$ but it was higher than 3.5 $g/W,kg^{0.75}$ in laying hens as reviewed by *Fisher (1981).* The mean values of OPROT in the present studies are in agreement with about 4.5 $g/W,kg^{0.75}$ reported by *Voreck & Kirchgessner (1980 a).* The present results indicate that layers are able to yield about 5 $g/W,kg^{0.75}$ total protein (i.e only 20% lower than in growing poultry).

The results from the present investigation are difficult to compare with the literature from measurements carried out on single hens and during relatively short experiments.

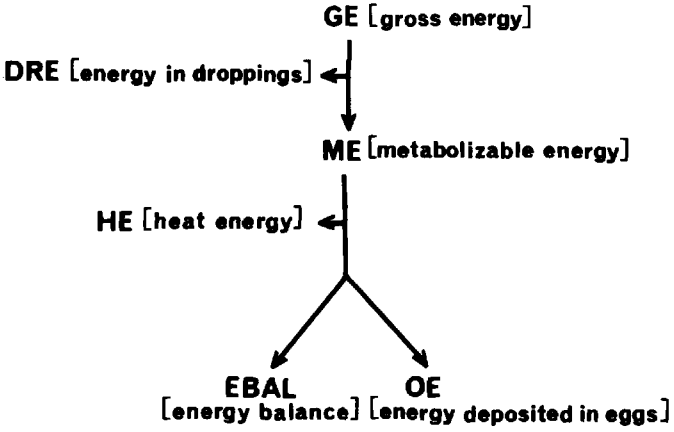
Temperature. The ambient temperatures of 17°C and 21°C had no significant effect on nitrogen deposition in eggs produced and nitrogen utilization (ON/IN) in all series (Table 6.2). The obtained results are in accordance with the same laying performance (cf. Table 3.2), egg size and chemical composition of eggs showing similar nitrogen content at the both temperatures (cf. Chapter IV).

Origin. The hens from origin B (series K) had 170 mg higher nitrogen deposition in eggs produced and 2% higher ON/IN than origin A (series H), both differences were significant (Table 6.2). The higher ON is in accordance with the bigger egg production in series K (cf. Table 3.2). The difference in ON was not only caused by the higher nitrogen intake (about 10%) and increased egg production but also by the better utilization of nitrogen, being in accordance with the better food conversion ratio (FCR) in origin B (cf. Table 3.2). The present results indicate that the selection for higher egg production in Shaver hens not only increased nitrogen output but also nitrogen utilization.

Housing. The effect of housing system on nitrogen deposition in produced eggs and nitrogen utilization was compared between the hens kept singly in the battery cages in series G with area of 2100 cm^2/hen and the hens of the same origin kept in groups in series H with area of 700 cm^2/hen. Together with higher food intake owing to the social facilitation by eating (cf. Chapter 3.3.2) nitrogen intake was 15% higher in series H but ON was not significantly different caused by the lower utilization of nitrogen when the hens are kept in groups (Table 6.2). The lower ON/IN corresponds with the FCR (cf. Table 3.2) and may be explained by a higher NBAL, thereby indicating a higher retention of nitrogen in body being in agreement with a higher body gain when the hens are kept together.

VII. Energy metabolism

The measurements of energy metabolism included the values of gross energy (GE), energy in droppings (DRE), metabolizable energy (ME), heat energy (HE), energy balance (EBAL), energy deposited in eggs produced (OE). Partitioned as in the following scheme:



The values of GE, DRE and OE were determined by means of calorimetric bombs. Metabolizable energy was calculated as ME = GE – DRE (cf. Chapter 8.1), HE and EBAL were estimated from balance and respiration experiments by means of C-N method as described in chapter 2.6. The masurements of EBAL include the part of energy stored in body protein and fat as well as the part retained in eggs being under development in the ovarian system. The mean daily values of energy metabolism for 8 balance periods are shown for each series in the Main Tables. In series G with hens kept singly the values are means of the individual observations while in series H, K and J, with groups of hens, the measurements are divided with the number of hens in the group in order to obtain comparable individual values. All series were started by an age of 26 weeks and were concluded by an age of 47 weeks. The data were partly used to describe the course of energy metabolism and partly to evaluate the effect of temperature, origin and housing on the energy metabolism.

7.1 The course of energy metabolism

The course of energy metabolism is shown graphically in Figures 7.1, 7.2, 7.3 and 7.4 for series G, H, K and J respectively.

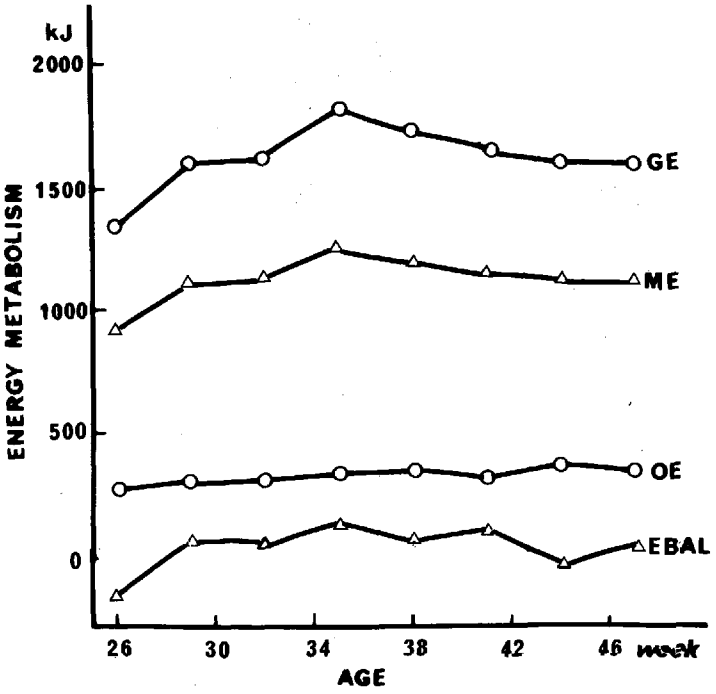


Figure 7.1. Mean values of energy metabolism in relation to age. Series G. o Gross energy (GE), △ Metabolizable energy (ME), o Energy in eggs (OE), △ Energy balance (EBAL).
Middelværdier for kvælstofomsætning i relation til alder. Serie G.

All series showed generally the same pattern for gross energy intake starting with mean values of 1.35 MJ, 1.51 MJ, 1.93 MJ, and 1.80 MJ independent of temperature. Then GE increased to maxima of 1.82 MJ, 2.05 MJ, 2.24 MJ and 1.99 MJ by an age of 35 weeks except in series J in which the maximum was reached at about 32 weeks of age. In the later part of the experiment a relative constant plateau was obtained in each series. Similar pattern was observed for metabolizable energy which increased from 0.92, 1.06, 1.33 and 1.30 MJ to 1.26, 1.49, 1.62 and 1.46 MJ in the respective series.

The energy balance showed a great variation often with negative values in period I (26 weeks) in which values of –151 kJ and –23 kJ in series G and H were found. The highest EBAL was measured in the middle of the experiment, by an age 35–38 weeks with 135 kJ, 290 kJ and 389 kJ in series G, H and K, respectively. The EBAL in series J varied in the whole experiment between 90–385 kJ caused by some hens in this series laying their eggs on the floor and the

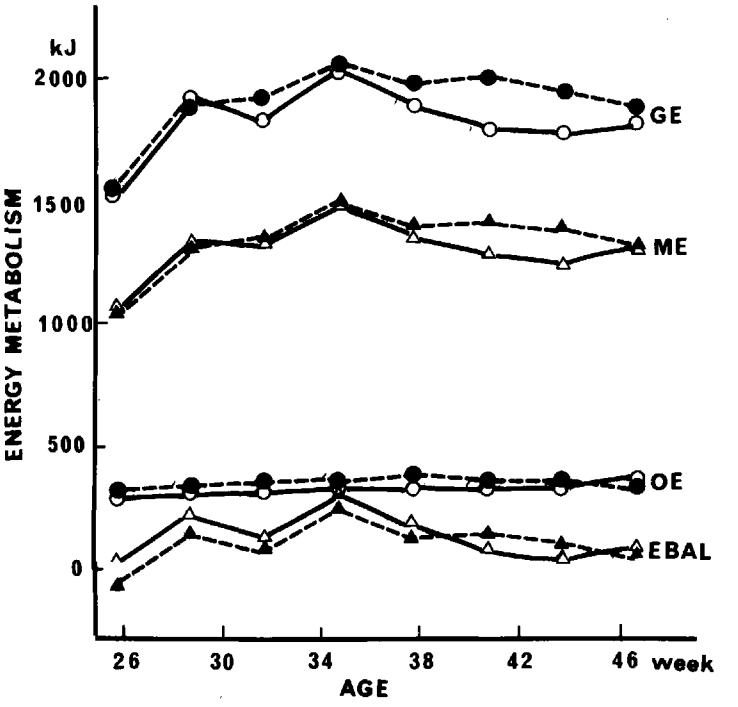


Figure 7.2. Mean values of energy metabolism in relation to age. Series H. • 17°C Gross energy (GE), ▲ 17°C Metabolizable energy (ME), • 17°C Energy in eggs (OE), ▲ 17°C Energy balance (EBAL), o 21°C GE, △ 21°C ME, o 21°C OE, △ 21°C EBAL.
Middelværdier for energiomsætning i relation til alder. Serie H.

collection of eggs was incomplete, giving a very irregular picture of energy metabolism.

Energy deposited in eggs produced increased slightly during the laying period, however, without significant ($P > 0.05$) differences between periods II-VIII being about the level of 330 kJ in series G, 340 kJ in series H and 400 kJ in series K. In series J, OE was about 320 kJ with big variation caused by the difficulties in egg collection. The mean values of energy deposited in eggs in relation to gross energy (OE/GE) varied between 18–23%, 17–21%, 17–21% and 13–21% for series G, H, K and J at both temperatures. The OE in relation to ME (OE/ME) was in the range 27–33%, 23–30%, 23–31% and 19–28% in series G, H, K and J. There were no significant ($P > 0.05$) differences in OE/GE and OE/ME between balance periods in series G, H and K.

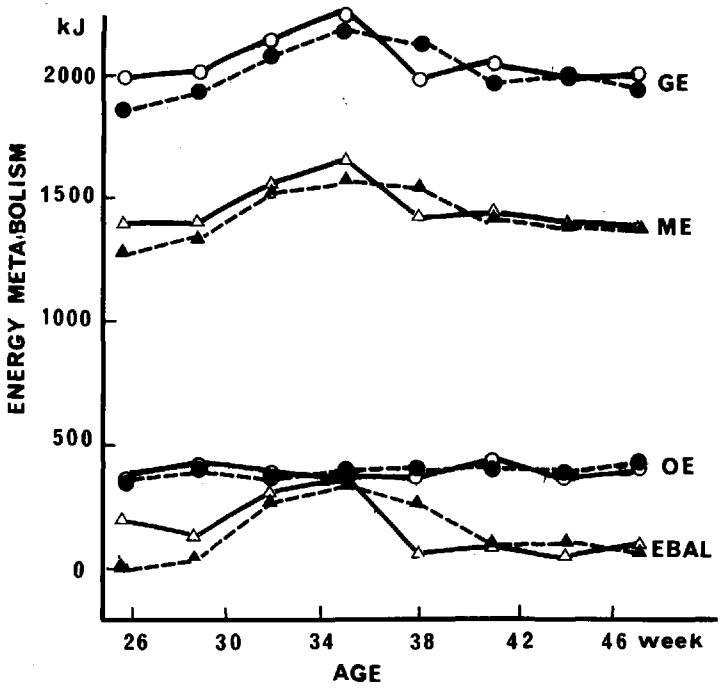


Figure 7.3. Mean values of energy metabolism in relation to age. Series K. • 17°C Gross energy (GE), ▲ 17°C Metabolizable energy (ME), • 17°C Energy in eggs (OE), ▲ 17°C Energy balance (EBAL), o 21°C GE, △ 21°C ME, o 21°C OE, △ 21°C EBAL.
Middelværdier for energiomsætning i relation til alder. Serie K.

7.2 The effect of temperature, origin and housing on energy metabolism

The grand means of all observations of gross energy, metabolizable energy, heat energy, energy deposited in eggs produced and the relations between energy in eggs and GE or ME for each series and temperature are presented in Table 7.1.

The mean values of daily intake of GE corresponded to the ad libitum food intake (cf. Table 3.1), showing the highest intake of GE with about 2.05 MJ in series K and lowest intake with 1.62 MJ in series G. The same pattern was observed for ME being highest in series K with 1.46 MJ and CV about 8% and lowest in series G with 1.12 MJ and CV about 14%. The metabolizability of energy (ME/GE) was 69%, 71%, 71% and 72% in series G, H, K and J, respectively, at both temperatures.

The mean heat energy was highest in series K with about 895 kJ at both tem-

Table 7.1 Energy metabolism. Mean values of intake of energy (GE), metabolizable energy (ME), metabolizability of energy (ME/GE), heat energy (HE), and energy deposited in produced eggs (OE) from 26 to 47 weeks of age

Tabel 7.1 Energiomsætning. Middelværdier for optagelse af energi (GE), omsættelig energi (ME), omsætteligheden af energi (ME/GE), varmeproduktionen (HE) og energi aflejret i producerede æg (OE) i alderen fra 26 til 47 uger

Series	No.	G	H		K		J	
Temp.	°C	21	17	21	17	21	17	21
Balances	n	81	27	24	32	24	8	8
GE	kJ	1621	1895	1832	2044	2066	1930	1860
SEM		24	35	34	23	27	29	30
ME	kJ	1125	1341	1300	1450	1463	1387	1348
SEM		18	26	27	21	24	24	25
ME/W,kg$^{0.75}$	kJ	790	890	874	955	948	909	941
SEM		11	16	17	14	17	21	19
ME/GE	%	69.4	70.8	70.9	70.8	70.8	71.8	72.5
SEM		0.19	0.21	0.24	0.30	0.34	0.63	0.46
HE	kJ	767	876	827	890	900	854	814
SEM		9.7	8.2	9.1	7.6	8.6	16.1	14.6
HE/W,kg$^{0.75}$	kJ	540	585	557	588	573	559	568
SEM		5.5	2.9	3.6	5.3	5.8	9.9	9.6
OE	kJ	327	351	334	398	393	310	324
SEM		6.1	5.7	5.8	6.5	8.2	12.6	13.3
OE/GE	%	20.2	18.5	18.3	19.6	19.0	16.1	17.4
SEM		0.37	0.34	0.41	0.27	0.38	0.64	0.64
OE/ME	%	29.1	26.2	25.8	27.4	26.7	22.3	24.0
SEM		0.49	0.50	0.65	0.49	0.57	0.84	0.87

peratures and lowest in series G with 767 kJ and with CV values of 11% in series G and about 5% in series H, K and J. In order to correct HE for differences in live weight (cf. Table 3.1), the individual data of HE were calculated per metabolic body weight (W,kg$^{0.75}$) and the mean values were 540, 572, 581 and 564 kJ/W,kg$^{0.75}$ in series G, H, K and J, respectively, at both temperatures.

The hens in series K deposited 395 kJ energy in eggs at both temperatures while OE in series G, H and J was 327 kJ, 343 kJ and 317 kJ, respectively with CV values of 17% in series G and about 10% in series H, K and J. The mean OE/GE was highest in series G with 20% in the other series the values were 18%, 19% and 17% for series H, K and J. The OE/ME followed the pattern of OE/GE being highest in series G with 29% and lowest in series J with 23%.

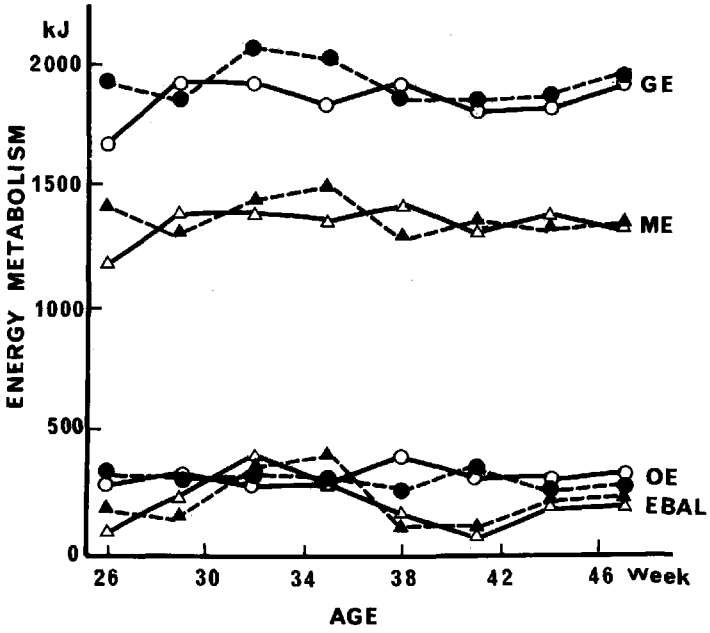


Figure 7.4. Mean values of energy metabolism in relation to age. Series J. • 17°C Gross energy (GE), ▲ 17°C Metabolizable energy (ME), • 17°C Energy in eggs (OE), ▲ 17°C Energy balance (EBAL), o 21°C GE, △ 21°C ME, o 21°C OE, △ 21°C EBAL.
Middelværdier for energiomsætning i relation til alder. Serie J.

Measurements of the energy balance which consist of the part of energy retained in eggs being under development in the ovarian system and the part retained in body tissue showed a big variation between observations in each series. The following minima and maxima of protein energy balance (PEBAL), fat energy balance (FEBAL), total energy balance (EBAL) and the mean values of EBAL in relation to gross energy (EBAL/GE) were measured in series G, H and K. The observations from series J are not included due to difficulties in egg collection.

Series	Range of			Mean
No.	PEBAL,kJ	FEBAL,kJ	EBAL,kJ	EBAL/GE,%
G	–74 to 96	–309 to 230	–383 to 326	1.6
H	–13 to 76	–88 to 350	–101 to 426	6.2
K	–29 to 88	–70 to 361	–99 to 449	8.2

The individual data of energy metabolism from different series were used in statistical analyses (cf. Chapter 2.7) in order to test the effect of temperature, origin and housing on all parameters of energy metabolism. The comparisons were made by means of 2 factor analysis of variance (ANOVA) and t-tests as described in chapter 3.2. The ANOVA for heat energy in series H and K showed significant ($P < 0.01$) interaction between temperature and origin and effects of the experimental factors on HE were not analysed. The results of EBAL were not used in statistical analyses due to very high individual variation. The results concerning the other parameters are presented in Table 7.2.

Table 7.2 Statistical analyses of energy metabolism
Tabel 7.2 Statistiske analyser af energiomsætning

Methods		Analyses of variance				t-test	
Series		H versus K				J	G vs. H
Variables		Origin (H–K)	Temp. (17–21)	Inter-action	Error (ms)	Temp. (17–21)	Housing[1] (S–Gr)
df		1	1	1	103	14	130
ME	dif. kJ	–135	18.5			39	–196
	f	36.8***	0.00	1.52	47952	1.09	7.26***
ME/W,$kg^{0.75}$	dif. kJ	–71	14			–32	–93
	f	20.2***	0.48	0.09	6420	1.14	5.63***
ME/GE	dif. kJ	0.0	–0.3			–0.7	–1.4
	f	0.61	0.32	0.04	2.448	0.81	5.30***
OE	dif. kJ	–52	13			–14	–16
	f	63.6**	2.75	0.30	3507	0.78	1.97
OE/GE	dif. %	–0.9	0.5			–1.3	1.8
	f	3.53	1.84	0.32	3.330	1.40	3.72***
OE/ME	dif. %	–1.1	0.6			–1.7	3.1
	f	2.66	1.90	0.12	7.944	1.40	4.45***

[1] S = Single hens in battery cages, Series G
Gr = Group of hens in battery cages, Series H
***) $P<0.001$

There were no significant ($P > 0.05$) differences in all tested parameters of energy metabolism between the two temperatures (17°C vs. 21°C) in series H and K as well as in series J. The hens from origin B (series K) had about 140 kJ higher ME and 50 kJ higher OE than origin A (series H), the differences were highly significant ($P < 0.001$). The metabolizability of energy (ME/GE) and the gross utilization of GE or ME for energy deposition in eggs produced (OE/GE or OE/ME) were not significantly ($P > 0.05$) different between the origins.

However, there was a tendency of higher gross utilization for origin B with 27.1% than for origin A with 26.0% of OE/ME. The comparison between the housing systems showed that the hens kept singly (series G) had about 200 kJ lower ME, 1.5% lower ME/GE than the groups (series H), the differences were highly significant ($P < 0.001$). There were no significant ($P > 0.05$) differences in OE between single hens and the groups but the gross utilization of GE or ME for energy deposition in eggs produced was 2% higher for OE/GE and 3% higher for OE/ME in series G than in series H, with highly significant ($P < 0.001$ differences.

Heat production units. In order to compare the heat production measured in the present experiment with the values recommended for design in environmental control system in poultry houses, the daily means of HE in series G, H and K were expressed per hour and recalculated to the heat production units (vpe) used in Danmark. According to Danish norm one vpe is per definition based on total heat loss at 20°C and corresponds to 1000 Watts what is equivalent of 3600 kJ per hour, *Strøm (1978)*. The following values tabulated together with the average food intake and egg production were obtained for both temperatures:

Series no.	G	H	K
Food,g	99	114	124
Egg,g	45	47	54
HE,kJ/h	32.0	35.5	37.2
vpe	0.011	0.012	0.012

The heat production units were 0.011 corresponding to 91 hens per 1 vpe in series G and 0.012 corresponding to 84 hens/vpe in series H and K.

7.3 Discussion

7.3.1 The course of energy metabolism

In the present experiment intake of energy followed the pattern of ad libitum food intake (cf. Fig. 3.1, 3.2). The intake of gross energy and metabolizable energy increased between 26–35 weeks of age and then it varied about a constant level (Fig. 7.1, 7.2, 7.3, 7.4). The mean values of ME in series G increased from about 0.92 to 1.26 MJ, in series H, at both temperatures, ME increased from 1.06 to 1.49 MJ, in series K from 1.33 to 1.62 MJ and in series J from 1.30 to 1.46 MJ. The ME values in the present investigation were not corrected to zero nitrogen balances. As stated by *Kleiber (1961)* metabolizable energy is »the energy available for anabolism (the building of body substance, milk or eggs) and for katabolism (the heat production of animals) and requires no correction for nitrogen balances«. The validity of »nitrogen corrected ME« in

poultry has been dicussed by many authors as reviewed by *Vohra (1972)* and *Sibbald (1982)*. The correction tends to underestimate the ME values from protein rich food and to overestimate from energy rich food. It is questionable whether the nitrogen corrected ME is a better expression because a correction should also be applied for the loss of nitrogen in shedding of scales and feathers and for nitrogen deposition in eggs.

The so-called energy balance (EBAL) in the present investigation was the part of energy output in not produced eggs (EBAL=ME–OE). In the literature this part of energy has been described as energy retained in body tissue, *Es van et al. (1973)* and in revies by *Grimbergen (1974)* and *Sykes (1979)*. However, this part of energy composed not only the energy retained in protein and fat of body tissues but also the energy in eggs being under development in the ovarian system. As it was discussed in chapter 6.3 no subdivision of nitrogen balance was made in the present experiment and consequently EBAL was not partitioned between energy retained in body and energy retained in partly developed eggs. The laying is not a continous process and the different amount of egg's material is under development in the ovary at the time of collection making the separation between energy retained in body and energy which belongs to eggs, impossible. It is characteristic of the present experiment that EBAL at the beginning of laying period (26 weeks) was either negative or close to zero in series G, H and K, being in agreement with body weight losses and nitrogen losses at this age and the highest EBAL was measured by an age of 35–38 weeks. In series J caused by some hens laying their eggs on the floor the collection was incomplete giving very irregular picture of energy output in eggs and in EBAL by which the results of energy metabolism from the hens kept freely are uncertain. The negative or very low mean values of EBAL have been observed in several calorimetric investigations with laying hens, however, without indication of the course of laying, *Waring & Brown (1965* and *1967), Es van et al. (1970), Grimbergen (1970), Es van et al. (1973), Hoffmann & Schiemann (1973), Grimbergen (1974)* and *Burlacu et al. (1974)*.

In the present experiment the energy deposited in eggs produced (OE) increased slightly during the laying period but without significant differences between 29–47 weeks of the age being about the level of 330 kJ, 340 kJ and 400 kJ in series G, H and K, respectively, at both temperatures. The course of OE generally followed the pattern of egg production (cf. Fig. 3.3, 3.4) being lower by an age of 26 weeks. Since energy content in eggs (OE, kJ/kg eggs) increased between 26–47 weeks of age with about 7% (cf. Chapter 4.1) an increase in OE might be expected also in the later part of the experiment, however, this was not observed probably caused by a big individual variation in OE values (Table 7.1) giving CV between 9–17% for all series. The mean values of OE in relation to GE (OE/GE) were between 18–23% for series G and 17–21% for series H and

K at both temperatures and the corresponding values of OE/ME were 27–33% and 23–31%. The range of OE/GE or OE/ME in the present investigation is similar to mean values given by *Supramaniam (1970), Petersen (1971), Polin & Wolford (1973), Davis et al. (1973), Hoffmann & Schiemann (1973), Reid et al. (1978), MacLeod & Shannon (1978), Voreck & Kirchgessner (1980b)* and *Byerly et al. (1980)*. The proportions OE/GE and OE/ME were not significantly different between balance periods indicating that the utilization of energy for energy deposition in eggs, for ad libitum fed hens in the age interval 26–47 weeks, is not affected by the age of hens and thereby does not depend on the egg production curve.

7.3.2 The effect of temperature, origin and housing on energy metabolism

Temperature. At both ambient temperatures (17°C and 21°C) the ad libitum food intake (cf. Chapter 3.3.2) and thereby gross energy intake (Table 7.1) followed the same pattern in each series. Metabolizable energy was not significantly different between hens allocated to 17°C or 21°C (Table 7.2), independent on origin and housing. It is generally accepted that when temperature increases over a broad range (5–30°C) the energy intake decreases as reviewed by *Sykes (1977), Kampen van (1981)* and *MacLeod (1984)*. The decrease of GE or ME can take place even in temperature range between 16–24°C as demonstrated in experiments of *Ota & McNally (1961)* and *Davis et al. (1973)* or between 15–20°C, *Es van et al. (1973)*. However, the narrow range of temperature as in the present investigation showed that temperatures of 17°C and 21°C had no different effect on GE and ME values. With the same GE and ME values in the present experiment the metabolizability of energy (ME/GE) was not significantly different for the two temperatures being in accordance with the results of *Es van et al. (1973)* who demonstrated no differences in ME/GE even for broader temperature range (10–25°C).

Caused by the interaction between temperature and origin in analyses of variance for heat energy in series H and K, no further statistical tests were performed. In series J the egg collection was incomplete giving uncertain values of HE being calculated according to C-N method (cf. Chapter 2.6) by difference HE = ME – (OE + EBAL) and the results from this series are not included in the comparison. Since it is generally accepted that heat production is related to body mass and surface which can be described by a power function of live weight (a W,kg^b) calculated from log HE = log a + b log W,kg with the exponent b = 0.75 (cf. Chapter 5.3) the data of HE were expressed per metabolic body weight (W,kg$^{0.75}$). The HE/W,kg$^{0.75}$ at 17°C was 3–5% higher than at 21°C in series H and K, the difference being small and in the range of individual variation indicating the same heat energy at both temperatures. It has to be underlined that in all series the hens were normally feathered and an influence of feather cover

on thermoregulation and thereby on heat production as discussed by *Lee et al. (1983)*, could be neglected. There is a considerable amount of information in the literature relating to the effect of environmental temperature on the heat energy as reviewed by *O'Neill & Jackson (1974)*, *Balnave (1974)*, *Strøm, (1978)*, *Sykes (1979)*, *Kampen van (1981)* and *MacLeod (1984)*. The relation between HE and ambient temperature over a broad range of temperature was described for laying hens by linear equations, *O'Neill et al. (1971)* and *Kampen van (1981)* but in the present experiment, with a limited range of temperature, such linearity could not be found. It has been demonstrated by *O'Neill et al. (1971)*, *Davis et al. (1973)* and *Strøm (1978)* based on observations from *Es van et al. (1973)*, and *Goverment Agr. Research Centre, Ghent (1966)*, that by increasing temperature from 15°C to 20°C the increase in HE was below 5%. The present results are also in agreement with *Balnave (1974)* who recalculated from data of *Barott & Pringle (1946)* the same heat production for adult birds kept at 18 or 21°C. Furthermore *Tzschentke & Nichelmann (1984)* estimated the optimum biological temperature (cf, Chapter 3.3.2) to 19°C for White Leghorn, then taking into consideration the parabolic curve of heat production in relation to temperature *(Nichelmann et al. 1983)*, it implies that the values of HE at 17 and 21°C will be placed on the opposite sides of the parabola but on the same level giving an equal heat production as it was measured in the present studies.

The energy balance (EBAL) showed a big variation between observations in each series and temperatures and no statistical analyses were carried out but a closer inspection of the mean values in each balance period (Fig. 7.1, 7.2, 7.3, 7.4) indicated that EBAL was of the same magnitude for the two temperatures. Similarly a big individual variation and no differences in EBAL between 15°C and 20°C were measured by *Es van et al. (1973)*. Furthermore *Davis et al. (1973)* by means of a comperative slaughter method showed no differences in energy retention in body tissues between 16°C and 24°C.

The deposition of energy in produced eggs (OE) was not significantly different between 17°C and 21°C as a consequence of the same laying performance (cf. Table 3.2), egg size and energy content in eggs (cf. Chapter 4.2). The same OE is in agreement with results of *Davis et al. (1973)* who did not find significant differences in OE between 16°C and 24°C and with *Es van et al. (1973)* who demonstrated no relationship between OE and temperatures of 15°C and 20°C.

With no changes in energy intake and energy deposition in eggs between the both temperatures in the present experiment, the gross utilization of GE or ME (OE/GE or OE/ME) were consequently equal. Similarly to the present experiment equal OE/ME can be recalculated from data given by *Es van et al. (1973)* when choosing observations with the same ME at 15°C and 20°C. Furthermore *Emmans & Charles (1977)* showed no differences in OE/ME between 18°C and

22°C. The improvement in gross utilization of ME for energy deposition in eggs over broader temperature range was reported by *Davis et al. (1973)* and *Vohra et al. (1979)*, however in these experiments an increase in OE/ME was caused by a decrease in ME together with fairly constant OE.

Origin. In the present experiment the ad libitum food intake and thereby the intake of GE was highest in origin B (series K) but metabolizability (ME/GE) was identical for the two origins (Table 7.2) with the mean value of about 71%. In consequence ME values were significantly higher for origin B than A. The results are in accordance with the experiment of *Hoffmann & Schiemann (1973* who found the same metabolizability of energy for different White Leghorn hybrids fed ad libitum. The present findings also indicate that different intake of GE (10%) owing to different food intake between the two origins had no effect on ME/GE. The same results were demonstrated for hens belonging to one origin but fed with different energy levels, *Burlacu et al. (1974), Grossu et al. (1976)* and *Kirchgessner & Voreck (1980 a)* although the last authors showed that if energy intake differs in a broader range the ME/GE significantly increases with increasing energy intake.

The inspection of the mean values of HE/W,$kg^{0.75}$ showed that the difference between origins was below 2% being negligible considering the individual variation with CV values between 2–5%. Furthermore the same heat production is indicated by no significant differences between the multiple regressions of gas exchange (cf. Chapter 5.2). Throughout literature there have been some reports demonstrating different heat production between races and strains of layers as demonstrated by *O'Neill et al. (1971), Balnave (1974), Farrell (1975), MacLeod & Shannon (1978), MacLeod et al. (1982)* and *MacLeod (1984)*, however, these reports are based on experiments carried out under fasting conditions and in short periods, being difficult to compare with the present results from ad libitum fed hens measured during 6 months laying period.

The mean values of EBAL were 6–8% in relation to GE in series H and K and taking into account the great individual variation, EBAL was not different between the origins. instead, the energy deposited in produced eggs was significantly higher in series K than in H being in accordance with higher egg production (cf. Table 3.2) but the same energy content in eggs (cf. Chapter IV). Although the gross utilization of energy was not significantly different between the origins there was a tendency of higher OE/GE or OE/ME for origin B indicating that the selection for higher egg production in origin B can improve energy utilization.

Housing. The effect of housing system on energy metabolism was compared between the hens kept singly in the battery cages in series G and the hens kept in groups in series H, in both series belonging to the same origin of White Leghorns. The food intake was significantly higher in series H from series G (cf.

Table 3.2) and thereby the GE intake was about 15% higher. The ME was 17% higher in series H than in series G, the difference being highly significant (Table 7.2). There were also significant differences in metabolizability of energy with 1.4% higher values in series H. The difference is difficult to explain but may be caused by a less accurate collection of droppings from groups of hens than from single hens or perhaps is due to 15% higher GE intake in series H which could elevate ME/GE as it was demonstrated by *Kirchgessner & Voreck (1980 a)*.

The heat energy in kJ/W,$kg^{0.75}$ was 6% higher in series H from series G, being in agreement with the higher level of gas exchange (cf. Chapter 5.2) in this series. The EBAL in relation to GE (EBAL/GE) was about 2% in single hens and 8% in groups, although with high individual variation, still indicating a higher energy retention in body for the groups, being in accordance with the higher body gain in series H (cf. Chapter 3.1). The hens in series H had the same energy deposition in produced eggs as single birds, being in accordance with the same egg production (cf. Table 3.2) and equal energy content in the eggs (cf. Chapter IV). However, together with the higher energy intake, HE and EBAL the OE/GE or OE/ME were significantly lower in the groups.

The possible explanation of the obtained differences in energy metabolism between hens kept singly and in groups is likely to be related to the social facilitation by eating (cf. Chapter 3.3.2) causing an increase in food intake and thereby in energy intake when more than one hen is kept in a cage. The increase in GE and ME in the present experiment was parallel with the elevation of HE since the stimulus effect of the hens on each other increases locomotor activity which accounts for about 10–20% of total energy expenditure, *Kampen van (1976 a,b)* and *MacLeod et al. (1982)*. It has been demonstrated that 2 birds in a cage had a higher pecking and movement activity than one bird, *Süs (1976)* as well as that crowding of hens was responsible for activity increase as demonstrated by *Hughes & Black (1974 b)* and *Bessei (1981)*. In the present experiment no quantitative measurements of activity were carried out but visually the hens in series H were more active than single hens in series G. Therefore it can be stated that the social facilitation by eating together with an increase in the locomotor activity might be the main reason of the increase in energy intake and heat energy when the hens are kept together. These changes did not influence the value of energy deposited in produced eggs but the level of EBAL was higher in the groups indicating a higher energy retention in body, being in accordance with a higher body gain. Thereby the proportions of OE/GE and OE/ME were lower in the groups than in single hens as the increased energy intake was partly used to cover an increase in the activity and partly was retained in body but did not change the amount of energy deposited in eggs.

Heat production units. The heat production units (vpe) calculated in the present experiment were 0.011 (91 hens/vpe) for single hens in series G and 0.012

(84 hens/vpe) for groups of hens in series H and K independent on the temperature and origin. The values are in the range (0.010–0.016 vpe) tabulated by *Strøm (1978)*. The present results indicate that for design of environmental control system in poultry houses the decrease in temperature from 21°C to 17°C for both origins does not change the number of vpe. However the data of heat production which is usually obtained from experiments with single hens cannot be directly applied for poultry houses with battery cage system.

VIII. Energetic effiency of egg production

8.1 Terminology

The following terminology was used in the present studies:

GE = gross energy
DRE = energy in droppings
ME = metabolizable energy
ME_m = ME available for maintenance
ME_{go} = ME available for energy retention in body and eggs under development in the ovary and available for energy deposition in eggs produced
ME_g = ME available for energy retention in body and eggs under development in the ovary
ME_o = ME available for energy deposition in eggs produced
ME_{op} = ME available for protein energy deposition in eggs produced
ME_{of} = ME available for fat energy deposition in eggs produced
EBAL = energy balance i.e. energy retained in body and in eggs under development in the ovary
OE = energy deposited in eggs produced
OPE = protein energy deposited in eggs produced
OFE = fat energy deposited in eggs produced
k_{go} = overall efficiency of ME utilization for EBAL and for deposition of energy in eggs produced
k_g = efficiency of ME utilization for retention of energy in body and in eggs under development in the ovary
k_o = efficiency of ME utilization for deposition of energy in eggs produced
k_{op} = efficiency of ME utilization for deposition of protein energy in eggs produced
k_{of} = efficiency of ME utilization for deposition of fat energy in eggs produced

Subtraction of the energy voided in droppings from gross energy intake gives metabolizable energy (ME = GE – DRE). ME is partly used for maintenance requirement (ME_m) and partly used for production i.e energy retention in body and eggs being under development in the ovary and energy deposition in eggs produced (ME_{go}). Information about the maintenance requirement and the efficiency of ME utilization for production is necessary in order to evaluate the energetic efficiency of egg production. The energy requirement for maintenance (ME_m) can be defined as the amount of ME which is needed to maintain a dynamic equilibrium of protein and fat turnover, to maintain a constant body

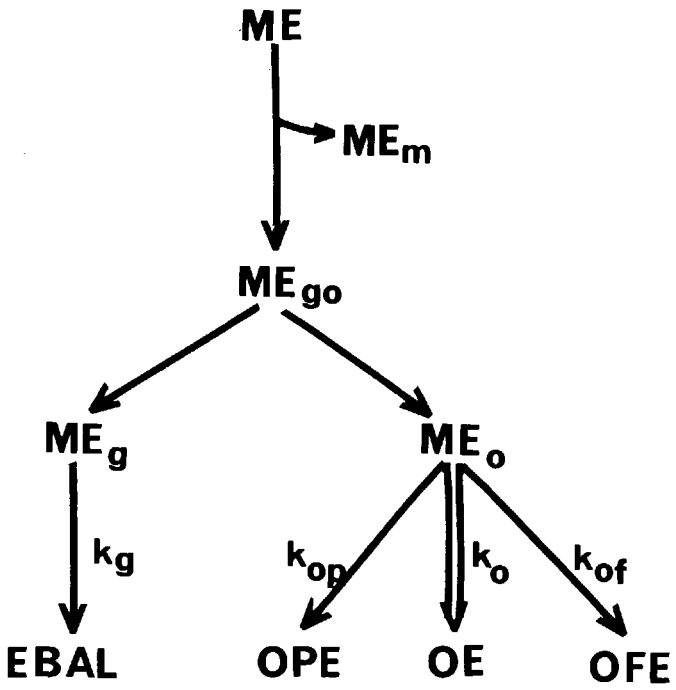


Figure 8.1. Partition of metabolizable energy.
Fordeling af omsættelig energi.

temperature and to maintain a minimum locomotor activity. The partition of metabolizable energy is demonstrated in Fig. 8.1.

Metabolizable energy available for production (ME_{go}) can be calculated by subtraction of ME_m from ME ($ME_{go} = ME - ME_m$) and can be subdivided into the part available for energy retention in the body and in eggs growing in the ovary (ME_g) and into the part available for energy deposition in the eggs being produced (ME_o). ME_g is used for retention in body tissue including protein and fat energy and in eggs being under development in the ovarian system (EBAL) although this subdivision was not possible in the present experiment. ME_o is used for energy deposition in eggs produced (OE) including protein energy (OPE) and fat energy (OFE).

Efficiency of utilization of ME for production can be defined as a measure of conversion of ME available for production into products (EBAL and OE) and is described by »k« coefficients (or quotients) of utilization. The efficiency of ME utilization for energy deposition in body and eggs under development in the ovary and in eggs produced (k_{go}) was calculated according to the definition

k_{go} = (EBAL + OE)/ME_{go}. The efficiency of ME utilization for EBAL (k_g) can be defined as k_g = EBAL/ME_g and the efficiency of ME utilization for energy deposition in the eggs produced (k_o) be defined as k_o = OE/ME_o. Both values can be calculated by means of regression analyses. The partial efficiency of ME utilization for protein energy deposition (k_{op}) and fat energy deposition (k_{of}) in the eggs produced can be defined as k_{op} = OPE/ME_{op} and k_{of} = OFF/ME_{of} and can be calculated by means of multiple regressions.

8.2 Maintenance requirement and energetic efficiency of egg production calculated according to different models

Maintenance requirement and efficiency of ME utilization for production can be estimated by means of regression analyses between ME and a number of variables of energy metabolism. The data from series G has been applied to different models as the measurements of energy metabolism in this series were carried out in individual balances and respiration experiments with the hens kept singly showing a low activity considered to be at minimum during the laying period. Because of negative energy balances (EBAL) in 29 observations, mostly at the begining of laying period, these measurements were omitted and the calculations were performed with 52 observations with positive EBAL.

Model with one-dimensional regression. In order to calculate the maintenance requirement (ME_m) and the overall efficiency of ME utilization for EBAL and for deposition of energy in eggs produced (k_{go}) the total energy retention per metabolic body weight (EBAL + OE)/W,$kg^{0.75}$ was regressed on ME/W,$kg^{0.75}$ and the following one-dimensional model was applied:

Model 1

$$(EBAL + OE)/W,kg^{0.75} = a + k_{go} \times ME/W,kg^{0.75}$$

The model provides an estimate of the overall efficiency (k_{go}) of ME utilization for EBAL and energy deposition in eggs produced (OE) and by extrapolating ME to zero level of total energy retention the maintenance requirement can be found as $ME_m/W,kg^{0.75} = a/k_{go}$. There were no significant ($P > 0.05$) differences between groupwise regressions within periods (cf. Chapter 2.7) and there was no significant difference between regressions calculated for the first four periods versus the last four indicating no influence of the age of hens on ME_m and k_{go}. Subsequently the total regression for all observations (n=52) during the laying period from 26 to 47 weeks of age was performed giving the following equation:

$$(EBAL + OE),kJ/W,kg^{0.75} = -287 + 0.71 \times ME,kJ/W^{0.75}$$

se: 54.9 0.065

n = 52, RSD = 35.1, CV = 11.3%, R^2 = 0.704

The regression gave a maintenance requirement of 404 kJ/W,kg$^{0.75}$ and the overall efficiency of ME utilization for EBAL + OE was $k_{go} = 0.71$.

Models with multiple regressions. Metabolizable energy is partly used for maintenance, partly for EBAL and partly for energy deposition in eggs produced (OE) and therefore the following model can be written:

Model 2

$$ME = a + b_1 \times W,kg^{0.75} + b_2 \times EBAL + b_3 \times OE$$

If the intercept (a) is not significant then the regression coefficient b_1 can be considered as an estimate of maintenance requirement per metabolic body weight ($ME_m/W,kg^{0.75}$). Regression coefficient b_2 is the cost of the energy balance and its reciprocal is the efficiency of ME utilization for EBAL (k_g). The regression coefficient b_3 is the cost of energy deposition in eggs produced (OE) while the value $1/b_3$ is equal to an efficiency of ME for OE (k_o). As the intercept was not significantly ($P > 0.05$) different from zero the regression was calculated through the origin and the following function for the measurements in series G with positive EBAL was obtained:

ME,kJ =	414 × W,kg$^{0.75}$ +	0.86 × EBAL,kJ +	1.56 × OE,kJ
se:	44.4	0.090	0.189

n = 52, RSD = 52.6, CV = 5.10%

The regression was calculated with satisfactory precision, as the coefficient of variation (CV) was 5% and R^2 from the regression with intercept was 0.787. The equation gave a maintenance requirement of 414 kJ/W,kg$^{0.75}$, the efficiency of ME utilization for EBAL $k_g = 1.16$ (1/0.86) and the efficiency of ME utilization for energy deposition in the eggs produced $k_o = 0.64$ (1/1.56).

In order to estimate the efficiencies of ME utilization for energy deposition in protein (OPE) and fat (OFE) in eggs produced, the following model has been applied:

Model 3

$$ME = a + b_1 \times W,kg^{0.75} + b_2 \times EBAL + b_3 \times OPE + b_4 \times OFE$$

The calculations showed that the intercept was not significant ($P > 0.05$) and the regression through the origin gave the following result for the observations in series G with positive EBAL:

ME,kJ =	419 × W,kg$^{0.75}$ +	0.84 × EBAL,kJ +	1.99 × OPE,kJ +	1.27 × OFE,kJ
se:	46.0	0.095	0.079	0.056

n = 52, RSD = 54.3, CV = 4.54%

The precision of the regression was satisfactory, CV was 4.5% and R^2 from the model with intercept was 0.759. The regression gave a maintenance requirement of 419 kJ/W,kg$^{0.75}$ and nearly the same coefficient for EBAL as in model (2). The cost of protein deposition was 2.0 kJ per 1 kJ OPE and the cost of fat deposition was 1.3 kJ per 1 kJ OFE. The values of the partical efficiencies were therefore k_{op} = 0.50 and k_{of} = 0.79.

The partition of ME. In order to summarise the calculations performed, the individual data of energy metabolism together with the estimated maintenance requirement and energetic efficiency of egg production was used in the partition of ME for the hens with positive EBAL in series G. All data were calculated per W,kg$^{0.75}$ and the mean values are demonstrated in Fig. 8.2.

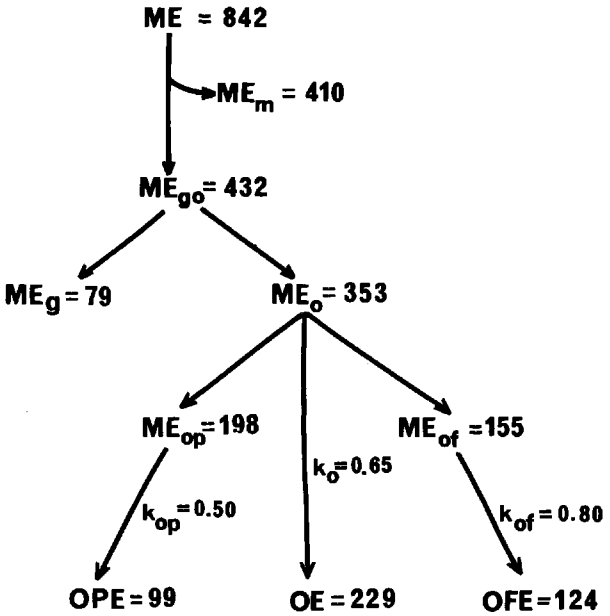


Figure 8.2. Partition of metabolizable energy based on the results from series G with positive EBAL. Mean values expressed per W,kg$^{0.75}$.
Fordeling af omsættelig energi baseret på resultaterne fra serie G med positiv EBAL. Middelværdier udtrykt pr. W,kg$^{0.75}$.

The three regression models gave ME_m about 410 kJ/W,$kg^{0.75}$ and this value was inserted in the calculations of ME available for production (ME_{go}) as $ME_{go} = ME - ME_m$, giving ME_{go} of 432 kJ/W,$kg^{0.75}$ and indicating that 51% of the total ME was used for production. The ME_{go} is partly used for EBAL and partly for OE. The ME available for OE (ME_o) was calculated by dividing the value of OE with the coefficient k_o estimated to 0.65 by means of model 2 if ME_m is 410 kJ/W,$kg^{0.75}$. In relation to the total ME, the ME_o was 42%. The difference between $ME_{go} - ME_o$ is ME_g being 79 kJ/W,$kg^{0.75}$ which in relation to the total ME was 9%. The ME_o consists of ME available for protein energy deposition (ME_{op}) and for fat energy deposition (ME_{of}) in eggs produced. These values were calculated by dividing the OPE and OFE by the coefficients k_{op} and k_{of} which for simplicity in calculation were rounded to 0.50 and 0.80 respectively. The small disagreement between the value of OE and the sum of OPE + OFE was caused by OE being measured directly in a calorimetric bomb while OPE and OFE were calculated from nitrogen and fat content in eggs (cf. Chapter 2.6). The ME_{op} and ME_{of} in relation to ME_o were 56% and 44% respectively.

8.3 The effect of temperature, origin and housing on energetic efficiency of egg production

The calculations carried out on the individual observations in series G with positive EBAL showed that maintenance requirement calculated by all three models (model 1, 2, 3) was about 410 kJ/W,$kg^{0.75}$. This value of ME_m was applied for calculations of overall energetic efficiency of ME utilization for EBAL and energy deposition in eggs produced in series H, K and J. The calculations were performed on the basis of model 1. The ME available for energy retention in body and eggs being under development in the ovary and for energy deposition in eggs produced (ME_{go}) was defined as $ME_{go} = ME - ME_m$ with $ME_m = 410$ kJ/W,$kg^{0.75}$ and subsequently the proportion between the total energy retention (EBAL+OE) and ME_{go} was the overall efficiency for egg production (k_{go}) in accordance with $k_{go} = (EBAL+OE)/ME_{go}$. The calculations were performed on the observations with positive EBAL and the mean values of k_{go} in the different series together with the statistical analyses are presented in Table 8.1.

The highest value of k_{go} was obtained in series G with 0.72 while in the other series the means varied between 0.65 and 0.70 with CV values between 5–11%. The individual data of k_{go} from the different series were used in the statistical analyses in order to test the effect of temperature, origin and housing on the overall energetic efficiency for egg production (Table 8.1). The statistical analyses (cf. Chapter 2.7) were performed in the same manner as in the previous chapters. The results of ANOVA for series H and K showed no significant ($P > 0.05$) interaction between temperature and origin, and no significant effect

Table 8.1 Overall efficiency of ME utilization for EBAL and for deposition of energy in produced eggs k_{go} = (EBAL + OE)/ME_{go} calculated with ME_m = 410 kJ/W,$kg^{0.75}$. Mean values and statistical analyses for observations with positive EBAL

Tabel 8.1 Total udnyttelsesgrad af ME til EBAL og energiaflejring i produceret æg k_{go} = (EBAL + OE)/ME_{go} beregnet med ME_m = 410 kJ/W,$kg^{0.75}$. Middelværdier og statistiske analyser for observationer med positiv EBAL

Series No.	G	H		K		J	
Temp. °C	21	17	21	17	21	17	21
Balances n	52	23	22	29	24	8	8
k_{go}	0.72	0.65	0.68	0.69	0.69	0.70	0.70
SEM	0.011	0.007	0.008	0.013	0.015	0.026	0.022

Statistical analyses

Methods		Analyses of variance				t-test	
Series		H versus K				J	G vs. H
Variables		Origin (H–K)	Temp. (17–21)	Inter-action	Error (ms)	Temp. (17–21)	Housing[1] (S–Gr)
df		1	1	1	94	14	95
k_{go}	dif.	–0.02	–0.01			0.00	0.05
	f	3.12	2.87	1.21	0.0034	0.13	4.08***

[1] S = Single hens in battery cages, Series G
Gr = Group of hens in battery cages, Series H
***) P<0.001

of temperatures 17°C or 21°C on k_{go} in series H, K, J was found. The origin B showed sligthly higher value of k_{go} (0.69) than origin A (0.67) but the differences were not significant ($0.05 < P < 0.010$). Concerning the housing systems the comparison between the hens kept singly (series G) and kept in groups in the battery cages (series H) showed a highly significant ($P < 0.001$) difference. The overall utilization of ME for egg production was 0.72 in series G and 0.66 in series H, being about 8% higher for the hens kept singly than for 3 hens per battery cage.

8.4 Discussion

8.4.1 Terminology

Partition of metabolizable energy into energy available for maintenance and for production is necessary in order to estimate the efficiency of energy conversion to the products (growth, milk, eggs). The classical definition of maintenance describes maintenance as the state »in which there is neither gain or loss of a nutrient by the body«, *Blaxter (1972)*. Therefore the ME requirement for maintenance (ME_m) has been defined as the amount of energy required to balance anabolism and katabolism, giving an energy retention around zero.

This definition is acceptable for adult and non-producing animals, however, it is difficult to apply it for laying hens. In laying hens such an equilibrium never occurs and ME_m has to be considered as a more theoretical figure. In the present studies the maintenance requirement of ME is defined as the amount of ME which is needed to maintain a dynamic equilibrium of protein and fat turnover, to maintain a constant body temperature and to maintain a minimum locomotor activity. The equilibrium of protein and fat turnover means equal rates of synthesis and degradation of protein and fat so that neither loss nor gain of energy content in the body and no deposition of energy in eggs occurs.

In modification to the classical definition of ME_m, an equilibrium of protein and fat turnover implies that each of the components of total energy retention, protein and fat are zero, but not only the total energy retention is zero, since it is possible that one of the components has a negative value while the second one has a positive value of the same magnitude thereby, in total, giving zero energy retention. The energetic cost of physical and chemical thermoregulation is a substantial part of maintenance as discussed in detail by *Kleiber (1961), Es van (1972), Kampen van (1981)* and *Fisher (1983 b)*. Locomotor activity has often been adduced as at least a partial explanation for differences observed in maintenance in poultry, *Wenk & Es van (1976), Kampen van (1976 a,b), Janssen & Hart (1979)* and *MacLeod et al. (1982)*. It is unsatisfactory to apply the values of ME_m from non producing hens to laying hens, taking into account that such a condition may mostly be obtained under fasting which will probably reduce the activity as it was demonstrated for rats by *Westerterp (1976)*. Thus *Thorbek et al. (1984)* reported that ME_m estimated from fasting pigs was up to 20% lower than from pigs being fed. It may be assumed that a hen which is neither laying nor losing or gaining body energy is still using energy for a certain level of locomotor activity and this component of energy expenditure belongs to maintenance. However, the division between energy required to maintain locomotor activity at maintenance and production level is rather a theoretical one and it seems more appropiate to include the whole energy required for activity into maintenance requirement; so far measurements are carried out with hens showing relatively low level of activity. For that reason it has been decided to estimate ME_m from the hens kept singly.

The maintenance requirement is often described by the allometric equation $ME_m = a \times W,kg^b$ in which W,kg^b indicates the metabolic body weight, which is related to body mass and surface area and in the present investigation the constant value of 0.75 was used for the exponent b (cf. Chapter 7.3.2), thereby giving comparative values of the factor »a«. This concept of ME_m being proportional to $W,kg^{0.75}$ probably cannot be applied to growing animals as it has recentaly been shown for rats *(Eggum & Chwalibog, 1983)* and for growing pigs *(Just et al., 1983* and *Thorbek et al., 1984);* there is however, no a priori evidence that

in laying hens maintenance requirement is not proportional to metabolic body weight and the results from different experiments are usually expressed per $W,kg^{0.75}$.

The metabolizable energy available for production (ME_{go}) includes the energy for retention in body tissue and eggs under development in the ovary as well as for the deposition in eggs produced. In order to distinguish between different products of energy retention, in the present studies, the term energy balance (EBAL) was introduced which includes not only the energy retained in body tissue but also the energy in eggs growing in the ovary. As it was previously discussed (Cf. Chapter 7.3.1) laying is not a steady state and in the calorimetric experiments it is impossible to measure which part of energy above the energy deposited in eggs produced (OE) belongs to body tissue and which part belongs to eggs in the ovary. The efficiency of ME utilization for egg production can be expressed in different ways. In the present studies, in which EBAL as well as OE have been measured, the coefficients of ME utilization were distinguished between the overall efficiency of ME utilization for EBAL and OE i.e $k_{go} = (EBAL + OE)/ME_{go}$ and the efficiency for energy deposition in eggs produced i.e $k_o = OE/ME_o$. Furthermore ME_o was separated between the ME available for protein energy (ME_{op}) and for fat energy (ME_{of}) and the partial efficiencies were defined as $k_{op} = OPE/ME_{op}$ and $k_{of} = OFE/ME_{of}$ for protein and fat energy deposition respectively.

8.4.2 Maintenance requirement and energetic efficiency of egg production calculated according to different models

Application of different methods. There are different methods for estimating maintenance requirement and efficiency of ME utilization for egg production which can generally be divided into two categories of experiments:

1. fasting experiments
2. feeding experiments on different feeding levels.

Fasting experiments, a classical approach for ME_m estimation, involve the establishment of the fasting heat production (FHP) and the method requires knowledge about the constant (k_m) for the transformation of FHP into ME_m i.e $ME_m = FHP/k_m$. However, as mentioned before, heat production during fasting is reduced partly caused by reduced activity *(MacLeod & Shannon, 1978* and *MacLeod et al., 1979),* therefore values of ME_m obtained from fasting experiments may be unsatisfactory predictions for feeding conditions. Furthermore it is difficult to apply ME_m from fasting hens as their physiological state is different from normally fed layers. Such hens use body fat as a source of energy to maintain constant body temperature as well as their metabolism of carbohydrate and protein may be changed as demonstrated for rats by *Chudy & Schiemann (1969), Westerterp (1976)* and *Simon (1980).*

More commonly maintenance requirement and energetic efficiency for egg production have been estimated from experiments on different feeding levels by means of one-dimensional regression of a total energy output (EBAL + OE) in relation to ME. By extrapolating ME to zero energy output the value of ME_m is obtained and the regression coefficient is the coefficient of efficiency of ME utilization for egg production. This method requires the assumptions that $ME_m/W,kg^{0.75}$ is constant and that energy output at each feeding level has a constant proportion between protein and fat energy retention as discussed in detail by *Henckel (1976)*.

Multiple regression models can be applied to the results from experiments on different feeding levels or on ad libitum food intake where the individual variation is relatively high as it was the case in the present investigation. A multiple regression model including maintenance requirement and retained protein and fat was first carried out by *Kielanowski (1965)* for growing pigs. For laying hens for the first time *Hoffmann & Schiemann (1973)* calculated the multiple regression in order to estimate ME_m, efficiency of ME utilization for body energy retention and for energy deposition in eggs.

In the present investigation, different models for calculation of ME_m and energetic efficiency of egg production were applied to data from series G. In this series all balance and respiration measurements were carried out individually on the hens fed ad libitum and kept singly in the battery cages at a constant ambient temperture of 21°C. From the visual observations the locomotor activity was lowest in single hens, being in accordance with lowest CO_2 production and O_2 consumption in relation to $W,kg^{0.75}$ and ME (cf. Chapter 5.2) as well as lowest $HE/W,kg^{0.75}$ (cf. Table 7.1). The present results agree with the reports of *Hughes & Black (1974 a,b)*, *Süs (1976)* and *Bessei (1981)* demonstrating that hens kept singly were less active than in groups, since the activity is probably related to the social facilitation by eating (cf. Chapter 3.2.2).

The present calculations were performed on the observations with positive EBAL (n=52) omitting the results with negative EBAL (n=29) which occured mostly at the beginning of the experiment (cf. Chapter 7.1). The effect of body energy losses on the estimation of ME_m and energetic efficiency of egg production has been considered in a number of investigations, *Es van et al. (1970)*, *Hoffmann & Schiemann (1973)*, *Grimbergen (1974)*, *Voreck & Kirchgessner (1980 c)* and *Chwalibog (1982)*, and different corrections have been carried out for the amount of energy expended in the conversion of body tissue to eggs. However such a correction is questionable as the efficiency of this conversion is not known and the assumption of the efficiency about 0.8 for the negative body energy retention, *Voreck & Kirchgessner (1980 c)* may not be appropiate. In balance experiments, as it has been demonstrated in the present studies, the negative EBAL includes both the negative energy retention in body and energy

retention in eggs growing in the ovary. Those two parts cannot be separated which makes such a correction impossible. Furthermore, when negative EBAL occurs, the value of energy mobilized from body tissue is much higher than the value of negative EBAL as –EBAL= –body energy + energy in ovary.

Model with one-dimensional regression. The deposited fat energy in relation to the total energy in eggs produced (OFE/OE) was constant during the experiment with 54%, in series G as well as in the other series, indicating the constant proportion between protein and fat energy in OE and thereby allowing one-dimensional regression as discussed by *Henckel (1976)* and *Thorbek et al. (1984)*. By regression of total energy output (EBAL + OE) on ME, both expressed per metabolic body weight, values of $ME_m/W,kg^{0.75}$ and k_{go} were obtained in series G. The regressions were calculated for each balance period as well as on the pooled observations in the first four periods (26–35 weeks) and in the last four periods (38–47) and there were no significant differences between groupwise regressions indicating that $ME_m/W,kg^{0.75}$ and k_{go} were constant during the laying period. The present result is in agreement with other results from the literature showing constant values of $ME_m/W,kg^{0.75}$ but generally from shorter experiments. The total regression gave the following equation: (EBAL+OE), $kJ/W,kg^{0.75} = -293 + 0.71 \times ME,kJ/W,kg^{0.75}$ by which ME_m was 404 $kJ/W,kg^{0.75}$ and k_{go} was 0.71 corresponding to the cost of 1.41 kJ per 1 kJ retained energy. The efficiency of body energy retention can be assumed to be of the same magnitude as for egg production as demonstrated by *Hoffmann & Schiemann (1973)*, and in series G the part of EBAL bound to body energy retention was very small, shown by a daily body gain below 1 g. Thus the coefficient k_{go} was primarily an estimate of the efficiency for energy retention in eggs, both in the ovary and eggs produced. From the literature, the following values of ME_m and k_{go} obtained by one-dimensional regression have been found for White Leghorns kept singly at temperatures of about 20°C.

Source	ME_m $kJ/W,kg^{0.75}$	k_{go}
Waring & Brown (1967)	556	0.86
van Es et al. (1970)	481	0.80
Burlacu et al. (1974)	492	0.78
Grimbergen (1974)	427	0.64
Farrell (1975)	300	0.84
Valencia et al. (1980)	581	0.64
Voreck & Kirchgessner (1980c)	411–446	0.60–0.65
Madrid et al. (1981)	504	0.58

The results from the literature showed great variation of ME_m between 300–581 $kJ/W,kg^{0.75}$ and k_{go} between 0.58–0.86. It is difficult to compare these results with the present findings. In the works of *Waring & Brown (1967), Burlacu*

et al. (1974) and *Farrell (1975)* negative EBAL occurred and were not corrected, whereas it is not clear if there were negative EBAL in the experiments of *Valencia et al. (1980)* and *Madrid et al. (1981)*. The corrections made by *Es van et al. (1970)* and *Grimbergen (1974)* did not separate between energy in body and in ovarian eggs. *Voreck & Kirchgessner (1980 c)* found ME_m of 411 kJ/W,$kg^{0.75}$ and k_{go} of 0.60 when correcting body energy loss (slaughter experiment) using the factor 0.8 but without correction the values were 446 kJ/W,$kg^{0.75}$ and 0.65, i.e. 10% higher. Independent of whether a correction was applied or not the values of k_{go} were lower than found in the present investigation.

Models with multiple regressions. In model 2 an attempt has been made to estimate ME_m and the efficiency of ME utilization for EBAL (k_g) and for energy deposition in eggs produced (k_o) by means of the multiple regression of ME in relation to W,$kg^{0.75}$, EBAL and OE. The intercept was not significant indicating that ME in relation to EBAL and OE passes through the origin and the following regression for all observations with positive EBAL in series G was obtained:

$$ME,kJ = 414 \times W,kg^{0.75} + 0.86 \times EBAL,kJ + 1.56 \times OE,kJ$$

The equation showed a linear relationship between ME and the independent variables with constant estimates of ME_m, k_g and k_o during the laying period. Maintenance requirement was 414 kJ/W,$kg^{0.75}$, k_g was 1.16 (1/0.86) and k_o was 0.64 (1/1.56). The value of ME_m was similar to 404 kJ/W,$kg^{0.75}$ obtained by the one-dimensional regression (model 1) considering that SE values were 55 and 44 in model 1 and 2 respectively. The estimates of ME_m and k_o are in very good agreement with *Hoffmann & Schiemann (1973)* who demonstrated the following multiple regression:

$ME,kJ = 414 \times W,kg^{0.75} + 1.20 \times +EBAL,kJ + 0.96 \times -EBAL,kJ + 1.68 \times OE,kJ$ with ME_m = 414 kJ/W,$kg^{0.75}$ and k_o = 0.60 being slightly below the present result. The multiple regression performed by *Voreck & Kirchgessner (1980 c)* when correcting for negative body energy retention (RE × 0.8) gave the equation: $ME,kJ = -41.6 + 535 \times W,kg^{0.75} + 1.28 \times (RE+OE),kJ$, indicating a higher ME_m and a higher efficiency for retention of energy in body and eggs but, caused by the intercept, it is difficult to compare the results with the present values.

The present multiple regression showed that the cost of EBAL was 0.86 kJ/kJ corresponding to a k_g value of 1.16, i.e the efficiency was over 100% and therefore unaceptable. This was not the case for the hens with positive EBAL in the regression of *Hoffmann & Schiemann (1973)* who showed the efficiency of 0.79 (1/1.20) while for negative EBAL the k_g was 1.04 (1/0.96) although the method of calculation is not clear. The overestimation of k_g in the present experiment may be caused by a great variation in EBAL attributed to possible differences

in amount of energy retained in the eggs under development as eggs are not produced in a steady process. In order to inspect the influence of the cost of EBAL on ME_m and k_o, it has been assumed that k_g is between 0.70 – 0.90 as reviewed for different birds by *Bayley (1982)* and the fixed values of b_2 coefficient (cf. model 2) as 1.4 and 1.1 corresponding to k_g of 0.70 and 0.90 were therefore inserted in the regression of ME available for maintenance and energy deposition in eggs produced (ME_{mo}) in relation to $W,kg^{0.75}$ and OE. The ME_{mo} was calculated as $ME_{mo} = ME - ME_g$ where $ME_g = b_2 \times EBAL$ and the following multiple regression was performed: $ME_{mo} = b_1 \times W,kg^{0.75} + b_3 \times OE$. In this regression the value of b_1 is the estimate of $ME_m/W,kg^{0.75}$ and $1/b_3$ is the k_o. The obtained results with fixed b_2 values together with measured values from model 2 are tabulated below:

b_2	(k_g)	b_1 (ME_m)	se	b_3	se	(k_o)	RSD	CV,%
With fixed values of b_2								
1.4	(0.70)	361	57.2	1.60	0.25	(0.63)	69.0	6.7
1.1	(0.90)	390	46.3	1.58	0.20	(0.63)	55.9	5.2
With measured values (model 2)								
0.86	(1.16)	414	44.4	1.56	0.19	(0.64)	52.6	5.1

It has been shown that by inserting fixed values of b_2 (i.e increasing k_g from 0.7 to 0.9) the value of ME_m increased from 361 to 390 $kJ/W,kg^{0.75}$ but in both cases the k_o was 0.63 being identical with the measured value of 0.64. Thus it was characteristic that different values of k_g showed an effect on ME_m but negligible influence on k_o.

An atempt has been made to estimate the partial efficiencies of ME utilization for energy deposition in protein (k_{op}) and fat (k_{of}) of eggs produced by using model 3. In this model ME was regressed on $W,kg^{0.75}$, EBAL, protein energy deposited in eggs produced (OPE) and fat energy deposited in eggs produced (OFE) and the following multiple regression was obtained for series G with positive EBAL:

$ME,kJ = 419 \times W,kg^{0.75} + 0.84 \times EBAL,kJ + 1.99 \times OPE,kJ + 1.27 \times OFE,kJ$

The regression gave a ME_m of 419 $kJ/W,kg^{0.75}$ being identical to the estimates from model 1 and 2, taking into account standard error of estimates (SE). The equation showed that since the energy values of 1 g protein and fat in the egg can be estimated by 23.9 kJ and 39.8 kJ respectively (cf. Chapter 2.6) the amount of ME_o required to deposit 1 g of protein in the egg is 48 kJ (1.99×23.9) and for 1 g fat is 51 kJ (1.27×39.8) indicating nearly the same cost of protein and fat deposition expressed in weight units. However the energetic cost of protein and fat energy deposition were different being 1.99 kJ/kJ OPE and 1.27

kJ/kJ OFE corresponding to k_{op} of 0.50 (1/1.99) and k_{of} 0.79 (1/1.27). These results are in agreement with the values of partial efficiency for protein and fat energy retention in growing animals as reviewed by *Müller & Kirchgessner (1979)* and *Fowler et al. (1980)*, showing much lower efficiency for energy retained in protein than in fat. For laying hens there have been only few attempts to estimate either the efficiencies for OPE and OFE or the total efficiency of energy retention in protein (P) and fat (F), both in body and eggs. The calculations by means of multiple regressions are tabulated below.

Source	Regression (in kJ)
Hoffmann & Schiemann (1973)	$ME_o = 2.27 \times OPE + 1.35 \times OFE$
Farrell (1975)	$ME = 430 \times W,kg^{0.75} + 1.95 \times P + 1.04 \times F$
Grossu et al. (1976)	$ME_{go} = 1.51 \times P + 1.13 \times F$

The present results are in good agreement with the values calculated by *Hoffmann & Schiemann (1973)*, demonstrating nearly similar k_{of} of 0.74 (1/1.35), and a slightly lower k_{op} of 0.44 (1/2.27) using ME_m = 414 kJ/W,$kg^{0.75}$. Also the calculations made by *Farrell (1975)* with ME_m = 430 kJ/W,$kg^{0.75}$ being very close to the present value showed the same efficiency of protein energy retention with 0.51 (1/1.95) as in the present experiment but the efficiency of fat energy retention was 0.96 (1/1.04) being higher, probably caused by the inclusion of EBAL without correcting for negative fat retention. It is difficult to compare the figures from *Grossu et al. (1976)* because they were calculated with a lower ME_m (380 kJ/W,$kg^{0.75}$) and it is also not clear whether negative EBAL was included in the calculations.

Burlacu et al. (1974) have calculated a very high k_{op} of 0.77 but the same k_{of} of 0.78 as in the present studies although the method of calculation is not clear. Recently *Kirchgessner (1982)* demonstrated that with fixed ME_m = 420 kJ/W,$kg^{0.75}$ and fixed k_{of} = 0.8, both values being of the same magnitude as the estimates from model 3, the k_{op} is about 0.5 being equal to the present result.

Partition of ME. The results from the calculations of ME_m and energetic efficiency of egg production for hens with positive EBAL in series G have been summarized in Fig. 8.2. In this series the total ME was 842 kJ/W,$kg^{0.75}$ and ME_m was found to be 410 kJ/W,$kg^{0.75}$ independently of the model of calculation (model 1, 2, 3). This value is in very good agreement with a number of reports showing ME_m between 400–460 kJ/W,$kg^{0.75}$, *Waring & Brown (1965), Hoffmann & Schiemann (1973), Grimbergen (1974), Farrell (1975), Scheele & Musharaf (1980)* and *Voreck & Kirchgessner (1980 c)*. Thus it seems that on the basis of the present studies the best estimate of maintenance energy would be about 410 kJ/W,$kg^{0.75}$ and this figure was inserted in the calculations of ME available for EBAL and energy deposition in eggs produced (ME_{go}) in an

attempt to demonstrate the partition of ME in laying hens. It has been shown that about 50% of the total ME is used for maintenance and 50% for production. From 432 kJ/W,kg$^{0.75}$ of ME_{go}, 79 kJ/W,kg$^{0.75}$ was used for EBAL and 353 kJ/W,kg$^{0.75}$ was used for OE indicating that only 9% of ME_{go} is available for EBAL (ME_g) while 42% is used for OE (ME_o). The ME_o consists in 56% of ME available for OPE and in 44% of ME available for OFE which in relation to the total ME are 24% and 18% respectively for ME_{op} and ME_{of}.

8.4.3 The effect of temperature, origin and housing on energetic efficiency of egg production

From the present calculations of the data from series G (model 1,2,3) the maintenance requirement for hens with positive EBAL kept singly at 21°C could be fixed at 410 kJ/W,kg$^{0.75}$ and this value was inserted in the calculations of efficiency for egg production in the other series with different temperature, origin and housing. The overall efficiency of ME utilization for EBAL and energy deposition in eggs produced (k_{go}) was calculated according to $ME_{go} = ME - ME_m$ in which ME_m = 410 kJ/W,kg$^{0.75}$ and k_{go} as the proportion (EBAL+OE)/ME_{go}.

Temperature. It is generally agreed that maintenance requirement depends of ambient temperature and at temperature below 32°C, *Kampen van (1974)*, maintenance energy will include a varying amount of extra heat production to satisfy the requirement for thermoregulation. Therefore the comparisons of ME_m over a broader range of temperature (about 10–30°C) usually show increasing ME_m with decreasing temperature, *Shannon & Brown (1969), Davis et al. (1973), Es van et al. (1973), Grimbergen (1974), O'Neill & Jackson (1974), Valencia et al. (1978, 1980), Vohra et al. (1979)* and *Fisher (1983b)*, but over a narrower temperature range as in the present experiment, *O'Neill & Jackson (1974)* demonstrated similar ME_m at 16–23°C. The application of the same ME_m at 17 and 21°C has been based on the previous results concerning performance, gas exchange, nitrogen metabolism and energy metabolism which showed no significant effect of the temperatures on all investigated parameters. Consequently the k_{go} was not affected by the temperature (Table 8.1). This result is in accordance with the former data showing no significant differences in FCR (cf. Table 3.2) and gross utilization of energy (cf. OE/GE and OE/ME in Table 7.2) as well as it is in agreement with the experiments of *Shannon & Brown (1969), O'Neill & Jackson (1974)* and *Valencia et al. (1978)* demonstrating no significant differences in k_{go} even for a broader temperature range.

Origin. In the present experiment the same ME_m with 410 kJ/W,kg$^{0.75}$ was inserted in the calculations of k_{go} for origin A in series H and origin B in series K assuming that ME_m was independent of the origin. In the literature there are some indications of a genetic effect on ME_m between light and heavy breeds of layers as reviewed by *McDonald (1977)*. Comparing ME_m as tabulated by *Bal-*

nave (1974) or *Farrell (1975)* it appears that White Leghorns have a higher maintenance energy requirement than heavier hens. However there is no evidence that differences in ME_m occur within one breed of different origins; *Hoffmann & Schiemann (1973),* for example obtained a common maintenance of 414 kJ/W,$kg^{0.75}$ for White Leghorns and White Leghorn hybrids.

As discussed recently by *MacLeod et al. (1982)* the differences in locomotor activity between strains may influence ME_m but in the present experiment it has been concluded, from the visual observations, that birds of both origins kept in the same housing showed a similar activity. There were no significant differences in overall efficiency of ME utilization between the origins (Table 8.2), however, origin B had a tendency for higher k_{go} (0.69) than origin A (0.67). In many reports the result are often controversial showing either different k_{go} between breeds, *Waring & Brown (1965, 1967), Farrell (1975)* or similar, *MacLeod & Shannon (1978),* by using different values of ME_m. As differences in ME_m influence the value of k_{go} in such a way that a higher maintenance gives higher k_{go} it is likely that different values of k_{go} presented in the literature, in fact express a variation in live weight and in activity between light and heavy breeds. This was not the case in the present experiment where the effect of different ME_m values on k_{go} was excluded since the same ME_m could be inserted in the calculations. Although the efficiency was not significantly different between the origins a tendency of a higher k_{go} in origin B implies that the selection for higher egg production and better FCR (cf. Table 3.2) in Shaver hens may also improve the overall efficiency of ME utilization.

Housing. The calculations of the overall efficiency of ME utilization for single hens (series G) and groups in battery cages (series H) belonging to the same origin were made with aid of the same maintenace requirement which was estimated from seris G at 410 kJ/W,$kg^{0.75}$. The use of the same ME_m in different housing systems might be questionable in view of the results from »field trials« showing generally a higher maintenance for groups of hens under farming conditions than for isolated individuals in laboratory experiments as reviewed by *Grimbergen (1974), McDonald (1977), Byerly (1979)* and *Byerly et al. (1980).* However, the field estimates are often attributed to large errors in the measurements of food intake caused by spillage and scattering as well as the calculations are made with a number of assumption concerning energy retention in body and eggs. The other reason for the divergence between hens kept singly and in groups can be differences in locomotor activity which increases the energy expenditure in groups. Thus *Madrid et al. (1981)* demonstrated increasing ME_m as the number of hens increased from 3 to 7 per cage (area 929 cm^2 to 412 cm^2) and explained this increase by a higher activity. In the present experiment activity was higher in groups than in single hens which is associated with the social facilitation by eating as it has been discussed in the previous chapters (cf. Chapter

3.3.2 and 7.3.2). However, maintenance requirement has been defined with a minimum level of locomotor activty and an extra energy expenditure caused by increased activity has been considered as a part of energy used for production. The k_{go} was 0.72 in single hens (series G) while it was 0.67 in groups (series H) and the difference was highly significant (Table 8.2). The result being in agreement with the better FCR (cf. Table 3.2), the lower level of CO_2 production and O_2 consumption (cf. Chapter 5.2), and heat production (cf. Table 7.1), the higher utilization of nitrogen (cf. ON/IN in Table 6.2) and the higher gross utilization of energy for egg production (cf. Table 7.2) in single hens.

As the k_{go} describes the efficiency of ME utilization both for energy retention in body and eggs under development in the ovarian system and for energy deposition in eggs produced, and because the value of maintenance requirement could not be a reason for different k_{go} it can be concluded that the lower overall efficiency in the groups of hens was due to an increase in locomotor activity. Therefore the increase in energy intake for hens kept in groups may be called a »luxus consumption« as these hens used 7% more ME for the same amount of EBAL+OE than single hens and the difference was the extra energy expenditure caused by an increased activity when the hens are kept together.

IX. Conclusions

The purpose of the present studies was to investigate energy metabolism of hens during the laying period and to estimate the effect of ambient temperature, origin and housing on energetic efficiency of egg production. The experiments included the measurements of laying performance, size and chemical composition of eggs, gas exchange, nitrogen metabolism, energy metabolism and energetic efficiency of egg production. The experiments were carried out in 4 series (G, H, K, J) during the laying period from 26 to 47 weeks of age. The hens in series G were kept at a constant temperature of 21°C while in series H, K and J the temperature was either 17°C or 21°C. White Leghorns from the Danish Test Station for Egg Layers in Favrholm called origin A were used in series G and H and compared with Shaver Starcross 288 from Nørgård called origin B measured in series K and J. In series G the hens were kept singly in battery cages with an area of 2100 cm^2/hen while they were kept in groups with 3 birds in each battery cage with an area of 700 cm^2/hen in series H and K. In series J the hens were kept freely in the respiration chambers with 6 birds in each chamber giving an area of 2100 cm^2/hen. Caused by some hens in series J laying their eggs on the floor the collection of eggs was incomplete giving irregular picture of the egg production and thereby of the nitrogen and energy metabolism in this series. The effect of temperature was tested in series H, K and J. The effect of origin was tested for series H versus K. The effect of housing was tested between single hens in series G and groups in series H.

Performance. The course of performance had the same pattern for all series with the ad libitum food intake reaching maximum about 35 weeks of age and the maximum egg production being obtained by the age of 38–41 weeks.

The temperatures had no significant effect on any of the parameters of the performance while differences occured concerning origin in which origin B had significantly higher food intake, egg production, laying rate and food conversion ratio (FCR) than origin A. Single hens had significantly lower food intake than the groups in battery cages owing to the social facilitation by eating. However, the egg production and the laying rate were not significantly different and in consequence the FCR was better for single hens than for groups of hens.

Size and chemical composition of eggs. The size of the eggs increased significantly during the laying period. This increase was joint with an increasing weight of yolks being a greater part of the egg content at the end of the laying period and the proportion yolk/egg increased from 29 to 33%. The content of dry matter and nitrogen in eggs was not significantly different during the laying period but there was a significant increase in the fat content from about 9 to 10.5% and in consequence in the energy content from 7.1 to 7.5 MJ/kg eggs.

The temperatures had no significant effect on the size and chemical compo-

sition of eggs. The hens from origin B had significantly higher egg size than origin A but the chemical composition was not different. The housing systems had no significant influence on the size and chemical composition of eggs showing the following mean values: 25% DM, 2.1% N, 10% fat, 0.9% ash and 7.3 MJ/kg eggs.

Gas exchange. The production of CO_2 was lower at the beginning of laying than in the later part. The curves of CO_2 were parallel to the curves of food intake indicating a close relationship between gas exchange and food intake. The predictions of gas exchange from the individual data in series G were performed by means of multiple regressions and demonstrated that the values of egg production can be excluded from the equations and the gas exchange can be predicted from the metabolic body weight and metabolizable energy in the following regressions:

$$CO_2, l = 17.3 \times W,kg^{0.75} + 0.0094 \times ME,kJ$$

$$O_2, l = 22.7 \times W,kg^{0.75} + 0.0063 \times ME,kJ$$

The temperatures and origins had no significant effect on the CO_2 production and O_2 consumption in relation to $W,kg^{0.75}$ and ME but the hens kept in groups had higher values of gas exchange than single hens caused by a higher locomotor activity combined with the social facilitation by eating.

Nitrogen metabolism. The nitrogen balance (NBAL) includes nitrogen retained in body tissue and nitrogen incorporated in eggs being under development in the ovarian system. The NBAL could not be experimentally partitioned between nitrogen in body and in eggs in the ovary as egg production is not a continous 24 hours process and therefore the amount of egg material in the ovary will be different by a fixed time of collection. The NBAL by the age of 26 weeks was negative or close to zero being in accordance with the low values of body gain, indicating a very low nitrogen retention in body at the beginning of laying. The nitrogen deposition in eggs produced (ON) was lower by the age of 26 weeks but then it was fairly constant. The utilization of nitrogen for egg production (ON/IN) was not significantly influenced by the age.

The temperatures had no significant effect on the nitrogen deposition in eggs and the proportions ON/IN. The hens from origin B deposited 1.2 g nitrogen in eggs while the mean value for origin A was 1.0 g and the proportion of ON/IN was 40% and 38% respectively. The differences were significant and corresponded to the higher food intake, egg production and the better FCR in origin B. The housing systems had no significant effect on the nitrogen deposition in eggs, however, single hens had significantly higher proportion of ON/IN with 42% than in the groups with 38%, being in agreement with the better FCR. The difference was caused by the higher NBAL indicating a higher nitrogen retention in the body.

Energy metabolism. The energy balance (EBAL) includes energy retained in

protein and fat of body tissue and energy in eggs being under development in the ovarian system and could not be partitioned between energy in body and in growing eggs as explaind above for NBAL. The EBAL by the age of 26 weeks was close to zero or negative in accordance with the body gain indicating a very low energy retention in body at the beginning of the laying period. The energy deposited in eggs produced (OE) increased slightly during the laying period. Gross utilization of energy for egg production (OE/GE or OE/ME) was not significantly influenced by the age.

The temperatures had no significant effect on the values of metabolizable energy, energy deposited in eggs and the proportions OE/GE or OE/ME, and the differences in heat energy and EBAL were negligible. The origin B had significantly higher values of ME than origin A caused by the higher food intake. The values of heat energy and EBAL were of the same magnitude for both origins. The energy deposited in eggs produced was about 340 kJ and 400 kJ for origins A and B resepectively, being significantly different in accordance with the higher egg production in origin B. There were no significant differences in OE/GE and OE/ME between the origins but origin B had a tendency to a higher gross utilization of energy. The housing systems had a significant effect on ME values being higher for the hens kept in groups than kept singly caused by the social facilitation by eating. The values of heat energy were higher for the groups owing to the increase in ME and to a higher locomotor activity. The changes in ME and heat energy did not influence the energy deposition in eggs but the level of EBAL was higher for the groups indicating a higher energy retention in body. Thereby the proportions of OE/GE and OE/ME were lower in the groups than in single hens as the increase in energy intake was partly used to cover an increase in the locomotor activity and partly used for energy retention in the body but the energy deposition in eggs was not changed.

Energetic efficiency of egg production. Maintenance requirement of metabolizable energy (ME_m) can be defined as the amount of ME which is needed to maintain a dynamic equilibrium of protein and fat turnover, to maintain a constant body temperature and to maintain a minimum locomotor activity.

Energetic efficiency of egg production can be distinguished between the overall efficiency of ME utilization for EBAL and energy deposition in eggs produced i.e. $k_{go} = (EBAL+OE)/ME_{go}$ and the efficiency of ME utilization for energy deposition in eggs produced i.e. $k_o = OE/ME_o$. Furthermore the partial efficiencies for deposition of protein energy (OPE) and fat energy (OFE) can be defined as $k_{op} = OPE/ME_{op}$ and $k_{of} = OFE/ME_{of}$ respectively.

The maintenance and efficiencies of ME utilization were calculated in accordance with three models based on the data from single hens with positive EBAL and the following regressions were obtained.

Model 1

$(EBAL+OE),kJ/W,kg^{0.75} = -287 + 0.71 \times ME,kJ/W,kg^{0.75}$

From this model the ME_m was estimated to 404 $kJ/W,kg^{0.75}$ (287/0.71) and k_{go} was 0.71.

Model 2

$ME,kJ = 414 \times W,kg^{0.75} + 0.86 \times EBAL,kJ + 1.56 \times OE,kJ$

From this model the ME_m was estimated to 414 $kJ/W,kg^{0.75}$ and k_o was 0.64 (1/1.56).

Model 3

$ME,kJ = 419 \times W,kg^{0.75} + 0.84 \times EBAL,kJ + 1.99 \times OE,kJ + 1.27 \times OFE,kJ$

From this model the ME_m was estimated to 419 $kJ/W,kg^{0.75}$, k_{op} was 0.50 (1/1.99) and k_{of} was 0.79 (1/1.27).

Independent of the model of calculation the maintenance requirement was found to be close to 410 $kJ/W,kg^{0.75}$.

The partition of metabolizabale energy for single hens with positive EBAL showed that about 50% of the total ME was used for maintenance and 50% for production. In relation to the total ME, metabolizable energy available for energy deposition in eggs produced (ME_o) was 42% and ME available for energy retention in body and eggs being under development in the ovarian system (ME_g) was 9%. From the ME_o 56% was used for protein energy deposition (OPE) and 44% for fat energy deposition (OFE) in eggs produced.

It was demonstrated that the temperature, origin and housing had no influence on ME_m being 410 $kJ/W,kg^{0.75}$ and this value was inserted in the calculations of the overall efficiency of ME utilization for EBAL+OE (k_{go}) in the different series. The temperatures had no significant effect on k_{go} as it was the case for the other experimental parameters. There were no significant differences in the overall efficiency of ME utilization between the origins, however, origin B had a tendency of a higher k_{go} than origin A. The housing systems significantly effected the values of k_{go} being 0.72 for single hens and 0.67 for the hens kept in groups. The higher utilization of energy in single hens was in agreement with the better FCR, the lower level of gas exchange and heat production, the higher utilization of nitrogen and the higher gross utilization of energy for egg production. The results indicated that the differences in k_{go} between the housing systems were caused by the extra energy expenditure for an increased locomotor activity associated with the social facilitation by eating when the hens were kept together.

General conclusion

Independent of the age of hens in the laying period (26–47 weeks of age) the decrease in temperature from 21 to 17°C had no significant effect on the laying performance and the energetic efficiency of egg production. The origin had a significant effect on the laying performance being higher in origin B than in origin A caused by an increase in food intake together with a tendency of an improved energetic efficiency of egg production. The housing had no significant effect on the laying performance but the hens kept in groups had a higher food intake caused by the social facilitation by eating. This increase in food intake may be called a »luxus consumption« as it was partly used for body gain and partly for a higher locomotor activity but not for egg production. Thereby the energetic efficiency of egg production was significantly lower for the hens kept together than for single hens.

X. Dansk sammendrag

10.1 Indledning

Ægproduktionen påvirkes af adskillige faktorer, som kan deles i to hovedgrupper, interne og eksterne faktorer. De interne faktorer er forbundet med dyrenes genetiske struktur og evne til at transformere de optagne næringstoffer til æg. De eksterne faktorer omfatter omgivelsernes indflydelse såsom fodersammensætning, omgivelsestemperatur, burforhold m.m. Fra adskillige praktiske forsøg foreligger der mange informationer vedrørende interne og eksterne faktorers indflydelse på selve ægproduktionen, hvorimod kendskabet til æglæggende høners energiomsætning og den energetiske udnyttelsesgrad til ægproduktionen er forholdsvis begrænset.

Det er almindelig, at ægproduktionen stiger i den første del af æglægningsperioden og at hønerne lægger større æg i den sidste del af perioden. Det er dog stadig uafklaret om stigningen i ægstørrelsen følges af et konstant forhold mellem æggehvide og blomme, eller om mængden af æggehvide eller blomme stiger i relation til ægstørrelsen *(Fletcher et al., 1981)*. Et stigende fedt- og energiindhold i æg i løbet af æglægningsperioden er påvist af *Sibbald (1979)* og *Fletcher et al. (1981)*.

Der foreligger adskillige undersøgelser over ægydelsen i forhold til omgivelsestemperatur, afstamning og burforhold. Næringstof- og energioptagelsen falder ved stigende temperatur *(Sykes, 1977)* og over et bredt temperaturområde blev såvel ægproduktion *(Payne, 1967; Cowan & Michie, 1980)* som ægstørrelse *(Fletcher et al., 1981)* reduceret. For et mere snævert temperaturområde var disse ændringer begrænsede *(Petersen, 1977)* og temperaturen per se har næppe en signifikant virkning på ægydelsen, når der ikke er forskel i foderoptagelsen *(Emmans, 1974)*. Forskellige racer og linier har forskellig ydelse. Hos Hvid Italiener har en hybrid, Shaver Starcross 288, en højere ægproduktion og en bedre foderudnyttelse (FCR) end andre linier *(Neergaard, 1983)*. Der foreligger adskillige praktiske undersøgelser over driftsystemets effekt på ægydelsen. Med hensyn til burforholdene, har *Robinson (1979), Cunningham & Ostrander (1982)* og *Hughes (1983)* demonstreret at 2 til 7 høner/bur med et areal på 300–500 cm^2/høne reducerer foderoptagelse, ægydelse samt forøger dødeligheden ved stigende belægningstæthed. *Eskeland et al. (1977)* har dog vist, at der ingen væsentlig forskel var i ægproduktionen mellem høner holdt enkeltvis (1520 cm^2/høne) eller to per bur (760 cm^2/høne). *Hughes & Black (1974 a)* har observeret at nærværelse af en anden høne stimulerer foderoptagelsen, såkaldet »social facilitation by eating«. Det fremgår af *Bessei (1981)* at høner, der er holdt i grupper er mere aktive end høner, der er holdt enkeltvis.

Vekselvirkningen mellem ægydelsen og de genetiske faktorer samt omgivelsesforholdene, således som det fremgår af praktiske forsøg, må formodes at

være sammenhørende med forskelle i energiomsætningen. Hos æglæggende høner er de fleste målinger af energiomsætningen gennemført i forsøg af kortere varighed hvilket kun giver en begrænset viden vedrørende relationerne mellem alder og kvælstof-energiaflejring samt ægproduktion. Fra slagteundersøgelser har *Davis et al. (1973), Neill et al. (1977)* og *Kirchgessner (1982)* demonstreret, at kvælstof- og energiaflejringen i kroppen ved æglægningens begyndelse blev enten negativ eller omkring nul. Disse resultater er i overensstemmelse med balanceforsøg *(Hoffmann & Schiemann, 1973; Grimbergen, 1974; Sykes, 1979; Chwalibog et al., 1984),* hvor der dog ikke var foretaget adskillelse af kvælstof- og energiaflejring i kroppen og i æg under dannelse i æggestok og æggeleder. Resultaterne fra de kortere forsøg *(Hoffmann & Schiemann, 1973; Voreck & Kirchgessner, 1980a)* har vist, at kvælstofaflejringen i æg (ON) og kvælstofudnyttelsen til ægproduktionen (ON/IN) er nogenlunde konstant i æglægningsperioden. I modsætning til kvælstofomsætningen ser det ud til, at energiaflejringen i æg (OE) stiger på grund af stigende ægproduktion og stigende energiindhold i æg, dog synes relationerne OE/GE og OE/ME at være konstante, som vist af *MacLeod et al. (1979).*

Der foreligger i litteraturen en del resultater over temperaturens virkning på energiomsætningen, dog primært vedrørende varmeproduktionen *(Sibbald, 1982; MacLeod, 1984).* Det er demonstreret, at varmeproduktionen stiger med faldende temperatur *(O'Neill et al., 1971; Kampen van, 1981)* men disse ændringer er næppe signifikante i et begrænset temperaturområde *(Balnave, 1974; Strøm, 1978).* I de senere undersøgelser har *Tzschentke & Nichelmann (1984)* vist, at den såkaldte optimale biologiske temperatur (BOT) er mellem 17–22°C for Hvid Italiener, hvilket tyder på, at i dette temperaturområde vil varmeproduktionen være konstant.

Det er velkendt, at høner af forskellig afstamning viser forskelle i ægydelsen, men det er et spørgsmål, om en højere ægproduktion kun er afhængig af en højere foderoptagelse og/eller en højere energetisk udnyttelsesgrad. Der foreligger kun få undersøgelser vedrørende varmeproduktionen hos forskellige racer eller afstamninger, enten gennemført under hunger eller med begrænset foderoptagelse *(MacLeod, 1984),* hvorfor det er vanskeligt at overføre disse resultater til praktiske forhold ved ad libitum fodring.

Foderoptagelse og lokomotorisk aktivitet kan være afhængig af burforholdene hvorved energiomsætningen vil være forskellig mellem høner holdt enkeltvis og i grupper, idet høner i grupper ofte vil have en højere energioptagelse og en større aktivitet. Den lokomotoriske aktivitet regnes for at udgøre ca. 10–20% af det totale energitab *(MacLeod et al., 1982).* Såfremt sammenstuvning af høner forøger aktiviteten, vil dette yderligere forhøje energitabet *(Madrid et al., 1981),* hvorved energiaflejringen i krop og æg eller energiudnyttelsen til ægproduktionen påvirkes.

Ved en vurdering af interne og eksterne faktorers indflydelse på udnyttelsen af den omsættelige energi (ME) er det nødvendigt at kende ME-behovet til vedligeholdelse (ME_m). For de udvoksede dyr kan ME_m angives som: $ME_m = a\ W,kg^b$, hvor W,kg^b er legemsvægten i kg opløftet til en exponent »b«. Den værdi exponenten »b« skal tillægges er indgående diskuteret af *Kleiber (1961), Blaxter (1972)* og *Es van (1972),* og det er almindeligt accepteret, at metabolisk legemsvægt udtrykkes i kg$^{0.75}$. Der foreligger i litteraturen en række angivelser, hvor ME_m varierer mellem 300–600 kJ/W,kg$^{0.75}$ og udnyttelsesgraden mellem 0.5–0.8, afhængig af de anvendte beregningsmetoder såvel som af de interne og eksterne forhold *(Hoffmann & Schiemann, 1973; Grimbergen, 1974; McDonald, 1977; Byerly, 1979; Voreck & Kirchgessner, 1980c; Kirchgessner, 1982).* I en del undersøgelser har ME_m været beregnet ved hjælp af en-dimensional regression af aflejret energi i relation til ME, hvorved ME_m er angivet ved skæringen på x-aksen svarende til, at energiaflejringen er lig med nul, og hvor regressionskoefficienten angiver den energetiske udnyttelsesgrad. Anvendelse af multiple regressioner giver mulighed for at beregne ME_m, samtidig med en adskillelse mellem udnyttelsesgraderne for energiaflejringen i kroppen og i æg, *(Hoffmann & Schiemann, 1973; Voreck & Kirchgessner, 1980c).*

Det er velkendt, at ME_m er afhængig af omgivelsestemperaturen *(Kampen van, 1974)* og i et bredt temperaturområde var ME_m og udnyttelsesgraden signifikant forskellige *(Balnave et al., 1978; Byerly, 1979),* medens ændringerne ikke var signifikant forskellige i et snævert temperaturområde *(O'Neill & Jackson, 1974).* De genetiske forskelle mellem racer kan påvirke udnyttelsen af ME til ægproduktion *(Farrell, 1975; McDonald, 1977; MacLeod & Shannon, 1978),* imidlertid er det ikke bevist, at ME_m og udnyttelsesgraden varierer mellem forskellige afstamninger indenfor Hvid Italiener. Med hensyn til burforhold har *Madrid et al. (1981)* demonstreret, at en stigende belægningsgrad fra 3 til 7 høner/bur forøger ME_m og udnyttelsesgraden, medens der ikke foreligger undersøgelser af, hvorvidt der er forskel mellem høner holdt enkeltvis og i grupper.

Staldtemperatur ved ægproduktion er ofte mellem 17–21°C og disse temperaturer blev anvendt i de foreliggende forsøg til at vurdere temperaturens indflydelse på energiomsætningen og den energetiske udnyttelsesgrad til ægproduktion. Med hensyn til afstamningseffekten blev Hvid Italiener fra Favrholm, fremover kaldt afstamning A, sammenlignet med hybriden Shaver St. 288 kaldt afstamning B. Med hensyn til burforholdene blev hønerne holdt enten enkeltvis (2100 cm^2/høne), som 3 høner/bur (700 cm^2/høne) eller frit med 6 høner i et resprationskammer (2100 cm^2/høne).

De foreliggende undersøgelser blev genemført med ialt 204 balance- og respirationsforsøg, og omfatter målinger af ægydelse, ægstørrelse og kemisk sammensætning, luftstofskifte, kvælstofomsætning, energiomsætning og energetisk udnyttelsesgrad til ægproduktion i forhold til alder (26–47 uger), omgivelsestemperatur, afstamning og burforhold.

10.2 Materialer og metoder

Forsøgsoversigt

Hovedformålet med det foreliggende arbejde har været at undersøge energiomsætning i æglægningsperioden og påvirkningerne af omgivelsestemperatur, afstamning og burforhold på den energetiske udnyttelsesgrad til ægproduktion. Forsøgene blev gennemført i 4 serier (G,H,K,J) i en æglægningsperiode, hvor hønernes alder var fra 26 til 47 uger. Dyrenes fordeling i de forskellige serier og behandlinger fremgår af tabel 2.1.

Temperatur. Hønerne i serie G blev alle holdt ved en konstant temperatur på 21°C, medens temperaturen var henholdsvis 17 og 21°C i serie H, K og J.

Afstamning. Hvid Italiener fra Kontrolstationen for Høner i Favrholm (afstamning A) blev fordelt tilfældigt til 12 høner i serie G og 24 høner i serie H. Shaver Starcross 288 indkøbt fra Nørgård Hønseri i Havstrup (afstamning B) blev fordelt med 24 høner i serie K og 12 høner i serie J.

Burforhold. Hønerne i serie G, H og K blev holdt i æglægningsbure med en belægning på henholdsvis 1 og 3 høner per bur, svarende til et gulvareal på 2100 og 700 cm^2 per høne. Hønerne i serie J blev holdt i respirationskamre, 6 dyr i hvert kammer, hvilket gav et gulvareal på 2100 cm^2 per høne.

Forsøgsteknik

Samtlige høner var 20 uger gamle ved ankomst til laboratoriet. Pasning og fodring af kyllingerne i opdrætningsperioden var i overensstemmelse med de principper, der er beskrevet af *Neergaard (1980, 1983)*. Det var planlagt at gennemføre 8 balanceperioder i hver serie, men på grund af visse tekniske problemer, der er nærmere beskrevet i afsnit 2.2, kunne enkelte målinger ikke gennemføres.

Hønerne i serie G, H og K var holdt i æglægningsbure, henholdsvis enkeltvis i serie G og i grupper på 3 høner i serie H og K (tabel 2.1). De anvendte bure var Oli-Standard 201 (Svensk) som bruges i praksis, dog tilpasset individuel fodring og opsamling af droppings (gødning) og æg. De enkelte bure havde følgende mål: 47 cm bredde × 45 cm dybde (2100 cm^2 gulvareal) og var udstyret med et svagt skrånende netgulv, som gav en burhøjde på 43 cm (forsiden) og 37 cm (bagsiden). Burene blev sammenstillet i sektioner på 4 bure, men adskilt ved hjælp af plastikvæg og udstyret med tværgående fodertrug samt forsynet med drikkenipler. Gødning kunne falde gennem et netgulv (2.5 mm) ned på opsamlingsbakker placeret 10 cm under gulvet. Æggene blev opsamlet i et udvendig trug adskilt for hvert bur. I serie G var burene placeret i en klima-stald med en konstant temperatur på 21°C og en relativ luftfugtighed mellem 60–70%. Der blev anvendt konstant belysning på 17 timer. I serierne H og K var burene anbragt i klima-respirationskamre, der oprindeligt var bygget til kvæg. Temperaturen i respirationskamrene var enten 17 eller 21°C, den relative luftfugtig-

hed mellem 60–70% og belysning på 17 timer. I serie J blev hønerne holdt i grupper på 6 høner på netgulv i respirationskamre, oprindeligt bygget til svin. Netto gulvarealet var 1.26 m^2 svarende til 2100 cm^2/høne, og dyrene kunne bevæge sig frit. Respirationskamrene var forsynet med fodersiloer og drikkenipler. Gødning kunne falde gennem netgulvet (3.5 mm) på en opsamlingsbakke placeret under gulvet. Æg blev opsamlet i to redekasser. Temperatur, fugtighed og belysning var som i serie H og K.

Balanceforsøgene startede efter en forperiode på 5–7 uger. I forperioden blev dyrene holdt under samme vilkår som i forsøgstiden. Hver balanceperiode bestod af en 7 døgns opsamling fulgt af en 14 døgns mellemperiode. Foder blev udvejet individuelt eller for grupper, for hver periode, og aliquote prøver blev udtaget til kemiske analyser. Foderresterne fra foregående døgn blev opsamlet og opbevaret i kølerum indtil periodens afslutning. Gødning blev opsamlet daglig før fodring og opbevaret i fryser indtil afslutningen af hver periode. Æg blev samlet op hver dag kl. 8^{00} og opbevaret i kølerum indtil afslutningen af hver periode.

Målingerne af luftstofskiftet blev gennemført ved hjælp af afdelingens respirationsanlæg, der fungerer efter det indirekte kalorimetri- princip med åben luft cirkulation. Anlægget består af 3 respirationsenheder, hver med 2 uafhængige, klimaregulerede kamre, og i alle enheder måles luftgennemstrømningshastigheden efter tryk-differens princippet. Sammensætningen af udgående luft blev målt efter infrarødt princip for CO_2 eller paramagnetisk princip for O_2. Respirationsanlæggene er nærmere beskrevet af *Thorbek (1969), Thorbek & Neergaard (1970)* og *Chwalibog et al. (1979)*. Hovedparametrene for respirationsanlæggene fremgår af tabel 2.2. For at opnå en homogen blanding af den udgående luft samt en passende CO_2-koncentration i de forskellige kamre var den interne ventilation 67 m^3/h i kamrene A og B, 120 m^3/h i C og D og 150 m^3/h i E og F (tabel 2.2) afhængig af belægningstætheden og kamrenes størrelse. Da kamrene er udstyret med »falsk« loft, således at trækfornemmelse skulle være mindst mulig, anses forskellene i den interne ventilation for at være uden betydning. Luftstofskiftet var beregnet fra forskellen mellem koncentration af CO_2 og O_2 i indgående- og udgående luft i kamrene, og beregningsmetoden er anført i sektion 2.3.3.1. Med jævne mellemrum blev respirationsanlæggene kalibreret ved hjælp af CO_2 som beskrevet i sektion 2.3.3.2 og resultaterne af kalibreringsforsøgene er angivet i tabel 2.3. Beregningerne viste, at middeldifferencen mellem ind- og udgående CO_2-volumen var 1.07% for alle 6 kamre. I tabel 2.4 er angivet den nøjagtighed, der blev opnået ved CO_2- og O_2 analyserne med anvendelse af den metode, der er beskrevet i sektion 2.5.1.

Forsøgsfoder

Hønerne var fodret ad libitum og med fri adgang til vand, og der var i mellem-

perioderne fri adgang til østersskaller. Foderblandingen fra Kontrolstationen for Høner i Favrholm blev leveret til laboratoriet i to portioner i 1980 og 1981. Fodersammensætningen er vist i tabel 2.5, og middeltallene for den kemiske sammensætning, der blev bestemt for hver portion, er angivet i tabel 2.6. Som det fremgår af tabellen, var forskellen mellem de to leveringer ubetydelig.

Kemiske analyser og nøjagtighed

Forberedelse af foder, gødning- og ægprøver til de kemiske analyser er beskrevet i sektion 2.5. Analyserne af tørstof, aske, kvælstof, træstof og energi blev gennemført efter laboratoriets sædvanlige metodik, som er beskrevet af *Weidner & Jakobsen (1962)*. Råfedt blev analyseret efter Stoldt-metoden *(Stoldt, 1957)* og kulstof ved hjælp af et Wästhoff-apparatet, *(Neergaard et al., 1969)*.

Den analystiske nøjagtighed vedrørende kvælstof, kulstof- og energibestemmelserne i foder, gødning og æg blev beregnet efter metoden angivet af *Rasch et al. (1958)* nærmere beskrevet i sektion 2.5.1. Resultaterne er angivet i tabel 2.7 og viser en tilfredsstillende nøjagtighed.

Beregninger og statistiske analyser

Dyrenes energiomsætning blev beregnet på grundlag af de målte kulstof- og kvælstofbalancer (CN-metoden) over en 7 døgns opsamlingsperiode og et 24 timers respirationsforsøg. Beregningsmetoden fremgår af afsnit 2.6. De internationale faktorer vedtaget ved det 3. Symp. on Energy Metabolism, *(Brouwer, 1965)*, blev anvendt i alle beregningerne.

De anvendte statistiske analyser er beskrevet i sektion 2.7. Som det fremgår af figur 2.1 er effekten af temperatur, afstamning og burforhold vurderet ved hjælp af to-sidede variansanalyser (ANOVA) og t-tester. Regressionsanalyser er udført som beskrevet af *Henckel (1973)* og de blev benyttet til at beregne funktioner for luftstofskiftet samt til at bestemme energibehovet til vedligeholdelse og den energetiske udnyttelsesgrad til ægproduktionen.

Middelværdierne for alle målinger i 8 balanceperioder (per. I-VIII) i hver serie fremgår af hovedtabellerne. I serie G med høner holdt enkeltvis blev middelværdierne beregnet ud fra de individuelle målinger, og i serier K, H og J med, høner holdt i grupper blev målingerne divideret med antal af høner i gruppen for at opnå sammenlignelige værdier.

10.3 Ydelse

Legemsvægt, foderoptagelse og ægproduktion i æglægningsperioden

Middelværdierne af legemsvægen var ved starten 1.5–1.7 kg og ved afslutningen 1.7–2.0 kg. Den gennemsnitlige tilvækst i hele forsøgstiden var 117 g i serie G og henholdsvis 217, 162 og 168 g i serie H, K, J ved 17°C og 291, 267 og 196

g ved 21°C. Den daglige tilvækst varierede fra –5 til 2 g i serie G og fra –2 til 5 g i serierne H, K og J. Af figur 3.1 og 3.2 fremgår det, at foderoptagelsen ved forsøgets start var 83, 93, 116 og 109 g i serie G, H, K og J for begge temperaturer, stigende til 111, 126 og 135 g ved 35 ugers alderen, medens det maximale niveau på 120 g i serie J blev opnået ved en alder på 32 uger, hvorefter foderoptagelsen var nogenlunde konstant i alle serier i resten af forsøget. Som det fremgår af figur 3.3 og 3.4 blev den maximale daglige ægydelse i serie G, H, K, opnået ved en alder på 38–41 uger. Den daglige ægproduktion i periode I (26 uger) var 41, 42 og 49 g i serie G, H og K, disse værdier var signifikant forskellige fra de maximale ægydelser på henholdsvis 49, 49 og 58 g i de respektive serier. Eftersom nogle æg i serie J blev lagt på gulvet, hvor de ofte knækkede og blev ædt af hønerne, var opsamlingen ufuldstændig, hvorfor resultaterne fra denne serie giver et noget usikkert billede af ægproduktionen (figur 3.4). Læggeprocenten blev beregnet som antal af æg divideret med antal af dage i opsamlingsperioden (æg antal/7 × 100). Middeltallene varierede fra 76–85% i serie G, fra 78–89% i serie H og fra 87–99% i serie K uden signifikant forskel mellem perioderne. I serie J var læggeprocenten ved forsøgets start 96%, men senere viste målingerne en stor variation mellem 57–95% på grund af den ufuldstændige opsamling.

Effekten af temperatur, afstamning og burforhold på ægydelsen

Af samtlige 204 balancer var 81 målinger foretaget i serie G med enkelt høner og henholdsvis 51 og 56 målinger for høner holdt i grupper (3 høner/bur) i æglægningsbure i serie H og K samt 16 målinger for grupper (6 høner/kammer) holdt frit i respirationskamre i serie J. Middelværdierne for legemsvægt, foderoptagelse, ægproduktion, læggeprocent og foderforbrug per g æg (FCR) er vist i tabel 3.1 for alle serier. Hønerne blev vejet enkeltvis ved start og slut af hver balanceperiode. Den gennemsnitlige legemsvægt var 1560 g for afstamning A (serie G og H) og 1630 g for afstamning B (serie K og J). Foderoptagelsen blev højst i serie K med 124 g og lavest i serie G med 99 g. Den gennemsnitlige ægproduktion blev henholdsvis 45, 47 og 54 g i serie G, H og K med SEM værdier (standard error of mean) mellem 0.7 og 1.1. I serie J var den gennemsnitlige ægproduktion 43 g med større SEM værdier fra 1.6–1.9, på grund af den ufuldstændige opsamling. Middelværdierne for læggeprocent blev henholdsvis 82, 84 og 94% i serie G, H og K med SEM mellem 1.0–2.6. I serie J var læggeprocenten 78% med SEM fra 3.7–4.4. Den gennemsnitlige FCR var 2.19, 2.43 og 2.30 i serie G, H og K, og 2.57–2.78 i serie J.

Samtlige målinger blev brugt i de statistiske analyser til vurdering af effekten af temperatur, afstamning og burforhold på ægydelsen ved hjælp af 2-sidede variansanalyser (ANOVA) og t-test (jvf. kapitel 2.7). ANOVA beregningerne blev benyttet i serie H versus K for høner med forskellig afstamning, men holdt

under samme burforhold for derved at vurdere temperaturens og afstamningens indflydelse på ægproduktionen. T-test blev anvendt i serie J til at sammenligne ægydelsen ved 17 og 21°C og mellem serierne G og H til at vurdere burforholdenes effekt på ægproduktionen. Resultaterne fra serie J blev ikke sammenlignet med resultaterne fra de andre serier på grund af den ufuldstændige ægopsamling i denne serie. Som det fremgår af tabel 3.2, viste de statistiske analyser for serie H versus K ingen signifikant vekselvirkning mellem temperatur og afstamning, og der var ingen signifikant forskel i ydelsen mellem 17 og 21°C. Differencerne mellem afstamningerne var derimod stærkt signifikante, afstamning A (serie H) havde gennensnitlig 10 g mindre foderoptagelse, 7 g mindre ægproduktion, 10% mindre læggeprocent og 0.13 g/g højere FCR end afstamning B. Med hensyn til effekten af burforhold indenfor samme afstamning, serie G versus H, viste t-testen en stærk signifikant lavere foderoptagelse og en ringere FCR i serie G (enkeltdyr), medens der ikke var nogen signifikant forskel i ægproduktion og læggeprocent imellem de to burforhold.

Diskussion

Den gennemsnitlige totale tilvækst var 100–300 g i løbet af den 22 ugers lange æglægningsperiode. I serie G viste 30% af samtlige målinger en negativ tilvækst på –5 g daglig, og negative værdier blev ligeledes målt i serierne H og K, men dog i mindre omfang. Den negative tilvækst blev primært målt ved begyndelsen af æglægningsperioden, som tidligere demonstreret af *Neill et al. (1977), Chwalibog et al. (1984)*. De fremlagte resultater er også i overensstemmelse med andre balanceforsøg, som viser en stor variation i tilvæksten, ofte med negative værdier *(Waring & Brown, 1965, 1967; Grimbergen, 1970; Es van et al., 1973;, Hoffmann & Schiemann, 1973)*.

Den daglige foderoptagelse steg i løbet af de første 4 balanceperioder til et maximalt niveau ved en alder på 35 uger, og varierede derefter omkring et ret konstant niveau. Middelværdierne af foderoptagelse havde samme størrelse som den gennemsnitlige foderoptagelse angivet af *Landsudvalget for Fjerkræ, Rapport (1983)*, baseret på ca. 1 million data fra danske producenter i årene 1981–82. Stigende foderoptagelse blev også demonstreret i en beretning fra Kontrolstationen for Høner i Favrholm *(Neergaard, 1980)*, hvorfra forsøgsmaterialet til serie G og H var leveret.

Den daglige ægproduktion (serie G, H, K) var lavere ved forsøgets begyndelse end i de følgende perioder, og forskellen mellem startydelsen og den maximale produktion var signifikant. Læggeprocenten var ikke signifikant forskellig mellem perioderne. Værdierne fra serie G og H svarer til angivelser fra *Landsudvalget for Fjerkræ, Rapport (1983)* og fra Kontrolstationen for Høner i Favrholm *(Neergaard, 1980, 1983)*, medens læggeprocenten i serie K var noget højere.

De statistiske analyser viste ingen signifikant forskel i ydelsen mellem 17 og 21°C. Som tidligere demonstreret af *Benedict et al. (1932), Sturkie (1954)* og *King & Farner (1964),* og senere bekræftet af *Kampen van & Romijn (1970)* og *Es van et al. (1973),* må temperaturer mellem 17 og 21°C anses for at ligge i den termoneutrale zone. Den biologiske optimale temperatur (BOT), der angiver den temperatur, hvor dyrene er udsat for det laveste varmestress med en deraf følgende højere ydelse *(Nichelmann, 1983),* synes for Hvid Italiener at ligge omkring 19°C *(Tzschentke & Nichelmann, 1984).* Det er påvist, at i temperaturområdet 10–30°C, falder foderoptagelsen med stigende temperatur *(Sykes, 1977; Kampen van, 1981; MacLeod, 1984).* En nedsat ægydelse og tilvækst er ligeledes observeret i dette område *(Cowan & Michie, 1980).* På den anden side er det registreret, at ægydelsen ikke var påvirket af temperaturer indenfor 10–30°C *(Payne, 1967; Ahmad et al., 1974; Haugen, 1976; Vohra et al., 1979).* De anvendte temperaturer i det foreliggende forsøg kan sammenlignes med undersøgelser af *Petersen (1977),* hvor et stor antal høner blev holdt på netgulv ved henholdsvis 17.7 og 21.4°C. Resultaterne fra disse forsøg viste en lidt højere ægproduktion ved 21.4°C men samtidig en noget lavere foderoptagelse, men som diskuteret af *Emmans (1974)* kan temperatureffekten »per se« kun vurderes, når foderoptagelsen er ens. I de foreliggende studier var foderoptagelse og ægproduktion ikke forskellige ved 17 og 21°C, svarende til resultater opnået af *Emmans (1974),* der fandt, at læggeprocenten for Hvid Italiener med den samme foderoptagelse var uafhængig af temperaturstigning fra 5 til 25°C.

Sammenligningen mellem de to afstamninger af Hvid Italiener (serie H vs. K), holdt under samme temperatur- og burforhold viste, at afstamning B havde signifikant højere foderoptagelse, ægproduktion, læggeprocent og bedre FCR end afstamning A, hvilket er i god overensstemmelse med angivelser fra Kontrolstationen for Høner på Favrholm *(Neergaard, 1983).*

De fremlagte forsøg viste, at høner holdt enkeltvis i bure (serie G) havde en signifikant lavere foderoptagelse end høner holdt i grupper (3 høner/bur) i serie H, men forskellen i ægproduktionen og læggeprocenten var ikke signifikant. Forskellen i foderoptagelse kan dels henføres til antal af høner per bur og dels til areal per høne. Det er muligt, at en lavere foderoptagelse hos enkelthøner er forbundet med den såkaldte »social facilitation by eating«. Dette udtryk blev oprindelig anvendt af *Tolman (1964)* i hans arbejde med kyllinger, hvor de parvis holdte kyllinger åd betydelig mere end enkeltdyr, hvilket også er beskrevet af *Savory (1975), Savory & MacLeod (1980)* og *Chwalibog et al. (1978).* Hos æglæggende høner har *Hughes & Black (1974a)* ligeledes fundet, at nærværelse af en anden høne forbedrer foderoptagelsen. Antallet af høner i bur er en faktor, der ofte er forbundet med arealet per høne og trugkapacitet (trugkant) per høne *(Robinson, 1979),* såvel som lokomotorisk aktivitet *(Hughes & Black, 1974b).* Aktiviteten blev ikke målt i de foreliggende forsøg, men det blev observeret, at høner holdt i grupper var mere aktive end de der var holdt enkeltvis.

Den lokomotorisk aktivitet bliver ofte citeret som delvis forklaring på en forskellig foderoptagelse *(Süs, 1976; Eskeland, 1977)*, og ægydelse *(MacLeod et al., 1982)*. I de foreliggende forsøg med 1 til 3 høner per bur blev arealet og trugkanten reduceret, men hvert bur havde en trugkant på 47 cm, der var stor nok til at alle høner kunne æde samtidigt, denne faktor var sandsynligvis uden betydning. Det er fundet, at ydelsen kan være uafhængig af antallet af høner, hvis gulvarealet per høne er konstant *(Wells, 1971; Robinson, 1979)*. *Hughes & Black (1974a)* and *Hughes (1983)* har konkluderet, at ægproduktionen stiger ved en reduktion af antallet af høner, hvilket er mest tydeligt for mindre grupper med et areal under 400 cm^2/høne *(Hill & Binns, 1973; Carpena, 1973; Purkiss & Perry, 1974; Robinson, 1979)*, hvorimod *Eskeland et al. (1977)* ingen reduktion fandt i læggeprocenten mellem 1 og 2 høner/bur med et areal på 1520 og 760 cm^2/høne, hvilket svarer til de foreliggende undersøgelser, hvor der ingen signifikant forskel var i ægproduktionen mellem høner på 2100 cm^2/høne (serie G) eller 700 cm^2/høne (serie H).

10.4 Ægstørrelse og kemisk sammensætning

Ægstørrelse og kemisk sammensætning i æglægningsperioden

Som det fremgår af figur 4.1 og 4.2 var den gennemsnitlige ægstørrelse henholdsvis 51, 50, 54 og 46 g i serie G, H, K og J ved en alder på 26 uger, hvorefter den steg i alle serier til omkring 59 g ved forsøgets afslutning (47 uger). Forskellene mellem start- og slut ægstørrelsen var stærkt signifikante. Vejninger af æggehvide og blomme i serie K, viste en stigning i æggeblommevægten fra 14.5 til 17.5 g (periode I-VIII) med et stigende forhold mellem blomme og ægvægt fra 28.8 til 32.6%, samtidig med at proportionen blomme/hvide steg signifikant fra 41.0 til 48%.

Middelværdierne af den kemiske sammensætning (æg uden skaller) i relation til alder fremgår af figur 4.3 og 4.4. I samtlige observationer var indholdet af tørstof mellem 24–26% og kvælstof 2.0–2.2%, uden signifikant forskel mellem perioderne. Fedtindholdet steg fra 9% i periode I til 10.5% i periode VIII og energiindholdet fra 7.1 til 7.5 MJ/kg æg, og i begge tilfælde var forskellene signifikante.

Effekten af temperatur, afstamning og burforhold på ægstørrelsen og den kemiske sammensætning

Middelværdierne for ægstørrelse og kemisk sammensætning i forsøgstiden fremgår af tabel 4.1. Den gennemsnitlige ægstørrelse var højst i serie K med 57 g for begge temperaturer og lavest i serie G med 55 g. Indholdet af tørstof varierede mellem 25–26%, kvælstof 2.1–2.2%, fedt 9.9–10.3% og aske 0.93–0.96% i alle serier. Energiindholdet var 7.2 MJ/kg æg i serie G, 7.3 MJ/kg æg i serie H og K og 7.4 MJ/kg æg i serie J.

De statistiske analyser (ANOVA), for serie H versus K viste ingen signifikant forskel i ægstørrelsen mellem 17 og 21°C.

Afstamning A (serie H) havde gennemsnitlig 1.8 g mindre æg end afstamning B (serie K), og forskellen var stærkt signifikant. Høner holdt enkeltvis (serie G) lagde 0.3 g mindre æg end høner holdt i grupper (serie H), men forskellen var ikke signifikant. Den kemiske sammensætning var uafhængig af temperatur, afstamning og burforhold.

Diskussion

Som det fremgår af figur 4.1 og 4.2 steg ægstørrelsen i forsøgstiden, og forskellene var signifikante. Dette er i overensstemmelse med litteraturen *(Clark, 1940; Jeffery, 1941, Fletcher et al., 1981; Neergaard, 1980; Landsudvalget for Fjerkræ, Rapport, 1983),* dog kan maximal ægstørrelse forekomme ved forskellige aldre, som det er vist af *Anderson et al. (1978), Hurnik et al. (1977), Ambrosen & Rotenberg (1981).* I de foreliggende undersøgelser var stigningen i ægstørrelsen forbundet med tiltagende vægt af æggeblommerne, samtidig med et stigende forhold mellem blomme/albumen. Der foreligger i literaturen mange samstemmende resultater, som viser, at albumenproduktionen stiger med stigende ægstørrelse *(Chung & Stadelman, 1961; Skala & Swanson, 1962; Ajjam et al. 1977),* men i modsætning til de fremlagte resultater blev en tiltagende albumenprocent og en aftagende blommeprocent demonstreret af *Cunnigham et al. (1960), Jenkins & Tyler (1960), Cotteril et al. (1962), Kline et al. (1965)* og *Ambrosen & Rotenberg (1981).* Imidlertid er de opnåede resultater i fuld overensstemmelse med *Fletcher et al. (1981),* som har målt et stigende forhold mellem blomme/æg fra 29 til 33%.

Indholdet af tørstof og kvælstof i æg var uafhængig af alder, men fedtprocenten og energiindholdet steg i løbet af æglægningsperioden. Resultaterne vedrørende det konstante kvælstofindhold er i overensstemmelse med *Anderson et al. (1978),* men i modsætning til *Fisher (1983 a)* som beskrev et faldende proteinindhold over en længere æglægningsperiode. *Hoffmann & Schiemann (1973)* fandt et aftagende energiindhold med en tiltagende ægstørrelse hos høner, der var mere end 62 uger gamle. Resultaterne fra *Sibbald (1979)* tyder dog på et stigende energiindhold i løbet af æglægningsperioden, hvilket svarer til de foreliggende undersøgelser.

De fleste forskere angiver kun en middelværdi af energiindhold i æg *(Tasaki & Sasa, 1970; Davis et al., 1972; Hoffmann & Schiemann, 1973; Kirchgessner & Voreck, 1980 b),* men de opnåede resultater viser, at energiindholdet stiger i æglægningsperioden, hvorfor det synes, at være rimeligt at anvende forskellige værdier for energiindholdet i æg, afhængig af alder og ægstørrelse.

De statistiske analyser viste ingen signifikant forskel i ægstørrelsen mellem de to temperaturer (17 vs. 21°C) og mellem burforhold (serie G vs. H), men en

signifikant afstamningseffekt (serie H vs. K). Der foreligger i litteraturen mange resultater over en aftagende ægstørrelse ved stigende temperaturer fra 25°C og opefter *(Jeffery, 1941; Payne, 1967; Smith & Oliver, 1972; Emmans, 1974; Vohra et al., 1979; Fletcher et al., 1981)*. For en temperatur på 21.4°C målte *Petersen (1977)* ca. 2.5% mindre æg end ved 17.7°C, dog skal det nævnes, at i disse forsøg var foderoptagelse og ægproduktion lidt mindre ved 21.4°C i modsætning til de foreliggende resultater, hvor foderoptagelsen ikke var påvirket. Den signifikante forskel i ægstørrelsen mellem afstamningerne er i overensstemmelse med flere andre forsøg, hvoraf det fremgår, at en genetisk baggrund kan påvirke ægstørrelsen, som diskuteret af *Cunningham & Ostrander (1982)*. Med hensyn til burforhold er resultater vedrørende ægstørrelse indgående diskuteret af *Hughes (1983)*, og det fremgår heraf, at resultater fra forskellige forsøg kan være ganske kontroversielle, idet der kan være tale om en vekselvirkning mellem adskillige andre parametre, bl.a. temperatur, afstamning og fodring. De foreliggende undersøgelser, der viste samme ægstørrelse hos høner holdt enkeltvis og i grupper, svarer til resultaterne fra *Eskeland et al. (1977)* opnået under lignende burforhold.

I det foreliggende materiale var den kemiske sammensætning uafhængig af temperatur, afstamning og burforhold med i gennemsnit 25% tørstof, 2.1% kvælstof (13% protein), 10% fedt, 0.9% aske og 7.3 MJ/kg æg, hvilket nøje svarer til de værdier, der er fremlagt af *Siewart & Bronsch (1972), Hoffmann & Schiemann (1973)* og *Kirchgessner & Voreck (1980 b)*.

10.5 Luftstofskifte

CO_2-produktion i æglægningsperioden

Luftstofskiftet blev beregnet per høne i 24 timer, i serie G fra individuelle respirationsmålinger og i serie H, K og J fra det totale luftstofskifte i hvert kammer med korrektion for individuel metabolisk legemsvægt (W,kg$^{0.75}$). Målingerne blev vurderet dels i forhold til dyrenes alder og dels i relation til W,kg$^{0.75}$, omsættelig energi (ME) og ægproduktion.

CO_2-produktionen i relation til alder er vist grafisk i figur 5.1 og 5.2. Det fremgår heraf at i serie G (21°C), steg produktionen fra omkring 35 til 37 l ved 35 uger, hvorefter den faldt til 35 l. I serie H steg CO_2-produktionen fra 37 til 42 l (17°C) og fra 34 til 41 l (21°C) ved 35 uger, hvorefter den varierede omkring 40–41 l. I serie K var CO_2-produktionen nogenlunde konstant på omkring 43 (17°C) og 45 l (21°C) i hele forsøgstiden. I serie J steg CO_2-produktionen fra 41 til 42 (17°C) og fra 37 til 41 l (21°C).

Da luftstofskiftet må forventes at være en funktion af såvel legemsvægt og foderoptagelse som ægproduktion, blev de individuelle målinger i serie G benyttet til beregning af forskellige regressionsligninger. Det første beregningssæt omfattede regression af CO_2-produktion og O_2-optagelse i relation til W,kg$^{0.75}$,

ME og ægproduktion, som vist i ligning (1) og (2), (jvf. kapitel 5.1). Beregningerne viste, at såvel intercept som regressionskoefficient for ægproduktionen ikke var signifikante, hvorfor ligninger uden intercept og uden variabel-ægproduktion nu kunne beregnes med flg. resultat:

CO_2, l = 17.3 × W,$kg^{0.75}$ + 0.0094 × ME,kJ

O_2, l = 22.7 × W,$kg^{0.75}$ + 0.0063 × ME,kJ

Luftstofskiftet i de forskellige serier

Middelværdierne for CO_2 og O_2 indenfor de respektive serier er angivet i tabel 5.1. Da værdierne i serie H, K og J var beregnet med korrektioner for metabolisk legemsvægt, medførte dette at der ikke blev gennemført nogen direkte statistisk analyse for disse serier. Det gennemsnitlige luftstofskifte var lavest i serie G, med henholdsvis 35 l CO_2 og 39 l O_2. De højeste værdier blev målt i serie K med 43 l CO_2 og 47 l O_2, ved begge temperaturer. Respirationskvotienterne (RZ = CO_2/O_2) var henholdsvis 0.90, 0.86 og 0.92 i serie G, H og K. I serie J blev RQ = 0.99, muligvis på grund af underestimerede O_2-værdier (jvf. tabel 2.4). Forskellene mellem 17 og 21°C var stort set ubetydelige i alle serier. Afstamning A havde ca. 3 l højere CO_2-produktionen og 1 l højere O_2-optagelsen end afstamning B. Høner holdt enkeltvis (serie G) havde 6–7 lavere CO_2 og O_2 end høner i grupper (serie H).

Effekten af temperatur, afstamning og burforhold på luftstofskiftet blev vurderet udfra de multiple regressioner af CO_2 og O_2 i relation til W,$kg^{0.75}$ og ME. Den statistiske analyse (jvf. kapitel 2.7) viste at der var ingen signifikant forskel mellem de to temperaturer (17 vs. 21°C) og afstamninger (serie H vs. K). Dette medføre, at de totale ligninger for serie H+K, nu kunne sammenlignes med ligningerne i serie G (jvf. side 47). Under forudsætning af, at foderoptagelsen var 100 g dvs. omkring 1130 kJ ME og legemsvægten var 1.8 kg dvs. 1.55 W,$kg^{0.75}$, blev CO_2-produktionen og O_2-optagelsen flg.:

Serie	Burforhold	CO_2,l	O_2,l
G	1 høne/bur	37	42
H+K	3 høner/bur	41	46

Det fremgår heraf, at høner holdt i grupper (serie H+K) under disse betingelser vil have 11% højere CO_2-produktion og 8% højere O_2-optagelse end høner holdt enkeltvis.

Diskussion

Der foreligger i litteraturen kun få forsøg vedrørende målinger af luftstofskifte, og resultater fra disse, der blev gennemført enten under hunger eller i kortere målinger *(Misson, 1974; Boshouwers & Nicaise, 1981)*, kan vanskelig benyttes til sammenligning med egne undersøgelser.

Luftstofskiftet i de fremlagte forsøg blev bestemt over en 22 ugers æglægningsperiode hos høner holdt under omgivelser, der lignede de praktiske forhold. De opnåede resultater vedrørende CO_2-produktionen i forhold til dyrenes alder (fig. 5.1 og 5.2) viste stort set de samme kurver som foderoptagelsen (jvf. figur 3.1 og 3.2), hvilket hænger sammen med, at CO_2-produktionen primært er afhængig af legemsvægt og foderoptagelse. Det er velkendt, at luftstofskiftet er afhængig af dyrenes størrelse og vægt, og at luftstofskiftet kan angives ved en exponentiel funktion af legemsvægt (metabolisk legemsvægt), hvor eksponenten i almindelighed angives ved 0.75, som diskuteret af *Kleiber (1965)* og *Blaxter (1972)*. Den lineære relation mellem luftstofskiftet og $W,kg^{0.75}$ kan opnås, såfremt, der er en stor variation i legemsvægten *(Geers et al., 1982)*, f.eks. hos voksende kyllinger, som angivet af *Chwalibog et al. (1978)*. Dermod bliver, luftstofskiftet hos æglæggende høner ikke kun afhængig af metabolisk vægt. I de foreliggende undersøgelser blev CO_2-produktionen og O_2-optagelsen regnet i relation til $W,kg^{0.75}$, ME og ægproduktionen. Det fremgår heraf at i serie G, hvor hønerne var målt enkeltvis, kunne ægproduktionen udelukkes fra de multiple regressioner.

Regressioner af luftstofskiftet ved de forskellige temperaturer og afstamninger i forhold til $W,kg^{0.75}$ og ME viste ingen signifikant forskel mellem 17 og 21°C, og mellem afstamningerne. Med hensyn til burforhold viste det sig, at under forudsætning af at legemsvægt og foderoptagelse i de pågældende serier var ens, havde høner holdt enkeltvis (serie G) et lavere luftstofskifte end høner holdt i grupper (serie H+K), muligvis på grund af en større aktivitet i forbindelse med »social facilitation by eating« hos høner holdt i grupper.

10.6 Kvælstofomsætning

Kvælstofomsætning i æglægningsperioden

Af figur 6.1, 6.2, 6.3 og 6.4 fremgår det at, kvælstofoptagelsen (IN) med den stigende foderoptagelse steg fra 1944, 2194 og 2711 mg ved forsøgets start til henholdsvis 2633, 2974 og 3222 mg i serie G, H og K ved en alder på 35 uger, hvorefter niveauet var nogenlunde konstant. På grund af den ufuldstændige ægopsamling i serie J er resultaterne fra denne serie usikre. Kvælstofudskillelsen i gødning (DRN) fulgte mønstret for IN. Kvælstofbalancen (NBAL) omfattede såvel kvælstof aflejret i kroppen som i æggene under opbygning i æggestok og æggeleder. Målingerne af NBAL viste en betydelig variation med stort set de laveste værdier ved forsøgets start svarende til en alder på 26 uger. I serie G varierede middelværdierne for NBAL fra –110 til 180 mg, i serie H fra 25 til 380 mg, i serie K fra –35 til 390 mg (17°C) og fra 25 til 540 mg (21°C). Middelværdierne for kvælstofaflejringen i æg (ON) var, undtagen i periode I (26 uger), nogenlunde konstante omkring 1000 mg i serie G og H og 1200 mg i serie K. Det gennemsnitlige forhold ON/IN var henholdsvis 39–46%, 37–45% og 36–44% i serie G, H og K, uden signifikant forskel mellem perioderne.

Effekten af temperatur, afstamning og burforhold på kvælstofomsætningen

Middelværdierne for kvælstofomsætningen er demonstreret i tabel 6.1. Det fremgår heraf, at IN var højst i serie K (2984 mg) og lavest i serie G (2346 mg). Proportionen DRN/IN var henholdsvis 55, 54, 53 og 51% i serie G, H, K og J. Kvælstof aflejret i æg var højst i serie K på ca. 1200 mg og omkring 1000 mg i serie G og H. Den relative spredning (CV) for ON var 16% i serie G og 8% i serie H og K. I serie G var ON/IN 42% mod 38% i serie H, 40% i serie K og 35% i serie J. Mængderne af NBAL (N aflejret i kroppen og i æg under dannelse i æggestok og æggeleder) viste en betydelig variation fra –0.5 til 0.6 g i serie G, fra –0.1 til 0.5 g i serie H og fra –0.2 til 0.6 g i serie K.

De statistiske analyser (jvf. kapitel 2.7 og 3.2) viste ingen signifikant vekselvirkning mellem temperatur og afstamning. Desuden var ON og ON/IN ikke signifikant forskellige mellem 17 og 21°C. Med hensyn til afstamning viste afstamning B en signifikant højere ON og en bedre ON/IN end afstamning A. Med hensyn til burforhold var der ingen signifikant forskel i ON, dog blev ON/IN signifikant mindre hos høner holdt i grupper (serie H) end hos høner holdt enkeltvis (serie G).

Diskussion

Målingerne over kvælstofomsætning efter balancemetoden inkluderer visse systematiske fejl, idet kvælstoftilførsel (IN) ofte bliver overestimeret og kvælstof udskilt i gødning (DRN) underestimeret, hvorved aflejret kvælstof bliver overestimeret. I balanceforsøg med fjerkræ bliver gødning desuden ofte blandet med fjer samtidig med, at der kan foregå et vist amoniaktab fra gødning på grund af gæring. Dette gæringstab må anses for at være ringe i henhold til undersøgelser af *Es van et al. (1970)* der ikke kunne påvise nogen stigning i amoniakkoncentration i luften fra respirationskamre ved 24 timers opsamlingsforsøg med æglæggende høner. Hertil kan tilføjes, at kvælstofaflejringen i kroppen hos æglæggende høner er forholdsvis lille, hvorfor en eventuel overestimeret kvælstofaflejring næppe vil ændre billedet af kvælstofomsætningen.

I de foreliggende undersøgelser, med den samme fodersammensætning, viste IN i relation til alder det samme mønster som for foderoptagelsen. Forholdet DRN/IN var næsten konstant med omkring 54% i alle serier, hvilket er betydeligt lavere end angivet af *Hoffmann & Schiemann (1973),* medens det er i god overensstemmelse med resultater fra *Harnish (1972).*

Den aflejrede kvælstofmængde i æg (ON) blev bestemt på grundlag af ægproduktionen og æggenes kemiske sammensætning, medens kvælstofbalancen blev beregnet som NBAL=IN–(DRN+ON), hvilket i de foreliggende studier omfatter såvel kvælstof i æg under dannelse i æggestok og æggeleder og kvælstof aflejret i kroppen. Det er ikke muligt, ved balancemetoden, at adskille kvælstof aflejret i æg i æggestok og æggeleder, og kvælstof aflejret i kroppen,

idet æglægningen ikke er en kontinuerlig process. Det tager ca. 25 timer at producere et æg, og afhængig af læggecyklus *(Fisher, 1981)* vil ægdannelsen foregå på forskellige tidspunkter. Dette medfører at ved opsamling af æg på et fast tidspunkt, som i foreliggende forsøg, vil den ægmængde som er under dannelse i æggestok og æggeleder være forskellig. Det fremgår heraf, at NBAL kan variere betydeligt fra den ene opsamling til den næste, idet der ikke foreligger nogen »steady state«. I de foreliggende forsøg var NBAL enten negativ eller omkring nul ved forsøgets begyndelse. Dette er sandsynligvis på grund af en reduceret proteinaflejring forud for æglægningens begyndelse *(Neill et al., 1977; Chwalibog et al., 1984)*. Den negative kvælstofaflejring blev noteret i en række balance- og slagteforsøg med æglæggende høner *(Hoffmann & Schiemann, 1973; Grimbergen, 1974; Farrell, 1975; Kirchgessner, 1982)*.

Kvælstofaflejringen i æg, undtagen i periode I, var næsten på et konstant niveau i forsøgstiden med 1 g ON i serie G og H og 1.2 g i serie K. Disse værdier er indenfor angivelser fra *Voreck & Kirchgessner (1980a)* og *Harnish (1972)*. Sidstnævnte har i overensstemmelse med de fremlagte resultater demonstreret, at hønernes alder ingen indflydelse har på ON. Udnyttelsen af optaget kvælstof til ON (ON/IN) var ikke forskellig imellem perioderne, men variationen var ret stor fra 39–46%, 37–45% og 36–44% i serie G, H og K. Disse værdier er lidt højere end angivet af bl.a. *Hoffmann & Schiemann (1973), Voreck & Kirchgessner (1980a)*, men i god overensstemmelse med resultaterne fra *Harnish (1972)*.

Der foreligger i litteraturen kun få resultater vedrørende kvælstofomsætning i forhold til temperatur, afstamning og burforhold, og gennemgående har forsøgene været gennemført i kortere perioder med enkelthøner i et bredt temperaturinterval, hvorfor de er vanskelige at sammenligne med de opnåede resultater. I de foreliggende undersøgelser havde temperaturer på henholdsvis 17 og 21°C ingen signifikant effekt på kvælstofaflejringen i æg og udnyttelsen af kvælstof til ægproduktion (tabel 6.2). Disse resultater stemmer overens med, at der ikke var nogen signifikant forskel i ægydelse (jvf. tabel 3.2), ægstørrelse og kemisk sammensætning (jvf. kapitel IV) mellem de to temperaturer.

Med hensyn til afstamningseffekten fremgår det af tabel 6.2, at afstamning B (serie K) havde højere ON og ON/IN end afstamning A (serie H). Disse forskelle er i overensstemmelse med en højere ægproduktion i serie K (jvf. tabel 3.2), imidlertid var kvælstofindholdet i æg ens for begge afstamninger af Hvid Italiener. De opnåede resultater viste ligeledes, at forskellen i ON ikke kun skyldtes en højere ægproduktion, men også en bedre kvælstofudnyttelse i overensstemmelse med en bedre FCR. De tyder også på, at selektion for en højere ægproduktion hos afstamning B forøger både ON og ON/IN.

Med hensyn til burforhold, blev det demonstreret at kvælstofoptagelsen var højere hos høner holdt i grupper (serie H) end hos høner holdt enkeltvis (serie G). Dette svarer til en højere foderoptagelse i serie H, og synes at være påvirket

af »social facilitation by eating« (jvf. kapitel 3.3.2). Imidlertid, var ON ikke signifikant forskellig (tabel 6.2), da kvælstofudnyttelsen var lavere hos høner holdt i grupper, hvilket kan skyldes en højere NBAL og dermed en højere kvælstofaflejring i kroppen.

10.7 Energiomsætning

Målingerne af energiomsætningen omfatter værdierne for bruttoenergi (GE), energi i gødning (DRE), omsættelig energi (ME), varmeenergi (HE), energibalance (EBAL) og energi aflejret i producerede æg (OE). Værdierne for GE, DRE og OE, blev bestemt ved anvendelse af kalorimetriske bomber, ME blev bestemt udfra differencerne ME=GE–DRE, medens HE blev bestemt som differencerne HE=ME–(EBAL+OE), hvor EBAL er beregnet på grundlag af de målte kvælstof- og kulstofbalancer i henhold til den tidligere omtalte CN-metode (jvf. kapitel 2.6). Værdierne for EBAL inkluderer såvel den mængde energi som er aflejret i kroppen som den energi, der aflejres i æggene under dannelse i æggestok og æggeleder.

Energiomsætning i æglægningsperioden

Energiomsætning i relation til alder er vist i figur 6.1, 6.2, 6.3 og 6.4 for serie G, H, K og J. Middelværdierne for bruttoenergi steg fra henholdsvis 1.35, 1.51, 1.93 og 1.80 MJ i serie G, H, K og J, til maxima på 1.82, 2.05, 2.24 og 1.99 MJ ved 35 ugers alder (undtagen i serie J), hvorefter et nogenlunde konstant niveau blev opretholdt. Den omsættelige energi fulgte mønstret for GE med stigning fra 0.96–1.26, 1.06–1.49, 1.33–1.62 og 1.30–1.46 MJ for de respektive serier. Værdierne for EBAL viste en betydelig variation med stor set de laveste værdier ved forsøgets start. I serie G variede EBAL således fra –155 til 135 kJ, i serie H fra –23 til 290 kJ og i serie K fra 85 til 385 kJ. I serie J var EBAL højere end i andre serier, men på grund af den ufuldstændige ægopsamling blev resultaterne vedrørende energiomsætningen usikre i denne serie. Energiaflejringen i producerede æg (OE) steg i æglægningsperioden dog uden signifikant forskel mellem perioderne II–VIII.

Effekten af temperatur, afstamning og burforhold på energiomsætningen

Middelværdierne for energiomsætning er demonstreret i tabel 7.1. Det fremgår heraf, at GE (2.05 MJ) og ME (1.46 MJ) var højst i serie K og lavest i serie G (GE=1.62, ME=1.12 MJ). Omsætteligheden af energi (ME/GE) var henholdsvis 69, 71, 71 og 72% i serie G, H, K og J. Den gennemsnitlige varmeproduktion var højst i serie K med 895 kJ ved begge temperaturer og lavest i serie G på 767 kJ. Den gennemsnitlige varmeproduktion udtrykt i relation til $W,kg^{0.75}$ var henholdsvis 540, 572 og 581 kJ/$W,kg^{0.75}$ i serie G, H og K. Hønerne i serie K aflejrede i gennemsnit 395 kJ energi i æg, medens aflejringen i serie G

og H var henholdsvis 327 og 343 kJ. Relationen OE/GE var højst i serie G på 20%, medens den var 18 og 19% i serie H og K, de tilsvarende værdier for OE/ME var mellem 29–26%. Værdierne for EBAL kan fordeles mellem energi aflejret i protein (PEBAL), og energi aflejret i fedt (FEBAL). De opnåede minima og maxima for PEBAL, FEBAL, EBAL samt for relationen EBAL/GE, fremgår af kapitel 7.2. I serie G var proportionen EBAL/GE særdeles lav med en værdi omkring 1.6%, medens forholdet steg til 6.2% og 8.2% henholdsvis i serie H og K.

De statistiske analyser blev gennemført som i de foregående kapitler. På grund af en vekselvirkning (fra ANOVA for serie H vs. K) mellem temperatur og afstamning for HE, og på grund af en meget stor variation i EBAL, blev disse målinger ikke analyseret. Resultaterne af de statistiske analyser vedrørende de andre parametre fremgår af tabel 7.2. Der var ingen signifikant forskel i energiomsætningen mellem 17 og 21°C, men med hensyn til afstamningseffekten havde afstamning B (serie K) 140 kJ højere ME og 50 kJ højere OE end afstamning A (serie H), og disse forskelle var stærkt signifikante. Forskellene med hensyn til omsætteligheden af energi var ikke signifikante, medens der var tendens for en højere bruttoudnyttelse af energi (OE/GE eller OE/ME) hos afstamning B. Med hensyn til burforhold havde høner holdt enkeltvis (serie G) 200 kJ lavere ME og 1.5% lavere ME/GE end høner holdt i grupper (serie H), og disse forskelle var stærkt signifikante, ligesom forskellene med hensyn til OE/GE og OE/ME var signifikant højere i serie G end i serie H, derimod var forskellen med hensyn til energiaflejringen i æg ikke signifikant.

Varmeproduktionsenheder

For at kunne sammenligne varmeproduktionen fra de foreliggende forsøg med de værdier, som anvendes indenfor klimaregulering i fjerkræstalde, blev de daglige mængder af HE (fra serie G, H, K) udtrykt per time (h) og omregnet til varmeproduktionsenheder (ny vpe). Varmeproduktionsenheden er defineret som 1 ny vpe = 1000 Watt total varmeafgivelse ved 20°C *(Strøm, 1978)*.

Da 1 Watt svarer til 0.860 kcal/h eller 3.6 kJ/h vil 1 vpe svare til 3600 kJ/h, hvorfor de fundne værdier for varmeproduktion kan transformeres til henholdsvis 0.011, 0.012 og 0.012 vpe i serie G, H og K.

Diskussion

I de foreliggende forsøg viste energioptagelsen i relation til alder det samme mønster som foderoptagelsen. Det fremgår af figur 7.1, 7.2, 7.3 og 7.4, at energioptagelsen steg ved alder fra 26–35 uger, hvorefter den varierede omkring et konstant niveau. Den såkaldte energibalance (EBAL), der blev beregnet som EBAL=ME–OE, inkluderede såvel energi aflejret i æg under dannelse i æggestok og æggeleder som energi aflejret i kroppen. I litteraturen er denne energi-

mængde ofte kun betragtet som den energi, der er aflejret i kroppen *(Es van et al., 1973; Grimbergen, 1974; Sykes, 1979)*. Som tidligere omtalt (jvf. kapitel 6.3) kan NBAL bestemt fra balanceforsøg næppe fordeles mellem kvælstof i æggestok og æggeleder og i kroppen, og det er ligeledes ikke muligt at fordele EBAL mellem dens komponenter. De opnåede resultater viste små eller negative EBAL ved begyndelsen af æglægning samt en betydelig variation i hele forsøgstiden svarende til resultater fra *Waring & Brown (1965, 1967), Es van et al. (1970), Grimbergen (1970), Es van et al. (1973), Hoffmann & Schiemann (1973), Grimbergen (1974)* og *Burlacu et al. (1974)*. De fremlagte forsøg viste en svag stigning for OE i æglægningsperioden, dog ikke signifikant, muligvis på grund af en stor individuel variation. Der var heller ikke signifikant forskel for OE/GE og OE/ME mellem perioderne, hvilket tydeligt viste, at bruttoenergiudnyttelsen var uafhængig af alderen, som tidligere fremhævet af *MacLeod et al. (1979)*. De opnåede værdier for OE/GE og OE/ME ligger indenfor angivelser fra *Supramanian (1970), Petersen (1971), Polin & Woldorf (1973), Davis et al. (1973), Hoffmann & Schiemann (1973), Reid et al. (1978), MacLeod & Shannon (1978), Voreck & Kirchgessner (1980 b)* og *Byerly et al. (1980)*.

Det er almindelig anerkendt, at foderoptagelsen og dermed energioptagelsen aftager indenfor et bredt temperaturområde (5–30°C) *(Sykes, 1977; Kampen van, 1981; MacLeod, 1984)*. Ændringer i energioptagelsen er dog allerede observeret imellem 15–25°C *(Ota & McNally, 1961; Davis et al., 1973; Es van et al., 1973)*.

I de foreliggende undersøgelser med et snævert temperaturområde fra 17 til 21°C var der ingen signifikant effekt på energioptagelsen. I dette temperaturområde var der heller ingen forskel på omsætteligheden af energi, hvilket svarer til resultater fra *Es van et al. (1973)*.

Det er velkendt, at varmeproduktionen er en funktion af den metaboliske legemsvægt a × W,kg$^{0.75}$ (jvf. kapitel 5.3), hvorfor de målte værdier er udtrykt i relation hertil. De opnåede resultater (serie H og K) viste at HE/W,kg$^{0.75}$ ved 17°C kun var 3–5% højere end ved 21°C, og denne forskel ligger indenfor den individuelle variation, hvilket tyder på, at denne temperaturændring næppe vil påvirke varmeproduktionen. Der foreligger i litteraturen mange undersøgelser vedrørende temperaturens indflydelse på varmeproduktion *(O'Neill & Jackson, 1974; Balnave, 1974; Strøm, 1978; Sykes, 1979; Kampen van, 1981; MacLeod, 1984)*, indenfor et bredt temperaturområde er denne afhængighed beskrevet ved lineære ligninger *(O'Neill et al., 1971; Kampen van, 1981)*. Såfremt temperaturen derimod ligger indenfor et snævert område (15–20°C), er der ingen afhængighed mellem temperatur og HE, som vist af *O'Neill et al. (1971), Davis et al. (1973), Balnave (1974)* og *Strøm (1978)*, samt i de her fremlagte forsøg.

Målingerne af EBAL viste en betydelig variation, hvorfor der ikke er gen-

nemført statistiske analyser. Det fremlagte materiale viste dog samme niveau for EBAL ved de to temperaturer, hvilket svarer til resultater fra *Es van et al. (1973)* og *Davis et al. (1973)*. Energiaflejringen i æg var ikke signifikant forskellig mellem 17 og 21°C, hvilket nøje svarer til tidligere omtalte resultater vedrørende ægydelse (jvf. tabel 3.2), ægstørrelse og energiindhold i æg (jvf. kapitel 4.2). De opnåede resultater er i god overensstemmelse med *Davis et al. (1973)* for temperaturer mellem 16 og 24°C, og *Es van et al. (1973)* for temperaturer mellem 15 og 20°C. Da energioptagelsen og energiaflejringen i æg ikke var forskellig mellem 17 og 21°C, blev bruttoudnyttelsen af energi (OE/GE eller OE/ME) heller ikke forskellig, hvilket stemmer overens med resultater fra *Emmans & Charles (1977)* for temperaturer mellem 18 og 22°C.

Med hensyn til afstamning blev optagelsen af energi noget større hos afstamning B (serie K) end hos afstamning A (serie H), men ME/GE var ens (71%) for begge afstamninger. Tilsvarende resultater er opnået af *Hoffmann & Schiemann (1973)*, der i forsøg med hybrider af Hvid Italiener fodret ad libitum, fandt den samme omsættelighed. De opnåede resultater viste yderligere, at en 10% højere energioptagelse i serie K end i serie H ingen effekt havde på ME/GE, hvilket er i god overensstemmelse med forsøg af *Burlacu et al. (1974), Grossu et al. (1976)* og *Kirchgessner & Voreck (1980a)*. Med hensyn til burforhold havde høner holdt i grupper (serie H) en betydelig højere GE, ME, HE/W,$kg^{0.75}$ og EBAL end høner holdt enkeltvis (serie G). Der var ingen forskel i energiaflejringen i æg, hvorimod OE/GE og OE/ME var signifikant højere hos høner holdt enkeltvis. Disse resultater kan delvis forklares på basis af de tidligere omtalte resultater vedrørende en højere foderoptagelse i serie H og den samme ægproduktion i begge burforhold samtidig med en bedre FCR i serie G (jvf. tabel 3.2). Som det tidligere er diskuteret (jvf. kapitel 3.2), skyldes en øget foderoptagelse og dermed energioptagelse og varmeproduktion såvel »social facilitation by eating« som en højere lokomotorisk aktivitet hos høner holdt i grupper *(Hughes & Black, 1974 b; Süs, 1976; Kampen van, 1976a,b; Bessei, 1981; MacLeod et al., 1982)*. Trods det at lokomotorisk aktivitet ikke var målt i de foreliggende forsøg, tyder de visuelle observationer på et højere aktivitetsniveau hos høner holdt i grupper. Da forskelle i energioptagelsen ikke påvirkede energiaflejringen i æg, har den ekstra energitilførsel hos høner holdt i grupper forøget EBAL og hermed energiaflejringen i kroppen. Samtidig blev varmeproduktionen som følge af tiltagende aktivitet større. Derved blev bruttoudnyttelsen af energi ringere hos høner holdt i grupper end høner holdt enkeltvis, dog blev energiaflejringen i æg ikke forskellig.

I de foreliggende forsøg var varmeproduktionsenhederne (vpe) henholdsvis 0.11 (91 høner/vpe) i serie G og 0.012 (84 høner/vpe) i serie H og K. Disse værdier ligger indenfor angivelser fra *Strøm (1978)*, men tyder dog på, at der skal tages hensyn til burforhold, idet resultater fra forsøg med høner holdt enkeltvis sandsynligvis ikke kan overføres til andre burforhold.

10.8 Energetisk udnyttelsesgrad til ægproduktion

I dette kapitel er der foretaget en beskrivelse af den anvendte terminologi (jvf. side 73), med definitioner for vedligeholdelsesbehov (ME_m) og energetisk udnyttelsesgrad. På basis af de individuelle målinger i serie G blev der, med anvendelse af forskellige regressionsmodeller, foretaget beregninger over ME_m og udnyttelsesgrader. Endelig blev den energetiske udnyttelsesgrad vurderet i forhold til temperatur, afstamning og burforhold.

Som det fremgår af figur 8.1, kan den omsættelig energi (ME) fordeles mellem ME anvendt til ME_m og til produktion (ME_{go}). Behovet af ME_m hos æglæggende høner kan defineres som den mængde ME, der er ndøvendig for at opretholde en dynamisk ligevægt for protein- og fedtturnover, for at opretholde en konstant kropstemperatur og for at opretholde en minimal lokomotorisk aktivitet. Omsættelig energi til produktion (ME_{go}), kan fordeles mellem ME anvendt til energiaflejring i kroppen og i æg under dannelse i æggestok og æggeleder (ME_g), og ME anvendt til energiaflejring i producerede æg (ME_o). Såfremt energiaflejringen i krop + æg under udvikling betegnes med EBAL og energiaflejring i færdigt producerede æg med OE, kan udnyttelsesgraden af ME til de forskellige produktioner udtrykkes henholdsvis ved k_{go} = (EBAL+ OE)/ME_{go}, k_g = EBAL/ME_g og k_o = OE/ME_o.

Energibehov til vedligehold og energetisk udnyttelsesgrad til ægproduktion beregnet efter forskellige modeller.

Materialet fra de individuelle målinger i serie G, blev først benyttet i en-dimensional regressionsberegning efter følgende model:

Model 1

$(EBAL+OE)/W,kg^{0.75} = a + k_{go} \times ME/W,kg^{0.75}$

Regressionskoefficienten (k_{go}) angiver den totale (overall) udnyttelsesgrad og kurvens skæring med x-aksen, der beregnes ved a/k_{go}, angiver energibehovet til vedligehold, udtrykt ved $ME_m/W,kg^{0.75}$. Regressionsanalyserne viste, at der ingen signifikant forskel var imellem ligningerne indenfor perioderne. Samtlige 52 observationer fra serie G med positiv EBAL blev derfor benyttet til beregning af den totale regression, som vist nedenfor:

$(EBAL + OE),kJ/W,kg^{0.75} = -287 + 0.71 \times ME,kJ/W^{0.75}$

se: 54.9 0.065

n = 52, RSD = 35.1, CV = 11.3%, R^2 = 0.707

Beregningerne viste et behov til vedligehold på 404 $kJ/W,kg^{0.75}$ og den totale udnyttelsesgrad, k_{go} = 0.71.

De individuelle data fra serie G blev derefter anvendt i en multipel regression efter følgende model:

Model 2

$ME = a + b_1 \times W,kg^{0.75} + b_2 \times EBAL + b_3 \times OE$

Regressionskoefficienten (b_1) kan betragtes som et estimat af $ME_m/W,kg^{0.75}$, medens de reciprokke værdier af b_2 og b_3 angiver henholdsvis udnyttelsen af energi til EBAL ($k_g=1/b_2$) og til energiaflejring i producerede æg ($k_o=1/b_3$). Beregningerne viste at intercepten ikke var signifikant og ligningen fik derfor følgende form:

ME,kJ =	$414 \times W,kg^{0.75}$ +	$0.86 \times$ EBAL,kJ +	$1.56 \times$ OE,kJ	
se:	44.4	0.090	0.189	

n = 52, RSD = 52.6, CV = 5.10%

Regressionsberegningen viste en CV-værdi på 5% og $R^2 = 0.787$ (fra model med intercept), hvilket viser en god overensstemmelse mellem de foreliggende data og den anvendte model. ME_m blev 414 kJ/W,$kg^{0.75}$, $k_g = 1.16$ (1/0.86) og $k_o = 0.64$ (1/1.56). Forsøgene omfattede bestemmelse af energi aflejret i protein (OPE) og i fedt (OFE) i de producerede æg og det var derfor muligt, at anvende de foreliggende data i en udvidet multipel regression efter følgende model:

Model 3

$ME = a + b_1 \times W,kg^{0.75} + b_2 \times EBAL + b_3 \times OPE + b_4 \times OFE$

Beregningerne viste, at intercepten (a) ikke var signifikant og den opnåede ligning fik følgende form:

ME,kJ =	$419 \times W,kg^{0.75}$ +	$0.84 \times$ EBAL,kJ +	$1.99 \times$ OPE,kJ +	$1.27 \times$ OFE,kJ	
se:	46.0	0.095	0.079	0.056	

n = 52, RSD = 54.3, CV = 4.54%

Beregningen viste en CV-værdi på 4.5% og R^2 var 0.759 (fra model med intercept), hvilket viser en god overensstemmelse mellem data og model. ME_m blev 419 kJ/W,$kg^{0.75}$, $k_g = 1.19$ (1/0.84), $k_{op} = 0.50$ (1/1.99) og $k_{of} = 0.79$ (1/1.27).

På grundlag af de fundne værdier for ME_m, k_{go}, k_o, k_{op} og k_{of}, i serie G, blev

der foretaget en fordeling af ME til vedligehold og produktion, som vist i figur 8.2. Da de tre regressionsmodeller gav stort set de samme værdier for ME_m, omkring 410 kJ/W,kg$^{0.75}$, denne værdi blev benyttet til at beregne ME anvendt til produktion (ME_{go}=ME–ME_m), hvilket gav en værdi på 432 kJ/W,kg$^{0.75}$ eller 51% af den totale ME. De videre beregninger viste, at 42% af total ME var anvendt til energiafalejring i de producerede æg, medens kun 9% var anvendt til EBAL.

Effekten af temperatur, afstamning og burforhold på den energetiske udnyttelsesgrad til ægproduktion

Det gennemsnitlige vedligeholdelsesbehov i serie G (model 1,2,3) var 410 kJ/W,kg$^{0.75}$ og denne værdi blev anvendt i de øvrige serier til at beregne den »overall« udnyttelsesgrad af ME til ægproduktion (k_{go}). Som det fremgår af tabel 8.1, var k_{go} 0.72 i serie G og mellem 0.65–0.70 i de andre serier. De statistiske analyser (jvf. kapitel 2.7) viste ingen signifikant vekselvirkning mellem temperatur og afstamning for serie H versus K, og der var ingen signifikant forskel i k_{go} mellem 17 og 21°C. Differencerne mellem afstamningerne var heller ikke signifikante, derimod var k_{go} signifikant højere hos høner holdt enkeltvis (serie G) end i grupper (serie H).

Diskussion

Energibehov til vedlighold er ofte defineret, som den mængde energi, der skal tilføres dyret for at holde det i ernæringsligevægt, *Blaxter (1972)*. Denne definition kan accepteres for udvoksede og ikke producerende dyr, derimod er det vanskeligt at bruge den til æglæggende høner, som aflejrer energi dels i krop og dels i æg. I de foreliggende forsøg er behovet til vedligehold (ME_m) derfor defineret som den mængde af omsættelig energi, der skal tilføres dyret til at opretholde en dynamisk ligevægt for protein- og fedtturnover, til at opretholde en konstant kropstemperatur og til at dække en minimal lokomotorisk aktivitet. Som diskuteret i detaljer af *Kleiber (1961), Es van (1972), Kampen van (1981), Fisher (1983 b)* er den energetiske omkostning ved den fysiske og kemiske termoregulering en del af energibehovet til vedligehold, ligesom den del af energien der er brugt til lokomotorisk aktivitet vil indgå i ME_m *(MacLeod & Shannon, 1978; MacLeod et al., 1979)*. Energibehovet til vedligehold sættes ofte i relation til den metaboliske legemsvægt, udtrykt ved W,kg$^{0.75}$ (jvf. kapitel 7.3.2), hvilket angiver at behovet er proportionalt med W,kg$^{0.75}$. Dette er muligvis fejlagtigt for voksende dyr *(Eggum & Chwalibog, 1983; Just et al., 1983; Thorbek et al., 1984)*, hvorimod der for æglæggende høner intet bevis er for, at ME_m/W,kg$^{0.75}$ ikke er konstant. I de foreliggende studier blev den mængde energi, som var aflejret i krop og i æg under dannelse i æggestok og æggeleder, benævnt energibalance (EBAL), men på grund af at det ikke er muligt i balanceforsøg

at adskille disse to komponenter (jvf. kapitel 7.3.1), blev udnyttelsesgraden af ME beregnet såvel for den totale energiaflejring (k_{go}=(EBAL+OE)/ME_{go}), som for energi i EBAL (k_g=EBAL/ME_g) og energi i producerede æg (k_o=OE/ME_o).

Der foreligger forskellige eksperimentelle metoder til bestemmelse af behovet til vedligehold udfra hungerforsøg eller fodringsforsøg på forskellige foderniveauer. Ved hungerforsøg måles den samlede varmeproduktion (FHP) og såfremt man kender udnyttelsesgraden (k_m) af ME til vedligehold, kan FHP transformeres til ME_m (ME_m=FHP/k_m). Da aktiviteten er reduceret under hunger *(MacLeod et al., 1979),* kan værdierne af ME_m næppe anvendes under praktiske forhold og yderligere kan der være tale om, at fedt-protein- og kulhydratomsætningen ændres under hunger i forhold til fodringsbetingelser som vist for rotter af *Chudy & Schiemann (1969), Westerterp (1976)* og *Simon (1980).*

Ved forsøg på forskellige foderniveauer eller med ad libitum fodring kan ME_m bestemmes ved hjælp af en-dimensionale eller multiple regressioner. I den en-dimensionale regression af aflejret energi i forhold til ME/W,$kg^{0.75}$ forudsættes det, at ME_m/W,$kg^{0.75}$ er konstant, og at der er et konstant forhold mellem aflejret protein- og fedtenergi, som diskuteret i detaljer af *Henckel (1976).* En multipel regressionsmodel omfattende såvel energibehov til vedligehold som energibehov til aflejring blev først foreslået af *Kielanowski (1965)* for svin. For æglæggende høner har *Hoffmann & Schiemann (1973)* anvendt en multipel model omfattende ME_m, udnyttelsesgrad til energiaflejring i krop og i æg. I det foreliggende materiale blev data fra høner holdt enkeltvis (serie G) med en lav aktivitet benyttet i tre forskellige regressionsmodeller. Beregningerne er kun udført med målinger der viste positive EBAL, da korrektion for negativ aflejring i kroppen, som foreslået af *Es van et al. (1970), Hoffmann & Schiemann (1973), Grimbergen (1974), Voreck & Kirchgessner (1980c)* og *Chwalibog (1982),* er vanskelig at anvende. Regression af den totale energiaflejring i relation til ME gav ME_m = 404 kJ/W,$kg^{0.75}$ og den totale udnyttelsesgrad, k_{go} = 0.71. I litteraturen varierer de værdier, der er beregnet fra en-dimensionale regressioner, mellem 300–580 kJ/W,$kg^{0.75}$ for ME_m og mellem 0.58–0.86 for k_{go}. Det er muligt, at den store variation skyldes, at målinger med negative EBAL har været inkluderet i beregningerne, enten uden korrektion for negativ aflejring i kroppen *(Waring & Brown, 1967; Burlacu et al., 1974; Farrell, 1975)* eller med korrektion for hele EBAL uden adskillelse mellem energi i krop og æg under udvikling *(Es van et al., 1970; Grimbergen, 1974).* Således fandt *Voreck & Kirchgessner (1980c)* på grundlag af slagteundersøgelser, at ME_m = 411 kJ/W,$kg^{0.75}$ og k_{go} = 0.60 med anvendelse af en korrektionsfaktor på 0.8 for negativenergiaflejring i kroppen, medens værdierne uden korrektionen var ME_m = 446 kJ/W,$kg^{0.75}$ og k_{go} = 0.65.

Den multipel regression (model 2), hvor ME var regresseret på EBAL og

OE, gav ME_m = 414 kJ/W,$kg^{0.75}$, udnyttelsen af ME til EBAL, k_g = 1.16 (;/0.86) og udnyttelsen af ME til energiaflejring i producerede æg, k_o = 0.64 (1/1.56). Værdien for k_g var overestimeret og uacceptabel muligvis på grund af stor variation i EBAL (jvf. kapitel 7.2), medens såvel ME_m som k_o er i en god overensstemmelse med resultater fra tilsvarende multiple regressioner af *Hoffmann & Schiemann (1973)*. Den næste regressionsmodel (3) med anvendelse af W,$kg^{0.75}$, EBAL, OPE og OFE gav ME_m = 419 kJ/W,$kg^{0.75}$ svarende til værdien opnået i model 1 og 2. Som i model 2 var k_g overestimeret, medens udnyttelsesgraden til energiaflejring i protein var k_{op} = 0.50 (1/1.99) og til energiaflejring i fedt var k_{of} = 0.79 (1/1.27), hvilket svarer til, at der medgår 2.0 kJ,ME / kJ OPE og 1.3 kJ,ME/ kJ OFE. I forsøg med æglæggende høner fandt *Hoffmann & Schiemann (1973)* k_{op} = 0.44 og k_{of} = 0.74.

De foreliggende resultater vedrørende ME_m viste en gennemsnitlig værdi på 410 kJ/W,$kg^{0.75}$, uafhængig af den anvendte model (model 1,2,3), og denne værdi er i en god overensstemmelse med de værdier for ME_m mellem 400–460 kJ/W,$kg^{0.75}$ fundet i en række forsøg *(Waring & Brown, 1965; Hoffmann & Schiemann, 1973; Grimbergen, 1974; Farrell, 1975; Scheele & Musharaf, 1980; Voreck & Kirchgessner, 1980c)* ved anvendelse af forskellige forsøgs- og beregningsmetoder. Med anvendelse af ME_m = 410 kJ/W,$kg^{0.75}$ samt de opnåede værdier for udnyttelsesgraderne (k_{go}, k_g, k_o, k_{op}, k_{of}), blev det vist, at ca. 50% af ME er anvendt til vedligehold og ca. 50% til produktion, der fordeler sig med 42% til producerede æg og 9% til EBAL.

På grundlag af de foreliggende beregninger med enkeltobservationer (serie G), blev værdien ME_m = 410 kJ/W,$kg^{0.75}$ benyttet i beregninger vedrørende den »overall« udnyttelsesgrad til ægproduktion (k_{go}) i alle serier (med positive EBAL). Beregningerne viste, at der ingen signifikant forskel var på k_{go} ved 17 og 21°C. Indenfor et bredt temperaturområde er det fundet, at k_{go} er afhængig af temperatur som demonstreret af *Shannon & Brown (1969), Davis et al. (1973), Es van et al. (1973), Grimbergen (1974), O'Neill & Jackson (1974), Valencia et al. (1978, 1980), Vohra et al. (1979)* og *Fisher (1983b)*, men disse ændringer er ikke fundet indenfor et snævert temperaturområde fra 16–23°C *(O'Neill & Jackson, 1974)*. Beregningerne over k_{go} hos de to afstamninger var ligeledes baseret på samme værdi for ME_m og viste at k_{go} ikke var signifikant forskellige, medens der var tendens til en højere udnyttelsesgrad hos afstamning B. Med hensyn til effekten vedrørende burforhold viste beregninger, at høner holdt enkeltvis (serie G) havde en signifikant højere k_{go} (0.72) end høner holdt i grupper (0.67). Disse resultater er i overensstemmelse med de tidligere omtalte resultater vedrørende en bedre FCR (jvf. tabel 3.2) og lavere luftstofskifte samt varmeproduktion, men samtidig en højere proportion ON/IN (jvf. tabel 6.2) og OE/GE, OE/ME (jvf. tabel 7.2) hos enkelthøner. Dette medførte ingen forskel i ægproduktion mellem de to burforhold (jvf. tabel 3.2), idet hø-

ner holdt i grupper (serie H) brugte ca. 7% mere ME_{go} til at aflejre den samme energimængde (EBAL+OE) på grund af »social facilitation by eating« og forhøjet lokomotorisk aktivitet.

10.9 Konklusioner

Ydelse. Foderoptagelsen, der var ad libitum, steg til et maximalt niveau ved en alder på 35 uger, hvorefter den var ret konstant. Ægproduktionen steg til et maximalt niveau ved en alder fra 38–41 uger. Temperaturen havde ingen signifikant effekt på ydelsen, mens sammenligningen mellem de to afstamninger af Hvid Italiener viste, at afstamning B havde en signifikant højere foderoptagelse, ægproduktion og læggeprocent samt en bedre foderudnyttelse (FCR) end afstamning A. Med hensyn til effekten af burforhold viste det sig, at høner holdt i grupper havde en stærk signifikant højere foderoptagelse på grund af den såkaldte »social facilitation by eating«, men en ringere FCR end høner holdt enkeltvis, medens der ikke var signifikant forskel i ægproduktion og læggeprocent imellem de to burforhold.

Ægstørrelse og kemisk sammensætning. Ægstørrelsen steg signifikant i løbet af æglægningsperioden, og stigningen var forbundet med en tiltagende vægt af æggeblommerne samtidig med, at forholdet mellem blomme og albumen steg fra 29–33%. Indholdet af tørstof og kvælstof i æg var uafhængig af alder, men fedtprocenten steg fra 9 til 10.5% og energiindholdet fra 7.1 til 7.5 MJ/kg æg i løbet af æglægningsperioden. Temperaturen havde ingen signifikant effekt på den gennemsnitlige ægstørrelse og æggens kemiske sammensætning. Afstamning B havde en signifikant højere ægstørrelse end afstamning A, men den kemiske sammensætning af æggene var uændret. Burforholdene havde ingen signifikant effekt på ægstørrelse og kemisk sammensætning. Den gennemsnitlige kemisk sammensætning i alle serier var 25% tørstof, 2.1% kvælstof, 10% fedt, 0.9% aske og 7.3 MJ/kg æg.

Luftstofskifte. De opnåede resultater vedrørende CO_2-produktion i forhold til dyrenes alder viste stort set samme mønster som foderoptagelsen, hvilket hænger sammen med, at luftstofskiftet primært er afhængig af legemsvægt og foderoptagelse. Multiple regressioner af CO_2-produktion og O_2-optagelse (serie G) i relation til metabolisk vægt, omsættelig energi og ægproduktion viste, at ægproduktion kunne udelukkes fra beregningerne, og at luftstofskiftet kan estimeres på grundlag af følgende ligninger:

$$CO_2, l = 17.3 \times W,kg^{0.75} + 0.0094 \times ME,kJ$$

$$O_2, l = 22.7 \times W,kg^{0.75} + 0.0063 \times ME,kJ$$

Effekten af temperatur, afstamning og burforhold på luftstofskiftet viste, at der ikke var signifikant forskel med hensyn til temperatur og afstamning, medens høner holdt enkeltvis havde et lavere luftstofskifte end høner holdt i grupper, idet disse havde en højere lokomotorisk aktivitet i forbindelse med »social facilitation by eating«.

Kvælstofomsætning. Kvælstofbalancen (NBAL) omfatter såvel kvælstof aflejret i kroppen som kvælstof aflejret i æg under dannelse i æggestok og æggeleder. Det er ikke muligt ved balancemetoden at adskille kvælstof aflejret i krop og i æg under udvikling, idet æglægningen ikke er en kontinuerlig 24 timers proces, og dette medfører, at ved opsamling af æg på et fastlagt tidspunkt, vil den ægmængde, som er under dannelse i æggestok og æggeleder, være forskellig. NBAL var enten negativ eller omkring nul ved æglægningens begyndelse, hvorefter den var svagt positiv. Kvælstof aflejret i producerede æg (ON) var næsten på et konstant niveau i hele forsøgstiden. Udnyttelsen af optaget kvælstof til ON (ON/IN) var uafhængig af alderen. Temperaturen havde ingen signifikant effekt på den gennemsnitlige kvælstofaflejring og udnyttelse af kvælstof til ægproduktion. Hos afstamning B var den gennemsnitlige kvælstofaflejring i æg 1.2 g mod 1.0 g hos afstamning A med en udnyttelsesgrad på henholdsvis 40 og 38%, og differencerne var signifikante. Burforholdene havde ingen signifikant effekt på ON, medens høner holdt enkeltvis havde en højere udnyttelsesgrad på 42% mod 38% hos høner holdt i grupper.

Energiomsætning. Energibalancen (EBAL) der omfatter den mængde energi som er aflejret i kroppen og energi i æg under dannelse i æggestok og æggeleder, tilsvarende som for NBAL, var ved en alder på 26 uger enten negativ eller omkring nul. Energi aflejret i producerede æg (OE) viste en svag stigning i løbet af æglægningsperioden, medens bruttoudnyttelsen af energi (OE/GE, OE/ME) ikke var signifikant afhængig af alder. Indenfor det anvendte temperaturområde (17–21°C) kunne der ikke påvises nogen signifikant effekt på energiomsætningen. Med hensyn til afstamningseffekten, viste afstamning B en højere energioptagelse (GE) end afstamning A, men der var ingen forskel i varmeproduktionen og EBAL imellem de to afstamninger. Energi aflejret i æg var 340 kJ hos afstamning A og 400 kJ hos afstamning B, og denne forskel var signifikant. Bruttoudnyttelsen af energi (OE/GE eller OE/ME) var ikke signifikant forskellig, medens der var tendens til en højere udnyttelse hos afstamning B. Med hensyn til burforhold havde høner holdt i grupper en gennemsnitlig højere energioptagelse, varmeproduktion og EBAL end høner holdt enkeltvis, hvorimod energiaflejringen i producerede æg ikke var påvirket, hvilket medførte, at bruttoudnyttelsen af energi var ringere hos høner holdt i grupper end høner holdt enkeltvis.

Energetisk udnyttelsesgrad til ægproduktion. Energibehov til vedligehold (ME_m) hos æglæggende høner kan defineres som den mængde af omsættelig energi, der skal tilføres dyret til at opretholde en dynamisk ligevægt for protein- og fedtturnover, til at opretholde en konstant kropstemperatur og til at dække en minimal lokomotorisk aktivitet. Udnyttelsesgraderne til ægproduktion kan fordeles mellem den »overall« udnyttelse af ME til EBAL samt energi aflejret i producerede æg; $k_{go} = (EBAL+OE)/ME_{go}$, og udnyttelse til energiaflejring i

producerede æg; $k_o = OE/ME_o$. De partielle udnyttelsesgrader til energiaflejring i protein (OPE) og i fedt (OFE) i æg, defineres som $k_{op} = OPE/ME_{op}$ og $k_{of} = OFE/ME_{of}$. Vedligeholdelsesbehovet og udnyttelsesgraderne blev beregnet ved hjælp af tre regression-modeller og gav følgende resultater for høner hold enkeltvis og med positive EBAL:

Model 1

$(EBAL+OE),kJ/W,kg^{0.75} = -287 + 0.71 \times ME,kJ/W,kg^{0.75}$

Model 2

$ME,kJ = 414 \times W,kg^{0.75} + 0.86 \times EBAL,kJ + 1.56 \times OE,kJ$

Model 3

$ME,kJ = 419 \times W,kg^{0.75} + 0.84 \times EBAL,kJ + 1.99 \times OPE,kJ + 1.27 \times OFE,kJ$

De tre regressioner gav værdier for ME_m omkring 410 $kJ/W,kg^{0.75}$.

En fordeling af ME viste, at hos høner holdt enkeltvis, blev 49% af den totale ME brugt til vedligehold og 51% til produktion, heraf de 42% til OE og de resterende 9% til EBAL. Temperatur, afstamning og burforhold havde ingen effekt på ME_m, og en gennemsnitsværdi af 410 $kJ/W,kg^{0.75}$ blev benyttet i beregningerne over den »overall« udnyttelsesgrad $k_{go} = (EBAL+OE)/ME_{go}$ i alle serier. Temperaturen havde ingen signifikant effekt på k_{go}, hvilket er i overensstemmelse med, at der ikke var nogen forskel i ydelsen og energiomsætningen. Der var ingen signifikant forskel i k_{go} mellem afstamningerne, medens der var tendens for en højere udnyttelsesgrad hos afstamning B. Høner holdt enkeltvis havde signifikant højere k_{go} (0.72) end høner holdt i grupper (0.67). Disse resultater er i overensstemmelse med en bedre FCR og lavere luftstofskifte samt varmeproduktion, men samtidig en højere udnyttelse af kvælstof og brutto udnyttelse af energi til ægproduktionen hos høner holdt enkeltvis. Resultaterne viste, at forskellene i k_{go}, mellem de to burforhold, var primært afhængig af en højere lokomotorisk aktivitet i forbindelse med »social facilitation by eating« hos høner holdt i grupper.

Generel konklusion

Uafhængig af hønernes alder i æglægningsperioden (26–47 uger) havde en reduktion i omgivelsestemperaturen fra 21 til 17°C ingen signifikant indflydelse på ægydelsen og den energetiske udnyttelsesgrad til ægproduktionen. Afstamning B havde en signifikant højere ægydelse end afstamning A og en større foderoptagelse, samtidig med at der var en tendens for højere energetisk udnyttelsesgrad. De anvendte burforhold havde ingen signifikant effekt på ægydelsen, men høner holdt i grupper havde en højere foderoptagelse på grund af »social facilitation by eating«. Stigningen i foderoptagelse (energi) kan betragtes

som en »luksus konsumption«, idet den større energioptagelse ikke forårsagede en højere ægproduktion, men blot forøgede energiaflejringen i kroppen. På grund af en højere lokomotorisk aktivitet hos høner holdt i grupper var den energetiske udnyttelsesgrad til ægproduktionen lavere end for høner holdt enkeltvis.

References

Ahmad, M. M., Mather, F. B. & Gleaves, E. W. (1974). Effect of environmental temperature and dietary energy on dwarf and normal hens and normal roosters. Poult. Sci., 53, 927–935.

Ajjam, I. K., Gharaib, F. H., Taha, T. J. & Sial, M. B. (1977). Effect of egg weight on the weights of its components. Agric. Pakistan, 28, 87–90.

Ambrosen, T. & Rotenberg, S. (1981). External and internal quality and chemical composition of hen egg as related to hen age and selection for production traits. Acta Agric. Scand., 31, 139–152.

Anderson, G. B., Bolton, W., Jones, R. M. & Draper, M. H. (1978). Effect of age of the laying hen on the composition of the egg. Br. Poult. Sci., 19, 741–745.

Balnave, D. (1974). Biological factors affecting energy expenditure. In: Energy requirement of poultry, 25–46. Ed. T. R. Morris & B. M. Freeman, British Poultry Science Ltd., Edinburgh.

Balnave, D., Farrell, D. J. & Cumming, R. B. (1978). The minimum metabolizable energy requirement of laying hens. Wld's Poult. Sci. J, 34, 149–154.

Bareham, J. R. (1972). Effects of cages and semi-intensive deep litter pens on the behaviour, adrenal response and production in two strains of laying hens. Br. vet. J., 128, 153–163.

Barott, H. G. & Pringle, E. H. (1946). Energy and gaseous metabolism of the chicken from hatch to maturity as affected by temperature. J. Nutr., 31, 35–50.

Bayley, H. S. (1982). Energy metabolism in birds. Proc. 9th Symp. on Energy Metabolism, Lillehammer (1982). EAAP Publ. No. 29, 309–319.

Benedict, F. G., Landauer, W, & Fox, E. L. (1932). The physiology of normal and frizzle fowl, with special reference to the basal metabolism. Storrs Agricultural Experiment Station, Bulletin 177, 101pp.

Bessei, W. (1981). Locomotor activity-interpretation and measurements. Proc. 1st European Symp. on Poultry Welfare, Køge (1981), 23–31. Ed. Y. Sørensen, Danish Branch of W.P.S.A.

Blaxter, K. L. (1972). Fasting metabolism and the energy required by animals for maintenance. In: Festskrift til prof. Knut Breirem, 19–36. Mariendals Boktrykkeri, A. S., Gjøvik, Norge.

Boshouwers, F. M. G. & Nicaise, E. (1981). Measurement of the respiratory metabolism of the fowl. Br. Poult. Sci., 22, 59–69.

Brouwer, E. (1965). Report of Sub-Committee on Constants and Factors. Proc. 3rd Symp. on Energy Metabolism, Troon (1964). EAAP Publ. No. 11, 441–443.

Burlacu, Gh., Moisa, D., Ionila, D., Tascenco, Vl. & Baltac, M. (1974). Efficiency of the utilization of the energy of food in laying hens. Proc. 6th Symp. on Energy Metabolism of Farm Animals, Hohenheim (1973). EAAP Publ. No. 14, 265–268.

Byerly, T. C. (1979). Prediction of the food intake of laying hens. In: Food intake regulation in poultry, 327–362. Ed. K. N. Boorman & B. M. Freeman, British Poultry Science Ltd., Edinburgh.

Byerly, T. C., Kessler, J. W., Gous, R. M. & Thoman, O. P. (1980). Feed requirement for egg production. Poult. Sci., 59, 2500–2507.

Carpena, C. (1973). Hur antalet höns per bur och burytan per höna inverker på dödlighet och äggproduktion. Inst. för husdjurens utfodr. och vård. Rapport nr. 28, 11pp.

Chudy, A. & Schiemann, R. (1969). Zur energetischen Verwertung der Nähr- und Futterstoffe für Erhaltung und Fettbildung. Arch. Tierernähr., 4, 231–247.

Chung, R. A. & Stadelman, W. J. (1961). Physical and chemical components of eggs as related to total egg size. Poult. Sci., 40, 1387.

Chwalibog, A. (1982). Energy efficiency for egg production. Proc. 9th Symp. on Energy Metabolism, Lillehammer (1982). EAAP Publ. No. 29, 270–273.

Chwalibog, A., Henckel, S. & Thorbek, G. (1978). Protein- and energy metabolism in growing broilers in relation to sex and feeding level. Z. Tierphysiol., Tierernährg.u. Futtermittelkde., 41, 87–99.

Chwalibog, A., Lind, J. & Thorbek, G. (1979). Description of a respiration unit for quantitative measurements of gas exchange in small animals applied for indirect calorimetry. Z. Tierphysiol., Tierernährg.u.Futtermittelkde., 41, 154–162.

Chwalibog, A., Männer, K. & Eggum, B. O. (1984). Effect of feeding level on energy metabolism in hens prior to egg laying. Z. Tierphysiol., Tierernährg.u.Futtermittelkde., 51, 197–204.

Clark, T. B. (1940). The relation of production and egg weight to age in White Leghorn fowls. Poult. Sci., 19, 61–66.

Cotteril, O. J., Stephenson, A. B. & Funk, E. M. (1962). Factors affecting the yield of egg products from shell eggs. Proc. World's Poultry Congress, 12, 443–447.

Cowan, P. J. & Michie, W. (1980). Increasing the environmental temperature later in lay and performance of the fowl. Br. Poult. Sci., 21, 339–343.

Cunningham, F. E., Cotteril, O. J. & Funk, E. M. (1960). The effect of season and age of bird. I. On egg size, quality and yield. Poult. Sci., 39, 289–299.

Cunningham, D. L. & Ostrander, C. E. (1982). The effects of strain and cage shape and density on performance and fearfulness of White Leghorn layers. Poult. Sci., 61, 239–243.

Davis, R. H., Hassan, O. E. M. & Sykes, A. H. (1972). The adaptation of energy utilization in the laying hen to warm and cool ambient temperatures. J. Agr. Sci. Cambridge, 79, 363–369.

Davis, R. H., Hassan, O. E. M. & Sykes, A. H. (1973). Energy utilization in the laying hen in relation to ambient temperature. J. Agr. Sci. Cambridge, 80, 173–177.

Eggum, B. O. & Chwalibog, A. (1983). A study on requirement for maintenance and growth in rats with normal or reduced gut flora. Z. Tierphysiol., Tierernährg.u.Futtermittelkde., 49, 104–114.

Emmans, G. C. (1974). The effect of temperature on the performance of laying hens. In: Energy requirement of poultry, 79–90. Ed. T. R. Morris & B. M. Freeman, British Poultry Science Ltd., Edinburgh.

Emmans, G. C. & Charles, D. R. (1977). Climatic environment and poultry feeding in practice, 31–49. In: Nutrition and Environment. Ed. W. Haresign, H. Swan & D. Lewis, Butterworths, London.

Es, A. J. H. van (1972). Maintenance. In: Handbuch der Tierernährung, Bd. II, 1–54. Ed. W. Lenkeit, K. Breirem & E. Crasemann. Parey, Hamburg & Berlin.

Es, A. J. H. van, Aggelen, D. van, Nijkamp, H. J., Vogt, J. E. & Scheele, C. W. (1973). Thermoneutral zone of laying hens kept in batteries. Z. Tierphysiol., Tierernährg.u.Futtermittelkde., 32, 121–129.

Es. A. J. H. van, Vik-Mo, L., Janssen, H., Bosch, A., Spreeuwenberg, W., Vogt, J. E. & Nijkamp, H. J. (1970). Balance trials with laying hens. Proc. 5th Symp. on Energy Metabolism of Farm Animals, Vitznau (1970). EAAP Publ. No. 13, 201–204.

Eskeland, B. (1977). Behaviour as an indicator of welfare in hens under different systems of management, population density, social status and beak trimming. Meldinger fra Norges Landbrukshøgskole, 56 (7), 20 pp.

Eskeland, B., Bjørnstad, S. & Hvidsten, H. (1977). Virkningen af dyretetthet, gruppestørrelse, innredningsform og nebbtrimming på produksjonsresultatene hos høner i bur og binge. Meldinger fra Norges Landbrukshøgskole, 56 (6), 39 pp.

Farrell, D. J. (1972). An indirect closed circuit respiration chamber suitable for fowl. Poult. Sci., 51, 683–688.

Farrell, D. J. (1975). A comparison of the energy metabolism of two breeds of hens and their cross using respiration calorimetry. Br. Poult. Sci., 16, 103–113.

Fisher, C. (1981). Protein deposition in poultry. In: Protein deposition in animals, 251–269. Ed. P. J. Buttery & D. B. Lindsay, Butterworths.

Fisher, C. (1983a). The physiological basis of the amino acid requirements of poultry. Proc. 4th Int. Symp. Protein metabolism and nutrition, Clermont-Ferrand (1983). EAAP Publ. No. 31, 385–404.

Fisher, C. (1983b). Egg production. In: Nutritional physiology of farm animals, 623–638. Ed. J. A. F. Rook & P. C. Thomas. Longman London and New York.

Fletcher, D. L., Britton, W. M., Rahn, A. P. & Savage, S. I. (1981). The influence of layer flock age on egg component yields and solids content. Poult. Sci., 60, 983–987.

Fowler, V. R., Fuller, M. F., Close, W. H. & Whittemore, C. T. (1980). Energy requirement for the growing pig. Proc. 8th Symp. on Energy Metabolism, Cambridge (1979). EAAP Publ. No. 26, 151–156.

Geers, R., Michels, H., Decuypere, E. & Neef, J. de (1982). Energy metabolism and other physiological criteria of fasting Rhode Island Red hens. Proc. 9th Symp. on Energy Metabolism, Lillehammer (1982). EAAP Publ. No. 29, 293–296.

Gill, J. L. (1978). Design and analysis of experiments in the animal and medical sciences. The Iowa State University Press. Vol. 1, 409pp.

Government Agricultural Research Centre, Ghent (1966). Government research station for small husbandry. Merelbeke 1966, Report 1966. 17pp.

Grimbergen, A. H. M. (1970). The energy requirement for maintenance and production of laying hens. Neth. J. agric. Sci., 18, 195–206.

Grimbergen, A. H. M. (1974). Energy expenditure under productive conditions. In: Energy requirements of poultry, 61–71. Ed. T. R. Morris & B. M. Freeman, British Poultry Science Ltd., Edinburgh.

Grimbergen, A. H. M., Dieker, J. W., van Kempen, G. J. M. & Stappers, H. P. (1968). Der Eiwiesbedarf von Legehennen am Anfang der Legeperiode. Arch. Geflügelkd., 32, 75–83.

Grossu, D., Burlacu, G. & Stravi, J. (1976). Energy requirement for maintenance and production in rock hens. Proc. 7th Symp. on Energy Metabolism of Farm Animals, Vichy (1976). EAAP Publ. No. 19, 285–288.

Harnisch, S. (1972). Energie- und Stickstoffbilanzen von Legehennen in Abhängigkeit von Alter und Eiweisversorgung. Arch. Geflügelkd., 36, 106–112.

Haugen, A. (1976). Egg production at different temperatures. Proc. 7th Symp. on Energy Metabolism of Farm Animals, Vichy (1976). EAAP Publ. No. 19, 303–306.

Henckel, S. (1973). Regression analysis. Statistical library. A/S Regnecentralen, Copenhagen. 40pp.

Henckel, S. (1976). Statistical methods for estimation of maintenance requirement and efficiences in animal production during growth. Proc. 7th Symp. on Energy Metabolism of Farm Animals, Vichy (1976). EAAP Publ. No. 19, 145–148.

Hill, A. T. & Binns, M. R. (1973). Effect of varying population density and size on laying performance. 4th. Europ. Poult. Conf., London, 605–609.

Hoffmann, L. & Schiemann, R. (1973). Die Verwertung der Futterenergie durch die legende Henne. Arch. Tierernähr., 23, 105–132.

Hughes, B. O. (1983). Conventional and shallow cages: a summary of research from welfare and production aspects. Wld's Poult. Sci. J., 39, 210–217.

Hughes, B. O. & Black, J. (1974a). The influence of social interactions upon the performance of laying hens in battery cages. Applied Animal Ethology, 1, 49–55.

Hughes, B. O. & Black, J. (1974b). The effect of environmental factors on activity, selected behaviour patterns and »fear« of fowls in cages and pens. Br. Poult. Sci., 15, 375–380.

Hurnik, J. F., Summers, J. D., Reinhart, B. S. & Swierczewska, E. M. (1977). Effect of age on the performance of laying hens during the first year of production. Poult. Sci., 56, 222–230.

Håkansson, J., Eriksson, S. & Svensson, S. A. (1978). Influence of feed energy and protein utilization by broiler chicks. Swedish Univ. of Agricultural Sciences, Report No. 59, 1–110.

Janssen, W. M. M. A. & Hart de, N. (1979). Measurements of heat production and activity of fasting hens. Proc. 2nd Europ. Symp. Poult. Nutr., Beekbergen (1979), 147–148.

Jeffery, E. P. (1941). Changes in pullet year albumen index as affected by age of bird. Poult. Sci., 20, 323–331.

Jenkins, N. K. & Tyler, C. (1960). Changes in egg shell thickness and white and yolk weight and composition over a period of a year. J. Agr. Sci., 55, 323–331.

Johnson, R. J. & Farrell, D. J. (1982). The effect of restricted feeding on the energy metabolism of layers. Proc. 9th Symp. on Energy Metabolism, Lillehammer (1982). EAAP Publ. No. 29, 258–261.

Jull, M. A. (1924). Egg weight in relation to production. Part I. The relationship of the weight and composition over a period of a year. J. Agr. Sci., 55, 323–331.

Just, A., Jørgensen, H. & Fernández, J. A. (1983). Maintenance requirement and the net energy value of different diets for growth in pigs. Livest. Prod. Sci., 10, 487–506.

Kampen, M. van (1974). Physical factors affecting energy expenditure. In: Energy requirements of poultry, 47–59. Ed. T. R. Morris & B. M. Freeman, British Poultry Science Ltd., Edinburgh.

Kampen, M. van (1976a). Activity and energy expenditure in laying hens. 1. The energy cost of nesting activity and oviposition. J. Agr. Sci. Cambridge, 86, 471–473.

Kampen, M. van (1976b). Activity and energy expenditure in laying hens. 2. The energy cost of exercise. 3. The energy cost of eating and posture. J. Agr. Sci. Cambridge, 87, 81–88.

Kampen, M. van (1981). Thermal influences on poultry. In: Environmental aspects of housing for animal production, 131–147. Ed. J. A. Clark, Butterworths.

Kampen, M. van & Romijn, C. (1970). Energy balance and heat regulation in the White Leghorn fowl. Proc. 5th Symp. on Energy Metabolism of Farm Animals, Vitznau (1970). EAAP Publ. No. 13, 213–216.

Kielanowski, J. (1965). Estimates of the energy cost of protein deposition in growing animals. Proc. 3rd Symp. on Energy Metabolism, Troon (1964). EAAP Publ. No. 11, 13–20.

King, J. R. & Farner, D. S. (1964). Terrestrial animals in humid heat: birds, 603–659. In: Handbook of Physiology, Section 4: Adaptation to the environment. Amer. Physiol. Soc., Washington D.C.

Kirchgessner, M. (1982). Efficiency of utilization of dietary energy by the laying hen in relation to different energy and protein supply. Proc. 9th Symp. on Energy Metabolism, Lillehammer (1982). EAAP Publ. No. 29, 266–273.

Kirchgessner, M. & Voreck, O. (1980a). Zur Umsetzbarkeit der Futterenergie bei der Legehenne in Abhängigkeit von der Energie- und Proteinversorgung. Arch. Geflügelkd., 44, 61–66.

Kirchgessner, M. & Voreck, O. (1980b). Zum Einfluss unterschiedlicher Energie- und Proteinversorgung auf die chemische Zusammensetzung von Hühnereiern. Arch. Geflügelkd., 44, 89–94.

Kleiber, M. (1961). The fire of life. John Wiley & Sons, New York & London. 454pp.

Kleiber, M. (1965). Metabolic body size. Proc. 3rd Symp. on Energy Metabolism, Troon (1964). EAAP Publ. No. 11, 427–435.

Kline, L., Meehan, J. & Sugehara, T. F. (1965). Relations between layer age and egg-product yields and quality. Food Technol., 19, 1296–1301.

Landsudvalget for Fjerkræ (National Council for Poultry). (1983). Report 1981–82. 132pp.

Lee, B. D., Morrison, W. D. & Leeson, S. (1983). Effects of feather cover and insulative jackets on metabolic rate of laying hens. Poult. Sci., 62, 1129–1132.

Lee, D. J. W., Bolton, W. & Dewar, W. A. (1978). Effects of battery cage shape and dietary energy regulation on the performance of laying hens offered diets containing dried poultry manure. Br. Poult. Sci., 19, 607–622.

Lucas, H. L. (1975). Design in animal science research. In: Design and analysis for nutrition research. Lectures at the International Post-Graduate Course (August 1975), 77–86, Institute of Animal Science, The Royal Veterinary and Agricultural University, Copenhagen.

Lundy, H., MacLeod, M. G. & Jewitt, T. R. (1978). An automated multi-calorimeter system: Preliminary experiments on laying hens. Br. Poult. Sci., 19, 173–186.

Machta, L. & Hughes, E. (1970). Atmospheric oxygen in 1967 to 1970. Science, 168, 1582–1584.

MacLeod, M. G. (1984). Factors influencing the agreement between thermal physiology measurements and field performance in poultry. Arch. exper. Vet. med., 38, 399–410.

MacLeod, M. G., Jewitt, T. R., White, J., Verbrugge, M. & Mitchell, M. A. (1982). The contribution of locomotor activity to energy expenditure in the domestic fowl. Proc. 9th Symp. on Energy Metbaolism, Lillehammer (1982). EAAP Publ. No. 29, 297–300.

MacLeod, M. G. & Shannon, D. W. F. (1978). Effect of food intake regulation on the energy metabolism of laying hens. Br. Poult. Sci., 19, 349–363.

MacLeod, M. G., Tullett, S. G. & Jewitt, T. R. (1979). Effect of food intake regulation on the energy metabolism of hens and cockerels of a layer strain. Br. Poult. Sci., 20, 521–531.

Madrid, A., Maiorino, P. M. & Reid, B. L. (1981). Cage density and energy utilization. Nutr. Rep. Intern., 23, 89–93.

McDonald, M. W. (1977). Feed intake of laying hens. Technical Publ. Queensland Agricultural College No. 1, 1–27.

Mead, R., Bancroft, T. A. & Han, C. P. (1975). Power of analysis of variance test procedures for incompletely specified fixed models. Ann. Stat., 3, 797–808.

Mitrov, B. A. (1964). Gaseous composition of the atmosphere and its analysis. Izdatelstr Akademii Nauk SSSR, Moskva (1961). Israel Program for Scientific Translation, Jerusalem. 22pp.

Misson, B. H. (1974). An open circuit respirometer for metabolic studies on the domestic fowl: Establishment of standard operating conditions. Br. Poult. Sci., 15, 287–297.

Morris, T. R. (1972). In: Egg Formation and Production, Ed. B. M. Freeman & P. E. Lake, p. 139, cit. in: Fisher, C. (1976): Protein in the diets of the pullet and laying bird. In: Protein Metabolism and Nutrition, Ed. by Cole et al., Butterworths, London.

Müller, H. L. & Kirchgessner, M. (1979). Zur Energetik der Proteinsynthese beim Wachstum. Z. Tierphysiol., Tierernähr.g.u.Futtermittelkde., 42, 161–172.

Neergaard, J. V. de (1980). Kontrolstationen for høner 1979–1980. Beretning 495, Statens Husdyrbrugsforsøg. 30pp.

Neergaard, J. V. de (1983). Kontrolstationen for høner 1979–1982. Beretning 541, Statens Husdyrbrugsforsøg. 56pp.

Neergaard, L., Petersen, C. B. & Thorbek, G. (1969). Carbon determination in biological materials related to respiration trials. Z. Tierphysiol., Tierernährg.u.Futtermittelkde., 25, 302–308.

Neill, A. R., Reichmann, K. G. & Connor, J. K. (1977). Biochemical, physiological and production indices related to fat metabolism in the laying fowl at various stages of physiological development. Br. Poult. Sci., 18, 312–324.

Nichelmann, M. (1983). Some characteristics of the biological optimum temperature. J. therm. Biol., 8, 69–71.

Nichelmann, M., Hewald, B. & Grune, B. (1983). Thermoregulatorische Wärmeproduktion bei Legehybriden – Beziekungen zwischen Lebensalter und Wärmeproduktion. Arch. exper. Vet. med., 37, 341–352.

O'Neill, S. J. B., Balnave, D. & Jackson, N. (1971). The influence of feathering and environmental temperature on the heat production and efficiency of utilization of metabolizable energy by the mature cockerel. J. Agr. Sci. Cambridge, 77, 293–305.

O'Neill, S. J. B. & Jackson, N. (1974). Observations on the effect of environmental temperature and environment at moult on the heat production and energy requirements of hens and cockerels of a White Leghorn strain. J. Agr. Sci. Cambridge, 82, 553–558.

Ota, H. & McNally, H. (1961). Poultry respiration calorimetric studies of laying hens. Single Comb White Leghorns, Rhode Island Reds, and New Hamshire × Cornish Cross. Beltsville (1961), U.S. Department of Agriculture, ARS. Report 42–43, 34pp.

Payne, C. G. (1967). Environmental temperature and egg production. In: Physiology of the domestic fowl, 235–241. Ed. C. Horton-Smith & E. C. Amoroso. Oliver & Boyd.

Pedersen, J. & Pedersen, S. (1979). Staldklimateknik. DSR-Forlag, K.V.L., København. 228pp.

Petersen, C. F. (1971). The effect of different energy levels and ambient temperature on egg production of White Leghorn hens. Wld's Poult. Sci. J., 27, 161–162.

Petersen, V. E. (1977). To driftssystemers indflydelse på æglæggende høner. 461. Beretning, Statens Husdyrbrugsforsøg. 128pp.

Polin, D. & Wolford, J. A. (1973). Factors influencing food intake and caloric balance in chickens. Fed. Proc., 32, 1720–1726.

Purkiss, J. & Perry, G. C. (1974). Space allowance effects on the egg quality of caged layers. Proc. World's Poultry Congress, 15, 566–567.

Rasch, G., Ludvigsen, J. & Thorbek, G. (1958). Evaluation of errors in determination of N, P and Ca in feeds, faeces and urine. Proc. 1st Symp. on Energy Metabolism, Copenhagen (1958). EAAP Publ. No. 8, 163–182.

Reid, B. L., Kurnick, A. A. & Hulett, B. J. (1965). Relationship of protein level, age and ambient temperature to laying hen performance. Poult. Sci., 44, 1113–1122.

Reid, B. L., Valencia, M. E. & Maiorino, P. M. (1978). Energy utilization by laying hens. I. Energetic efficiencies of maintenance and production. Poult. Sci., 57, 461–465.

Robinson, D. (1979). Effects of cage shape, colony size, floor area and cannibalism preventatives on laying performance. Br. Poult. Sci., 20, 345–356.

Savory, C. J. (1975). Effects of group size on the feeding behaviour and growth of domestic chicks. Br. Poult. Sci., 16, 343–350.

Savory, C. J. & MacLeod, M. G. (1980). Effects of grouping and isolation on feeding, food conversion and energy expenditure of domestic chicks. Behavioural Processes, 5, 187–200.

Scheele, C. W. & Musharaf, N. A. (1980). Energy metabolism and feed evaluation at high environmental temperatures with respect to laying hens. Proc. 8th Symp. om Energy Metabolism, Cambridge (1979). EAAP Publ. No. 26, 377–381.

Shannon, D. W. & Brown, W. O. (1969). Calorimetric studies on the effect of dietary energy source and environmental temperature on the metabolic efficiency of energy utilization by mature Light Sussex cockerels. J. Agr. Sci. Cambridge, 72, 479–489.

Sibbald, I. R. (1979). The gross energy of avian eggs. Poult. Sci., 58, 404–409.

Sibbald, I. R. (1982). Measurement of bioavailable energy in poultry feedingstuffs: a review. Can. J. Anim. Sci., 62, 983–1048.

Siewert, E. & Bronsch, K. (1972). Die Eischale und die Zusammensetzung des Eies. In: Handbuch der Tierernährung, 645–658, Band II, Parey, Hamburg und Berlin.

Simon, J. S. (1980). Stand der Kenntnisse zur Proteinsyntheserate bei Versuchsratte und Schwein. Arch. Tierernähr., 30, 89–98.

Skala, J. H. & Swanson, M. H. (1962). Studies of variation in initial quality of chicken eggs. 1. Physical measurements of albumen and yolk. Poult. Sci., 41, 1533–1536.

Smith, A. J. & Olivier, J. (1972). Some nutritional problems associated with egg production at high environmental temperatures. 1. The effect of environmental temperature and rationing treatments on diets of different energy content. Rhod. J. agric. Res., 10, 3–21.

Snedecor, G. W. (1956). Statistical methods applied to experiments in agriculture and biology. The Iowa State College Press. 534pp.

Stoldt, W. (1957). Mitteilung der Fachgruppe Futtermitteluntersuchung. Landwirtsch. Forsch., 10, 273–275.

Strøm, J. S. (1978). Varmeafgivelse fra kvæg, svin og fjerkræ som grundlag for varmetekniske beregninger. Statens Byggeforskningsinstitut, København. SBI-Landbrugsbyggeri, 55, 47pp.

Sturkie, P. D. (1954). Avian Physiology. Comstock Publishing Associates. 423pp.

Supramaniam, P. (1970). Studies on the restricted feeding of the laying hen. M. Phil. thesis, University of London.

Sykes, A. H. (1977). Nutrition-environment interactions in poultry. In: Nutrition and climatic environment, 17–29. Ed. W. Haresign, H. Swan & D. Lewis. Butterworths, London.

Sykes, A. H. (1979). Environmental temperature and energy balance in the laying hen. In: Food intake regulation in poultry, 207–229. Ed. K. N. Boorman & B. M. Freeman. British Poultry Science Ltd., Edinburgh.

Süs, H. (1976). Die Bewegungsabläufe von Legehennen in der Käfighaltung, 1. Teil. Arch. Geflügelkd., 3, 80–83.

Sørensen, P., Chwalibog, A. & Eggum, B. O. (1983). Protein and energy metabolism in two lines of chickens selected for growth on high or low protein diets. Br. Poult. Sci., 24, 237–250.

Tasaki, I. & Sasa, Y. (1970). Energy metabolism in laying hens. Proc. 5th Symp. on Energy Metabolism, Vitznau (1970). EAAP Publ. No. 13, 197–200.

Thomsen, K. V. (1972). Foderstofanalysen. Ugeskr. Agron. Hort., 1, 316–320.

Thorbek, G. (1969). Studier over energiomsætningen hos voksende svin. I. Opbygning og funktion af et nyt respirationsanlæg for svin. 373. Beretning, Forsøgslab., København. 46pp.

Thorbek, G. (1975). Studies on energy metabolism in growing pigs. II. Protein- and fat gain in growing pigs fed different feed compounds. Efficiency of utilization of metabolizable energy for growth. Beretning 424, Statens Husdyrbrugsforsøg, København. 193pp.

Thorbek, G. (1980). Studies on protein and energy metabolism in growing calves. Beretning 498, Statens Husdyrbrugsforsøg, København. 104pp.

Thorbek, G. & Chwalibog, A. (1984). Influence of environmental temperture on nitrogen and energy metabolism in growing chickens. Arch. exper. Vet. med., 38, 458–466.

Thorbek, G., Chwalibog, A. & Henckel, S. (1984). Kvælstof- og energiomsætning hos svin af Dansk Landrace fra 20 til 120 kg legemsvægt. Normer for protein- og energibehov til vedligehold og vækst. Beretning 563, Statens Husdyrbrugsforsøg. 114pp.

Thorbek, G. & Henckel, S. (1977). Apparent digestibility of crude fat determination in trials with calves and pigs in relation to analytical methods applied. Z. Tierphysiol., Tierernähr.g.u.Futtermittelkde., 39, 48–55.

Thorbek, G. & Neergaard, L. (1970). Construction and function of an open circuit respiration plant for cattle. Proc. 5th Symp. on Energy Metabolism, Vitznau (1970). EAAP Publ. No. 13, 243–246.

Tolman, C. W. (1964). Social facilitation of feeding behaviour in the domestic chick. Anim. Behav., 12, 245–251.

Tzschentke, B. & Nichelmann, M. (1984). Beeinflussung der biologisch optimalen Temperatur von Legehybriden durch die Luftgeschwindigkeit. Arch. exper. Vet. med., 38, 319–326.

Valencia, M. E., Maiorino, P. M. & Reid, B. L. (1978). Dietary fat, temperature and energy utilization by laying hens. Federation Proceedings, 37, 280.

Valencia, M. E., Maiorino, P. M. & Reid, B. L. (1980). Energy utilization in laying hens. III. Effect of dietary protein level at 21°C and 32°C. Poult. Sci., 59, 2508–2513.

Vogt, H. & Harnisch, S. (1978). Proteasen im Geflügelfutter. Arch. Geflügelkd., 42, 183–193.

Vohra, P. (1972). Evaluation of metabolizable energy for poultry. Wld's Poult. Sci. J., 29, 204–214.

Vohra, P., Wilson, W. D. & Siopes, T. D. (1979). Egg production, feed consumption and maintenance energy requirements of leghorn hens as influenced by dietary energy at temperatures of 15.6°C and 26.7°C. Poult. Sci., 58, 674–680.

Voreck, O. & Kirchgessner, M. (1980a). Stickstoffbilanz und N-Verwertung der Legehenne bei unterschiedlicher Energie- und Proteinversorgung. Arch. Geflügelkd., 44, 50–54.

Voreck, O. & Kirchgessner, M. (1980b). Futter- und Nährstoffaufwand für die Eiproduktionen in der Periode der maximalen Legeleistung bei verschiedener Energie- und Proteinversorgung. Arch. Geglügelkd., 44, 158–162.

Voreck, O. & Kirchgessner, M. (1980c). Zum Erhaltungsbedarf an Energie und Rohprotein bei der Legehenne. Arch. Tierernähr., 30, 771–781.

Waring, J. J. & Brown, W. O. (1965). A respiration chamber for the study of energy utilization for maintenance and production of the laying hen. J. Agric. Sci., 65, 139–146.

Waring, J. J.& Brown, W. O. (1967). Calorimetric studies on the utilization of dietary energy by the laying White Leghorn hen in relation to plane of nutrition and environmental temperature. J. Agr. Sci. Cambridge, 68, 149–155.

Weidner, K. & Jakobsen, P. E. (1962). Dyrefysiologi II. Øvelsesvejledning for landbrugs-, mejeribrugs- og licentiatstuderende ved Den kgl. Veterinær- og Landbohøjskole. DSR-Forlag, K.V.L., København. 118pp.

Wells, R. G. (1971). Studies on stocking arrangements for caged layers. Wld's Poult. Sci. J., 27, 361–366.

Wenk, C. & Es, A. J. H. van (1976). Energy metabolism of growing chickens as related to their physical activity. Proc. 7th Symp. on Energy Metabolism of Farm Animals, Vichy (1976). EAAP Publ. No. 19, 189–192.

Westerterp, K. R. (1976). How rats economize energy loss in starvation. Thesis. Rijksuniversiteit Gronningen. 80pp.

Main Tables

Hovedtabeller

Age, week	Age week	Alder, uge
LW	Live weight	Legemsvægt
Food	Food	Foder
Egg prod.	Egg production	Ægproduktion
DM	Dry matter	Tørstof
N	Nitrogen	Kvælstof
Fat	Fat	Fedt
OE	Energy in eggs	Energi i æg
Laying %	Laying %	Æglægningsprocent
Egg size	Egg size	Ægstørrelse
CO_2	CO_2 production	CO_2-produktion
O_2	O_2 consumption	O_2-optagelse
IN	Intake of nitrogen	Optagelse af kvælstof
DRN	Nitrogen in droppings	Kvælstof i gødning + urin
NBAL	Nitrogen balance	Kvælstofbalance
ON	Nitrogen in eggs	Kvælstof i æg
GE	Gross energy in food	Bruttoenergi i foder
ME	Metabolizable energy	Omsættelig energi
HE	Total heat energy	Total varmeenergi
EBAL	Energy balance	Energibalance

The values are measured individually (Ser. G) or in groups (Ser. H, K and J) and expressed per hen per day.

Værdierne er målt individuelt (Ser. G) eller i grupper (Ser. H, K og J) og angivet pr. høne pr. dag.

Series G. 21°C. Hens in individual cages

Age, live weight, egg production and chemical composition of eggs
Alder, legemsvægt, ægproduktion og kemisk sammensætning af æg

Per. no.	Groups n	Age week	LW g	Food g	Egg prod. g	Egg composition DM %	N %	Fat %	OE kJ/kg	Laying %	Egg size g/egg
I	11	26	1555	83	40.9	24.2	2.07	9.19	6986	80.5	50.8
II	12	29	1570	98	44.2	24.4	2.13	9.54	7084	84.7	52.2
III	11	32	1532	100	42.5	24.2	2.05	9.42	7065	80.5	52.7
IV	9	35	1599	111	47.0	24.6	2.09	9.72	7214	84.3	55.7
V	10	38	1625	106	48.8	24.5	2.05	9.91	7161	84.3	57.8
VI	9	41	1604	101	44.7	25.1	2.07	10.09	7253	77.7	57.5
VII	9	44	1678	98	49.4	25.2	2.08	10.45	7528	84.2	58.4
VIII	10	47	1672	98	44.9	25.3	2.08	10.59	7444	75.6	59.4

Gas exchange, nitrogen and energy metabolism
Luftstofskifte, kvælstof – og energiomsætning

Per. no.	CO_2 l	O_2 l	IN mg	DRN mg	NBAL mg	ON mg	GE kJ	ME kJ	HE kJ	EBAL kJ	OE kJ
I	34.7	39.3	1944	1175	–111	881	1346	922	787	–151	286
II	34.8	39.5	2313	1198	139	975	1596	1122	746	64	313
III	35.9	38.4	2370	1278	181	910	1635	1129	781	47	300
IV	37.1	41.3	2633	1464	153	1017	1817	1256	782	135	338
V	35.6	40.3	2505	1391	76	1039	1728	1190	774	67	348
VI	33.9	37.8	2394	1257	176	961	1651	1153	728	102	324
VII	34.9	39.4	2309	1267	–24	1066	1602	1120	780	–27	367
VIII	34.4	38.6	2301	1220	110	971	1597	1110	755	17	338

Series H. 17°C. Groups of hens. 3 in each group

Age, live weight, egg production and chemical composition of eggs
Alder, legemsvægt, ægproduktion og kemisk sammensætning af æg

Per. no.	Groups n	Age week	LW g	Food g	Egg prod. g	Egg composition DM %	N %	Fat %	OE kJ/kg	Laying %	Egg size g/egg
I	4	26	1600	92	42.0	25.9	2.23	9.82	7480	83.7	50.2
II	4	29	1658	116	45.9	24.7	2.13	9.91	7184	84.1	54.6
III	4	32	1692	117	47.8	25.1	2.12	10.11	7345	86.9	55.0
IV	3	35	1724	126	47.4	24.7	2.09	9.99	7250	85.6	55.4
V	3	38	1727	120	50.7	25.9	2.17	10.40	7587	88.9	57.0
VI	3	41	1741	122	50.4	25.5	2.11	10.12	7369	88.6	56.9
VII	3	44	1784	120	47.7	24.9	2.06	10.30	7459	82.8	57.9
VIII	3	47	1815	114	48.2	25.3	2.03	10.58	7388	82.3	58.6

Gas exchange, nitrogen and energy metabolism
Luftstofskifte, kvælstof – og energiomsætning

Per. no.	CO_2 l	O_2 l	IN mg	DRN mg	NBAL mg	ON mg	GE kJ	ME kJ	HE kJ	EBAL kJ	OE kJ
I	36.7	43.4	2188	1194	23	972	1510	1064	810	–61	314
II	40.3	46.2	2751	1482	260	1010	1899	1323	852	141	330
III	42.2	47.2	2775	1579	150	1046	1914	1349	902	97	351
IV	42.4	49.3	2991	1587	377	1028	2064	1486	879	263	344
V	41.5	47.3	2855	1534	185	1136	1969	1398	875	140	384
VI	41.2	47.3	2883	1493	279	1111	1989	1412	888	153	371
VII	42.2	48.2	2810	1516	282	1012	1950	1387	921	111	355
VIII	40.8	47.5	2687	1464	208	1016	1865	1312	884	72	356

Series H. 21°C. Groups of hens. 3 in each group

Age, live weight, egg production and chemical composition of eggs
Alder, legemsvægt, ægproduktion og kemisk sammensætning af æg

Per. no.	Groups n	Age week	LW g	Food g	Egg prod. g	Egg composition DM %	N %	Fat %	OE kJ/kg	Laying %	Egg size g/egg
I	3	26	1531	93	43.0	24.7	2.17	9.05	7045	85.7	50.2
II	3	29	1633	117	44.1	24.7	2.13	9.64	7099	82.6	53.4
III	3	32	1673	115	45.8	25.2	2.16	9.96	7320	84.2	54.4
IV	3	35	1704	125	47.0	25.1	2.14	10.15	7391	84.1	55.9
V	3	38	1699	116	45.2	25.0	2.13	9.92	7318	79.4	56.9
VI	3	41	1744	111	47.8	24.7	2.06	9.84	7086	82.4	58.0
VII	3	44	1772	109	45.3	25.1	2.05	10.53	7511	77.8	58.2
VIII	3	47	1822	112	48.2	25.0	2.06	10.71	7513	80.7	59.7

Gas exchange, nitrogen and energy metabolism
Luftstofskifte, kvælstof – og energiomsætning

Per. no.	CO_2 l	O_2 l	IN mg	DRN mg	NBAL mg	ON mg	GE kJ	ME kJ	HE kJ	EBAL kJ	OE kJ
I	33.6	40.1	2202	1198	33	970	1500	1062	731	28	303
II	39.5	45.3	2778	1534	272	972	1900	1342	809	220	314
III	40.6	46.1	2715	1520	170	1025	1837	1330	855	139	335
IV	40.7	46.5	2957	1533	385	1040	2040	1494	830	317	347
V	39.3	47.9	2741	1504	237	1001	1891	1346	829	185	331
VI	39.1	45.1	2620	1400	196	1024	1808	1278	850	90	338
VII	39.3	46.7	2559	1438	161	960	1776	1245	861	43	340
VIII	39.5	46.4	2635	1382	221	1032	1826	1300	849	89	362

Series K. 17°C. Groups of hens. 3 in each group

Age, live weight, egg production and chemical composition of eggs
Alder, legemsvægt, ægproduktion og kemisk sammensætning af æg

Per. no.	Groups n	Age week	LW g	Food g	Egg prod. g	Egg composition DM %	N %	Fat %	OE kJ/kg	Laying %	Egg size g/egg
I	4	26	1658	112	47.9	24.3	2.15	8.92	6999	90.2	53.1
II	4	29	1689	118	55.4	25.0	2.19	9.48	7277	98.8	56.1
III	4	32	1712	127	52.8	24.7	2.13	9.82	7238	94.3	56.0
IV	4	35	1729	133	54.6	25.3	2.15	10.05	7417	95.3	57.3
V	4	38	1768	129	55.2	25.2	2.11	10.19	7389	95.3	57.9
VI	4	41	1789	124	56.9	25.1	2.06	10.49	7386	97.6	58.3
VII	4	44	1817	121	53.3	25.2	2.09	10.37	7407	89.1	59.8
VIII	4	47	1820	120	57.7	25.7	2.11	10.87	7548	96.5	59.8

Gas exchange, nitrogen and energy metabolism
Luftstofskifte, kvælstof – og energiomsætning

Per. no.	CO_2 l	O_2 l	IN mg	DRN mg	NBAL mg	ON mg	GE kJ	ME kJ	HE kJ	EBAL kJ	OE kJ
I	42.2	46.3	2629	1590	–33	1072	1867	1283	941	7	335
II	43.1	47.8	2832	1544	27	1261	1951	1354	907	43	403
III	43.7	47.7	3063	1490	403	1170	2112	1539	861	295	383
IV	43.6	47.5	3179	1586	365	1228	2207	1592	837	351	405
V	42.9	47.3	3120	1519	389	1212	2155	1573	882	384	407
VI	43.5	47.6	2960	1631	112	1217	2053	1439	904	115	420
VII	42.0	44.8	2928	1587	172	1169	2018	1418	905	118	395
VIII	43.3	47.6	2924	1547	108	1269	1991	1402	882	85	435

Series K. 21°C. Groups of hens. 3 in each group

Age, live weight, egg production and chemical composition of eggs
Alder, legemsvægt, ægproduktion og kemisk sammensætning af æg

Per. no.	Groups n	Age week	LW g	Food g	Egg prod. g	Egg composition DM %	N %	Fat %	OE kJ/kg	Laying %	Egg size g/egg
I	3	26	1704	121	48.6	24.7	2.17	9.12	7108	87.9	55.3
II	4	29	1772	122	54.9	24.9	2.14	9.46	7241	97.7	56.2
III	4	32	1779	130	54.8	24.7	2.13	9.81	7224	96.3	56.9
IV	4	35	1802	137	52.9	25.0	2.10	10.00	7333	91.8	57.6
V	3	38	1764	116	50.7	25.7	2.16	10.52	7531	87.3	58.1
VI	2	41	1904	125	58.0	25.3	2.08	10.66	7501	97.5	59.5
VII	2	44	1936	122	53.5	24.7	2.02	10.38	7307	90.7	59.0
VIII	2	47	1971	122	54.2	25.3	2.06	10.53	7510	90.3	60.0

Gas exchange, nitrogen and energy metabolism
Luftstofskifte, kvælstof – og energiomsætning

Per. no.	CO_2 l	O_2 l	IN mg	DRN mg	NBAL mg	ON mg	GE kJ	ME kJ	HE kJ	EBAL kJ	OE kJ
I	40.1	43.9	2821	1651	65	1105	2003	1395	859	190	346
II	42.6	46.2	2950	1617	102	1231	2033	1413	884	132	398
III	44.1	48.1	3137	1581	340	1216	2163	1574	861	317	396
IV	44.6	47.1	3264	1559	543	1163	2267	1655	873	394	388
V	44.7	47.2	2808	1481	194	1133	1943	1399	968	50	381
VI	44.5	47.8	2980	1693	23	1264	2066	1451	905	111	435
VII	44.0	47.7	2940	1610	204	1126	2027	1417	961	65	391
VIII	43.8	47.6	2969	1596	204	1169	2022	1404	892	105	407

Series J. 17°C. Groups of hens. 6 in each group

Age, live weight, egg production and chemical composition of eggs
Alder, legemsvægt, ægproduktion og kemisk sammensætning af æg

Per. no.	Groups n	Age week	LW g	Food g	Egg prod. g	Egg composition DM %	N %	Fat %	OE kJ/kg	Lay-ing %	Egg size g/egg
I	1	26	1656	116	47.8	24.7	2.18	9.10	7107	95.0	50.3
II	1	29	1697	112	44.8	25.2	2.22	9.47	7316	81.0	55.3
III	1	32	1727	124	45.2	25.3	2.18	10.00	7363	81.0	55.8
IV	1	35	1782	122	42.0	25.8	2.20	10.08	7525	73.8	56.9
V	1	38	1795	112	35.2	26.2	2.18	10.57	7644	61.8	56.9
VI	1	41	1815	112	46.5	25.5	2.11	10.58	7489	81.0	57.4
VII	1	44	1826	112	33.2	25.5	2.12	10.59	7515	57.2	58.0
VIII	1	47	1824	118	39.2	25.5	2.13	10.44	7500	66.7	58.8

Gas exchange, nitrogen and energy metabolism
Luftstofskifte, kvælstof – og energiomsætning

Per. no.	CO_2 l	O_2 l	IN mg	DRN mg	NBAL mg	ON mg	GE kJ	ME kJ	HE kJ	EBAL kJ	OE kJ
I	40.9	40.9	2711	1346	273	1092	1925	1420	881	199	340
II	40.4	42.1	2703	1446	225	1032	1862	1318	828	162	328
III	40.9	41.1	2997	1634	341	1022	2066	1453	790	331	333
IV	41.9	42.9	2924	1428	533	963	2030	1500	799	385	316
V	41.8	41.8	2706	1546	365	795	1869	1301	911	121	269
VI	43.0	43.8	2685	1336	328	1021	1862	1370	902	120	348
VII	41.0	41.9	2706	1447	525	734	1865	1348	872	227	249
VIII	42.2	42.3	2883	1576	441	866	1964	1382	848	240	294

Series J. 21°C. Groups of hens. 6 in each group

Age, live weight, egg production and chemical composition of eggs
Alder, legemsvægt, ægproduktion og kemisk sammensætning af æg

Per. no.	Groups n	Age week	LW g	Food g	Egg prod. g	Egg composition DM %	N %	Fat %	OE kJ/kg	Lay-ing %	Egg size g/egg
I	1	26	1511	101	41.2	24.5	2.12	9.21	7088	97.7	42.2
II	1	29	1525	116	44.0	25.6	2.22	9.64	7428	83.3	52.8
III	1	32	1558	115	38.8	24.7	2.09	9.99	7209	71.5	54.3
IV	1	35	1590	111	40.2	25.0	2.10	10.11	7388	73.8	54.4
V	1	38	1630	115	53.5	25.3	2.05	10.57	7492	95.2	56.2
VI	1	41	1689	111	44.7	25.4	2.10	10.82	7568	78.5	56.9
VII	1	44	1727	111	41.1	26.8	2.13	11.58	7853	71.5	57.6
VIII	1	47	1707	116	44.5	25.5	2.09	10.71	7493	76.2	58.4

Gas exchange, nitrogen and energy metabolism
Luftstofskifte, kvælstof – og energiomsætning

Per. no.	CO_2 l	O_2 l	IN mg	DRN mg	NBAL mg	ON mg	GE kJ	ME kJ	HE kJ	EBAL kJ	OE kJ
I	36.2	37.2	2360	1294	156	910	1676	1188	797	99	292
II	40.8	40.7	2788	1298	475	1015	1920	1392	825	240	327
III	38.4	39.1	2780	1355	580	845	1917	1394	746	368	280
IV	39.8	37.9	2641	1237	524	880	1834	1347	787	263	297
V	40.2	40.3	2779	1309	329	1141	1920	1411	838	172	401
VI	41.9	42.0	2645	1423	234	988	1834	1317	889	90	338
VII	38.7	39.0	2686	1255	511	920	1851	1375	811	241	323
VIII	41.1	41.4	2835	1488	382	965	1930	1363	817	213	333