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# A Dynamic Model for Naturally Ventilated Low Cost Poultry Houses

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**Abstract**

*Ventilation as a method of controlling the internal environment in poultry houses serves two main purposes. It provides the desirable levels of temperature and humidity to achieve good poultry performance and it also provides a desired amount of fresh air, without drafts, to all parts of the building. Ventilation also controls ammonia levels to limits appropriate for operating personnel. This paper discusses a simulation model developed to study the dynamic changes of the internal thermal environment in low cost poultry houses in Zambia. The model is based on the interaction of various internal, external and building construction related parameters. The model can be used to predict the temperature in a naturally ventilated poultry house for a given set of input parameters. Furthermore, it can calculate the heating or cooling load required to keep the temperature at desired levels for the birds. It can also be used to study the effects of changing various parameters on the internal thermal environment. The model was validated using data obtained from an open-sided naturally ventilated poultry house housing birds at an average age of 8 weeks. The model was able to predict the internal temperature closely to the measured values.*

Keywords: *Natural ventilation, Dynamic modelling, Poultry houses*

## Introduction

Natural ventilation is one the methods of controlling the internal environment in poultry buildings and other animal shelters in Zambia. Simplicity, low initial cost and low energy and maintenance costs make natural ventilation the most commonly used method of environmental control in poultry houses. It provides the desirable levels of temperature and humidity and also provides a desired amount of fresh air, without drafts, to all parts of the building.

Low cost poultry houses in Zambia incorporate large openings covered with chicken wire mesh on the long walls for maximum cross ventilation. These may allow solar radiation to reach internal surfaces, especially floors, depending on the solar angles (angle of incidence, solar altitude and azimuth). Reed mats or polythene curtains are commonly used to offer protection against both wind in cold weather and direct sunshine in hot weather. Some designs incorporate ridge openings made by overlapping the roofing sheets, but problems associated with driving rain, insect and bird activity limit the use of these openings. A typical low cost open-sided poultry house in common use in Zambia is shown in Fig. 1. This building, at the University of Zambia Agricultural Sciences Research Station was used in the simulations reported in this paper.

A dynamic simulation model was developed to predict the interior temperature in the poultry house as bird growth and climatic conditions changed. The simulation is based on established theoretical and experimental work which takes into account the interaction of various internal, external and building construction related parameters. Internal parameters include the birds' heat and moisture production, and heating or cooling regimes. The external parameters include solar radiation, ambient temperature and relative humidity, and wind speed and direction. Finally, construction-related parameters include building orientation, thermal properties of materials, and size and location of openings.

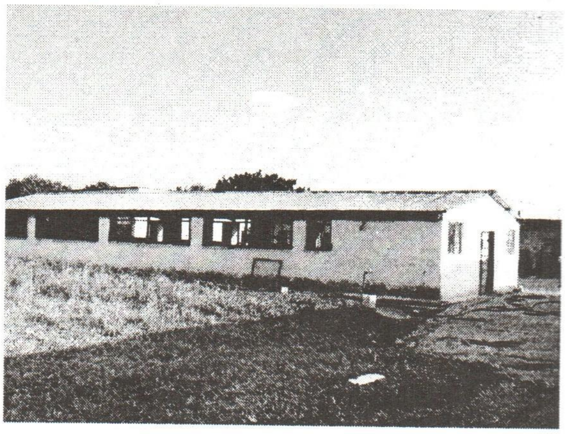

Fig. 1: The open-sided poultry house at the University of Zambia Field Station

The simulation has a wide range of applications. By interchanging specified environmental and construction-related parameters with unknowns, a range of temperatures at animal level can be developed for optimising productivity throughout the growing period. Control applications involve sensing time-varying ambient conditions along with assigning the steady-state construction and environmental specifications to regulate the ventilation system and determine requirements of supplemental heating or cooling.

**Dynamic and steady-state modelling of the internal environment**

The mathematical model makes use of the internal, external and building construction related parameters mentioned above. The dynamic nature of the simulation results from the fact that some of the parameters are transient. Several authors have used the transient theory of heat and moisture exchange to predict interior environmental conditions in ventilated livestock buildings. Albright and Scott (1974) performed an analysis of steady-periodic building temperature variations in warm weather. Van't Klooster (1996) also used a dynamic energy balance model for a naturally ventilated pig house to develop an animal-based environmental control algorithm. Axaopoulos *et al.* (1994) developed a transient simulation computer program for growing-finishing pig buildings.

For steady-state conditions, many authors have relied on the work presented by Albright (1990) and American Society of Agricultural Engineers Standards (1999). Diesch and Froehlich (1988) used a steady-state heat and moisture exchange model to predict interior environmental conditions in ventilated livestock buildings. They assumed that the structure wais well ventilated and of small mass and that it would therefore not retain sufficient energy or moisture from the previous day. Hence they neglected thermal storage effects. It has been shown, however, that the transient analysis is a better method to predict the temporal behaviour of an agricultural building (Axaopoulos, 1994). Arinze *et al.* (1984) also indicated that a transient rather than steady-state analysis was required for accurate prediction, modification and control of a greenhouse thermal environment. They developed a dynamic thermal performance simulation model which incorporated thermal storage. A general schematic representation of the energy balance in a poultry house is given in Fig. 2.

The dynamic change in the internal temperature of a poultry house can be calculated using the energy (sensible heat) balance equation given by Albright and Scott (1974) as follows:

$$q_v + q_s - q_l + q_e + q_{sup} - q_b = M_a C_a \frac{dT_i}{dt} \qquad (1)$$

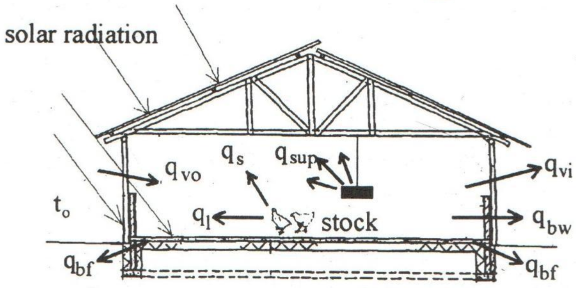


Fig. 2: Heat exchange in poultry houses

***Sensible heat content of ventilating air ($q_v$)***

It is assumed that air enters the building at a lower temperature $T_o$ and leaves the building at a higher temperature $T_i$. The heat removed by ventilating air is the difference between the outside (incoming) and inside (outgoing) sensible heat content of the air and can be evaluated as:

$$q_v = (q_{vi} - q_{vo}) = M_a C_a (T_i - T_o) \qquad (2)$$

The mass flow rate, or air exchange in naturally ventilated poultry houses is affected by the forces of wind and thermal forces. The ventilation rate due to wind is given by Hellickson and Walker (1983) as:

$$Q_w = E A_v V \qquad (3)$$

Changes in wind direction influence the ventilation rate due to wind by changing the external pressure coefficients. The greatest rate occurs when the wind is perpendicular to the inlet. The value of E, the effectiveness of opening varies between 0.5 and 0.6 for the case where wind is at right angles to the face of the opening; and 0.25 to 0.35 for diagonal winds (Hellickson *et al*, 1983). In this study, the value of E was considered to vary linearly from 0.6 for perpendicular (90°) winds to 0.25 for parallel (0°) winds.

Equation 3 applies for the case where the area of inlet is equal to the area of the outlet. Where they are different, a correction factor has to be applied (Hellickson *et al*, 1983; Markus and Morris, 1980). The correction factors used in this study were presented by the Hellickson *et al* (1983).

Cross ventilation by wind offers the best means of cooling during hot weather in poultry houses in tropical countries. This is most effectively achieved when the inlet and outlet are at opposite sides of the building, generally the long sides, and are of equal size.

Thermal buoyancy forces or the stack effect resulting from differences in air temperature also set up air movements in poultry houses. Heat production from poultry is available to warm the air entering from outside. Natural ventilation by the stack effect can provide the minimum ventilation required in cold weather conditions.

It has been shown that where the flow rate due to wind is much larger than that due to the buoyancy effect, the combined flow rate will be approximately the same as the flow rate due to wind only (Hellickson *et al*, 1983; Kittas *et al*, 1997; Markus and Morris, 1980; Zhang *et al*, 1989). Koenigsberger *et al* (1973) also indicated that in tropical climates, thermal forces will rarely be sufficient to create appreciable air movements and that the only natural force that can be relied on is the dynamic effect of winds. Therefore, in this study buoyancy effects were not considered, and Eqn (2) can be written in terms of volumetric flow rate as:

$$q_v = \rho_a Q_a C_a (T_i - T_o) \qquad (4)$$

***Heat production by birds ($q_s$ and $q_l$)***

The total heat production of poultry is affected by animal size, age, activity, feed consumption, productivity, and environmental temperature (Hellickson and Walker, 1983). For poultry housing, the heat production values are given by Sallvik and Pedersen (1999). The total heat production is the sum of the sensible heat and latent heat production and is given as:

$$q_t = q_s + q_l \qquad (5)$$

The total heat production for each bird depends on its body mass: For broilers it is given by:

$$q_t = 10 m_b^{0.75} \qquad (6)$$

while for layers on floors the total heat production is given by:

$$q_t = 6.8 m^{0.76} + 25Y \qquad (7)$$

It should be noted from Eqn (1) that the sensible heat from the birds adds to the total heat content of the environment, while the latent heat is removed from the environment due to evaporation of moisture produced by birds. Therefore, although the total heat production is known, the separate quantities must be determined for use in Eqn (1). The general expression of the sensible heat dissipation at house level within the ambient temperature range from 10°C to 40°C is given by Sallvik and Pedersen (1999) as follows:

$$q_s = q_t (0.8 - 1.28x10^{-7} (T_i - K_t)^4) \qquad (8)$$

Latent heat production is also dependent on internal temperature in the building. It is difficult to estimate as it depends on many variables such as moisture from the respiratory tract, available moisture in faeces, moisture in the bedding, surface moisture, humidity of the air, temperature of the moisture itself and of the air and velocity of the air movement. However, following Sallvik and Pedersen (1999), latent heat can be evaluated from Eqn (5) as the difference between the total heat and the sensible heat produced by the birds.

$$q_l = q_t (0.2 + 1.28x10^{-7} (T_i - K_t)^4) \qquad (9)$$

Then from Eqn (1),

$$q_s - q_l = q_t (0.6 - 21.28x10^{-7} (T_i - K_t)^4) \qquad (10)$$

***Heat produced by equipment ($q_e$)***

Light bulbs when used continuously for lighting to encourage feed intake in poultry housing may produce sufficient heat which should be taken into account for simulation and analysis of heating or cooling loads. In general, little use is made of machinery in poultry housing in Zambia. Therefore, sources of heat from equipment can be neglected.

*Supplemental heat ($q_{sup}$)*

The heat supplied through heaters must be accounted for using the rated heat output. Charcoal is commonly used by small-scale to medium-scale producers for heating in poultry houses. Under a steady supply of fuel and in a well-ventilated building, the rate at which charcoal burns is constant. The calorific value of charcoal is 30.4 MJ/kg, while the fuel consumption of traditional charcoal burners commonly used in households and poultry houses is estimated at 0.35 kg/hr (Kerekezi and Ranja, 1997). The total heat output from burning charcoal is given as:

$$q_{sup} = M_c C_c \qquad (11)$$

*Heat loss through the building fabric ($q_b$)*

The heat conduction through the building fabric occurs across the roof, wall and floor surfaces. To estimate the heat exchange for a whole building enclosed by various elements where possibly the temperature differences vary from side to side, the following equation is used:

$$q_b = \sum A_n U_n (T_i - T_o) \qquad (12)$$

In determining the temperature difference to be used in Eqn (12), the effects of solar radiation on surfaces exposed to direct sunshine must be accounted for because buildings are externally exposed to a combination of solar radiation and ambient air temperature. Sol-air temperature is an equivalent temperature of the outside air that gives the same rate of heat transfer to the exterior envelope as actually occurs by solar and long-wave radiation, convection, and conduction. This is evaluated as:

$$T_o = T_{om} + \frac{a_s I}{h_c} \qquad (13)$$

The incident radiation intensity is given by Hutchinson (1974) for Zambia as:

$$I = H_o (0.248 + 0.435 \frac{D}{d}) \qquad (14)$$

The average insolation at the top of the atmosphere can be approximated from:

$$H_o = I_{sc}((1 + 0.033 \cos(\frac{360n}{365}) (\cos\varphi \cos\delta \cos\omega + \sin\varphi \sin\delta)) \qquad (15)$$

The declination is given by:

$$\delta = 23.45 \sin(\frac{360}{365}(284 + n)) \qquad (16)$$

The hour angle is given by the following equation:

$$\omega = 0.25H \qquad (17)$$

The maximum number of daylight hours on a given day can be evaluated using the sunset hour angle which is given by:

$$\omega_s = \cos^{-1}(-\tan\varphi \tan\delta) \qquad (18)$$

Equation 12 assumes steady state conditions where the temperatures remain constant for a period of time. In practice the heat gains and losses of a building are seldom steady state for any length of time owing to fluctuations of solar radiation and external temperature. In general there is a more rapid thermal response to temperature differences with a lightweight structural element than with a heavyweight one (Markus and Morris, 1980). The rate at which the heat is transferred depends on the conductivity and the thermal capacity of the element. In practice the time lag, $\psi$ and the decrement factor, $\mu$ values are used (Koenigsberger *et al*, 1973). In this study, only dense constructions (massive walls) such as those made of concrete, concrete blocks, bricks and stabilised earth were considered to have a time lag. Typical values of $\psi$ and $\mu$ for these materials are given in Koenigsberger *et al* (1973). Using these values, the time lag was assumed to be equal to 5 hours and the decrement factor was assumed to be equal to 0.25 (for a typical 150mm thick wall). In case of these materials, the heat transfer equation is given by:

$$q_{b\psi} = AU[(T_i - T_o) + \mu(T_i - T_\psi)] \qquad (19)$$

For concrete slabs resting on soil, the heat flow must be based on the dimensions of the floor and the edge conditions (Markus and Morris, 1980). This is because as the area of the floor increases the rate of heat flow per unit area of floor decreases. Diesch and Floehlich (1988) indicated that the heat transfer from a concrete slab floor is mostly through the structure's perimeter rather than through the floor and can be estimated by the equation:

$$q_{bf} = FP(T_i - T_o) \qquad (20)$$

The total heat transfer of the building fabric is the sum of all the quantities across the various building elements.

Summing all the heat components results in the following equation:

$$\rho_a Q_w C_a (T_o - T_i) + 0.6q_t - 2q_t \alpha (T_i - K)^4 + q_c + q_{sup} - \sum A_n U_n (T_i - T_o) - FP(T_i - T_o) - [A_m U_m [(T_i - T_o) + \mu(T_i - T_\psi)] = m_a C_a \frac{dT_i}{dt} \qquad (21)$$

Equation 21 gives the instantaneous variation in the internal temperature as a function of time, the internal temperature and other parameters.

### Simulation

The analytical model presented in the equations above was implemented as a computer program. The first order differential equation, Eqn. (21), is solved numerically using a second order Runge-Kutta predictor-corrector algorithm. The initial values of the internal temperature in the numerical solution is taken as outside temperature. New values are evaluated at time $t = t + \Delta t$. The increment step $\Delta t$ is equal to 1 second.

The simulation uses the outdoor environmental conditions – diurnal variations in average ambient temperature, daily average relative humidity, and wind speed and direction. Hourly climatic data was used to determine the changes in the internal conditions. Average daily weather data from 1960 to 2006 shown in Table 1 as used in the simulations.

Table 1 Average daily weather data from 1960 to 2006 (Source: Meteorological Data Sheets, Lusaka City Airport)

| Month | Mean daily sunshine hours | Maximum daily sunshine hours | Mean daily wind speed (m/s) |
|---|---|---|---|
| Jan | 5.4 | 12.9 | 1.75 |
| Feb | 5.9 | 12.6 | 1.5 |
| Mar | 7.4 | 12.2 | 1.85 |
| Apr | 8.7 | 11.7 | 2.35 |
| May | 8.7 | 11.4 | 2.35 |
| Jun | 9.0 | 11.2 | 2.45 |
| Jul | 9.1 | 11.3 | 2.65 |
| Aug | 9.6 | 11.6 | 3.15 |
| Sep | 9.4 | 12.0 | 3.2 |
| Oct | 9.0 | 12.4 | 3.35 |
| Nov | 7.4 | 12.8 | 3.10 |
| Dec | 6.1 | 13.0 | 2.25 |

Building dimensions and the configuration of the roof were obtained from the experimental poultry unit and are given in Table 2.

The thermal properties of the building elements were obtained from Koenigsberger *et al* ( 1973). The position and size of ventilation openings were also noted and used in the simulations.

The data on poultry includes the type of birds, their average weight and their lower and upper critical temperatures.

### Results and discussion

The following results for both the sol-air temperature and predicted internal temperature were obtained for three days as shown in Tables 3 to 5.

Table 2 Data from University of Zambia Field Station Poultry House

| | |
|---|---|
| ***(i) Heat transfer coefficients*** | |
| Walls: 200mm hollow concrete block with 10mm plaster | 2.36 $W/m^2K$ |
| Floor: 100mm reinforced concrete | 5.59 $W/m^2K$ |
| Roof: Corrugated sheet metal, no ceiling | 3.85 $W/m^2K$ |
| ***(ii) Building dimensions*** | |
| Internal volume | 367.54 $m^3$ |
| Area of gable walls | 40.5 $m^2$ |
| Area of side walls | 53.06 $m^2$ |
| Area of openings (on side walls) | 12.68 $m^2$ |
| Area of roof | 142.3 $m^2$ |
| Area of the floor | 137.4 $m^2$ |
| ***(iii) Bird growth characteristics*** | |
| Number of birds | 2000 |
| Average Bird weight | 1.8 kg |
| Bird age | 8 weeks |

Figures 4 to 6 show the graphs of the predicted and measured values. It can be observed from the tables and graphs that a relationship exists between the measured and the predicted values. In all cases the predicted temperature was higher than the measured temperature inside the poultry house. One reason for this is that the simulation uses the calculated sol-air temperature to predict the internal temperature in the house. Factors such as average of the maximum possible hours of day length, average daily hours of bright sunshine, average extraterrestrial solar radiation for the location, and average radiation intensity are used in calculating the sol-air temperature at a given time of day. These factors are average values and may not be accurate. This makes the prediction of sol-air temperature difficult. Other factors such as wind speed and direction vary in a very short time, making their use over a long period of time (i.e. hourly) inaccurate.

Despite the above stated deficiencies, the predicted values give a good indication of the expected internal temperatures in the poultry house and can be useful in designing a natural ventilation control system. In addition to predicting trends, the model also provides results for any changes made in a system which could be used in making management decisions. The model can also be used for the day to day management of the house because it shows when the temperatures are likely to deviate from the recommended values and thus facilitate the opening or closing of openings.

Table 3 Results for the 129th Day (8th May 2006)

| Time (hrs) | Calculated Sol-air temp. (°C) | Predicted internal temp. (°C) | Measured internal temp. (°C) | Difference between predicted and measured temp. (°C) |
|---|---|---|---|---|
| 0800 | 20.80 | 22.70 | 22.00 | 0.70 |
| 0900 | 21.80 | 23.78 | 22.50 | 1.28 |
| 1000 2 | 1.80 23.78 21 | .50 2.28 | | |
| 1100 2 | 3.80 25.93 23 | .50 2.43 | | |
| 1200 2 | 4.80 27.00 24 | .50 2.50 | | |
| 1300 2 | 3.80 25.93 23 | .50 2.43 | | |
| 1400 2 | 3.80 25.93 23 | .50 2.43 | | |
| 1500 2 | 2.80 24.85 23 | .00 1.85 | | |
| 1600 2 | 2.80 24.85 23 | .00 1.85 | | |

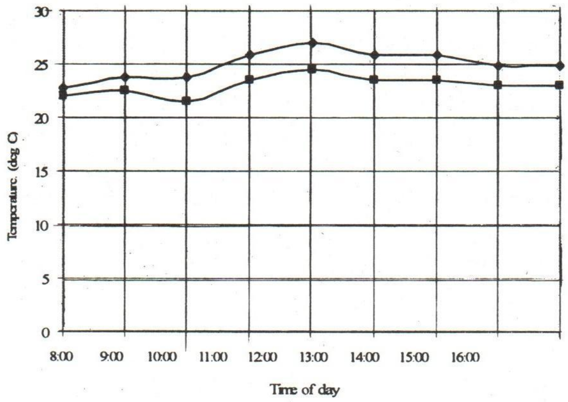


Fig. 3 Results for the 129th Day (8th May 2006)

Table 4 Results for the 130th Day (9th May 2006)

| Time (hrs) | Calculated Sol-air temp. (°C) | Predicted internal temp. (°C) | Measured internal temp. (°C) | Difference between predicted and measured temp. (°C) |
|---|---|---|---|---|
| 0800 | 22.30 | 24.14 | 23 | 1.14 |
| 0900 22 | .8024.85 23 | 1.85 | | |
| 1000 | 22.80 | 24.85 | 23 | 1.85 |
| 1100 | 23.30 | 25.39 | 23 | 2.39 |
| 1200 | 23.80 | 25.93 | 24 | 1.93 |
| 1300 | 24.80 | 27.00 | 24.5 | 2.50 |
| 1400 | 25.30 | 27.54 | 25 | 2.54 |
| 1500 | 24.80 | 27.00 | 24.5 | 2.50 |
| 1600 | 23.80 | 25.93 | 24 | 1.93 |

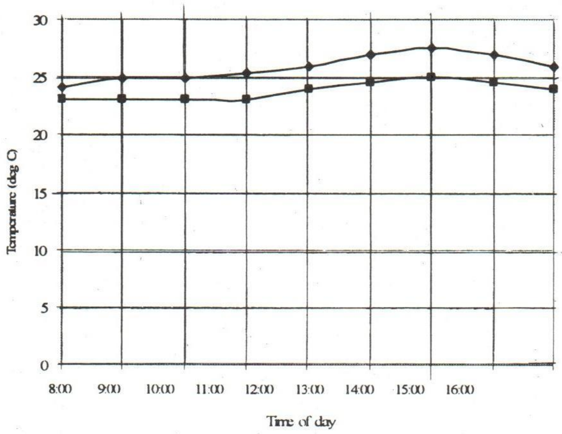


Fig. 4 Results for the 130th Day (9th May 2006)

Table 5 Results for the 131st Day (10th May 2006)

| Time (hrs) | Calculated Sol-air temp. (°C) | Predicted internal temp. (°C) | Measured internal temp. (°C) | Difference between predicted and measured temp. (°C) |
|---|---|---|---|---|
| 0800 | 23.30 | 25.39 | 22.0 | 3.39 |
| 0900 | 23.80 | 25.93 | 22.5 | 3.43 |
| 1000 | 22.80 | 24.85 | 22 | 2.85 |
| 1100 | 24.30 | 26.47 | 24 | 2.47 |
| 1200 | 24.80 | 27.01 | 24.5 | 2.51 |
| 1300 | 25.80 | 28.08 | 25.5 | 2.58 |
| 1400 | 27.80 | 30.23 | 25.5 | 4.73 |
| 1500 | 27.80 | 30.23 | 26 | 4.23 |
| 1600 | 27.80 | 30.23 | 26 | 4.23 |

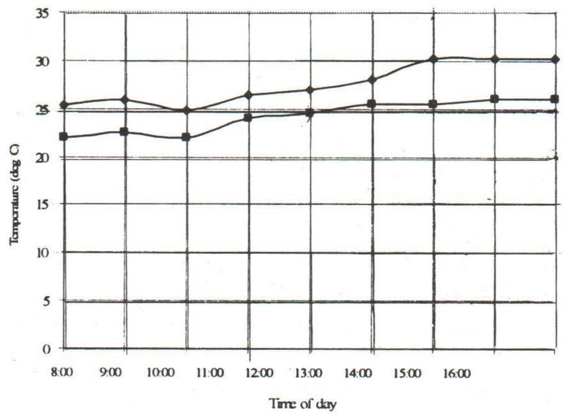


Fig. 5 Results for the 131st Day (10th May 2006 )

Legend:

- ◆ Predicted internal temperature (°C)
- ■ Measured internal temperature (°C)

## Conclusions

Since the mathematical model was able to predicted temperatures which have been verified to a reasonable level of accuracy, it can be used to predict temperatures in other similar designs of naturally ventilated poultry houses. The value of the model is that it allows generalisations and may be used to predict temperatures without the need for experimentation. There may then be substantial savings, in terms of time and money, by using this model as a management tool for poultry farmers.

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## Notation

$A_n$ area of a given building element, $m^2$

$A_v$ area of a ventilation opening, $m^2$

$C_a$ specific heat capacity of dry air, J/kg °C

$C_c$ calorific value of charcoal, J/kg

d average of the maximum possible hours of day length, hours

D average daily hours of bright sunshine, hours

E effectiveness of opening for ventilation due to wind forces

F heat transfer coefficient of the perimeter of a floor, W/m°C

$h_c$ heat transfer coefficient (outside), W/m$^2$ °C

$h_{fg}$ latent heat of vaporisation, J/kg

H minutes from true solar time noon, min

$H_o$ average extraterrestrial solar radiation for the location, W/m$^2$

I average radiation intensity, W/m$^2$

$I_{sc}$ solar constant (1367 W/m$^2$)

$K_t$ coefficient equal to lower critical temperature, °C

$m_a$ mass of the air in the building, kg

$m_b$ body mass of bird, kg

$M_a$ mass flow rate of ventilating air, kg/s

$M_c$ rate of mass consumption of charcoal, kg/s

N day of the year

N number of birds

P perimeter of a floor, m

$q_b$ total heat loss through the building fabric, W

$q_{bf}$ heat loss through floor perimeter, W

$q_{bw}$ heat loss through the massive walls with a time lag, W

$q_e$ heat produced by equipment within the shelter, W

$q_l$ latent heat absorbed for evaporation, W

$q_s$ sensible heat produced by the birds, W

$q_{sup}$ supplemental heat, W

$q_t$ total heat production by birds, W

$q_v$ difference between the outside and inside sensible heat content of air, W

$q_{vo}$ sensible heat content of outside ventilating air entering the building, W

$q_{vi}$ sensible heat content of inside air, W

$Q_w$ ventilation rate due to wind forces, m$^3$/s

T time, s

$T_i$ temperature inside the building, °C

$T_o$ Sol-air temperature, °C

$T_{om}$ mean measured outside temperature, °C

$T_\psi$ temperature of outside air, at a time $\psi$ hours before (also sol-air temperature), °C

$U_n$ heat transfer coefficient, W/m$^2$ °C

V velocity of wind, m/s

v specific volume of air, m$^3$/kg dry air

$W_i$ water content of internal air, kg/kg of dry air

$W_o$ water content of external air, kg/kg of dry air

Y meat and egg production in poultry, kg/day

$\alpha_s$ solar absorbance of a surface

$\delta$ declination

$\mu$ decrement factor

$\varphi$ latitude

$\psi$ time lag, hours

$\omega$ hour angle

$\omega_s$ solar sunset hour angle