To the Graduate Council:

I am submitting herewith a dissertation written by Nazar Jabrail Alias entitled "Environmental Control of Poultry Buildings for Minimum Energy Input." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Agricultural Engineering.

Luther R. Wilhelm

Luther R. Wilhelm, Major Professor

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ENVIRONMENTAL CONTROL OF POULTRY BUILDINGS
FOR MINIMUM ENERGY INPUT

A Dissertation

Presented for the

Doctor of Philosophy

Degree

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Nazar Jabrail Alias

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ABSTRACT

A computer model was developed to simulate some of the environmental factors in poultry laying buildings. The geometric shape and building orientation were also included in this study.

Data were collected from three existing buildings and compared with the results of the computer model.

The main purpose of this research was to analyse the effect of the environmental and geometrical factors on energy consumption. The temperature inside the building was the main factor and was considered the response variable in the analysis of the energy consumption.

It was found that: (1) proper insulation and ventilation would help conserve the heat produced by birds and higher inside temperatures could be maintained, (2) no artificial heating during winter would be needed in regions where the outdoor monthly average temperature was above zero ^{o}C if a bird density of 0.03 to 0.06 m^2/bird was used, (3) the best orientation was the east-west direction of the major axis with roof facing south, and (4) reducing the roof slope would help maintain slightly higher inside temperatures during winter and lower inside temperatures during summer.

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CHAPTER I

INTRODUCTION

The energy required for heating and ventilating farm buildings constitutes an important segment of energy use in agricultural operations. With the limited availability of fossil fuels, methods to improve farm buildings for increasing energy efficiency in livestock systems are becoming necessary.

The first step for energy conservation in farm buildings is to study the environmental and construction factors affecting energy consumption. These factors are: (1) insulation, (2) ventilation, (3) heating and cooling, (4) lighting, (5) building orientation, (6) design of building and building materials, and (7) heat production (e.g. animals) in the building.

Insulation material plays a very important role on energy input. Farm structures in most countries of the world were build without considering the amount of insulation required for energy efficient design in that region. Sometimes, farmers don't even realize the importance of insulation for their buildings. Insulation helps reduce the amount of heat loss from buildings and keep buildings warm during winter. It also reduces the heat stress during summer, and protect animals from sudden changes in weather conditions.

In poultry buildings, energy is needed for two purposes: (1) to ventilate the building for maintaining acceptable temperature, moisture level and ammonia concentration; and (2) to heat buildings during winter so that feed consumption will be reduced. A significant portion of this energy goes into ventilation. Therefore, a proper performance and timing of the ventilation system by setting thermostats to control the operation of the ventilators would help reduce the energy consumption.

Solar energy is another factor needing investigation. To make optimum use of this energy source, buildings should be designed and constructed to gain maximum solar radiation during winter and minimum radiation in summer, if possible. Four factors seems to influence the design of buildings for the best use of solar energy. These factors are: (1) orientation of the building, i.e. the angle that the major axis of the building makes with south, (2) slope of roof, (3) shape of building, (4) ventilator location (e.g. on south facing wall vs. on north facing wall).

There is no need for supplemental heating in poultry laying houses if the temperature inside the house can be kept above freezing. Bird density is the key toward keeping the building warm enough during winter. As the bird density increases, the sensible heat produced increases, and higher temperatures inside the house can be maintained. However, increasing the bird density creates the problem of maintaining the moisture level inside the house within desired limits. This necessitates higher ventilation rates and more energy consumption for ventilation. Thus, all the above factors should be examined, and studied together to evaluate the effect of each factor and their interactions.

The specific objectives of this study were:

1. To evaluate and determine the insulation requirement in poultry buildings.
2. To develop a computer model for energy balance analysis considering the energy factors previously noted.
3. To minimize the energy input through studying the various factors involved in the design and operation of poultry buildings.

CHAPTER II

REVIEW OF LITERATURE

Until the last decade, most of the research on farm structures and environment did not include solar radiation as an energy source for heating or cooling farm buildings. The only objective considered was to design buildings or animal shelters to get rid of sun heat during summer. The reasons for that approach was the ready availability of low cost fuel.

As early as the turn of the century, Woodward (1902) calculated the amount of solar heat received during one day on one square foot of the north, south, east, west walls, and on the flat horizontal roof of buildings. The total heat received for three different houses of the same volume were compared. The first was a perfect cube in shape. The second was a rectangular house placed with its longest dimension on an east-west axis, called the best position. The third had the same dimensions as the second, but turned around such that its longest dimension was north and south, called the worst position. It was found that, in comparison to the other houses, the east-west oriented house, received the lowest amount of solar radiation during summer and the highest amount during winter. The north-south oriented house received higher amounts of radiation during summer than it did during the winter. However, the cubical house received only slightly higher radiation during the summer than it did in the winter.

Based on this result and other calculations, Woodward proposed a useful relationship for proportioning the dimensions of a house oriented such that the major axis is in the east-west direction.

The relationship was:

a:b:c = N:E:T

where:

N = the average daily intensity of heat on the north and south faces added together.

E = the average daily intensity on the east and west faces together.

T = the average daily intensity on the roof of the house.

a = the width of the house north and south.

b = the length east and west.

c = the height.

He further mentioned a positive advantage in not shading the south face by trees or other artificial means, because in winter, when the greatest amount of sunshine is very desirable, most of it is received on the south face. Also, a roof projecting three feet will keep the sun off the wall during summer, while in winter the shading will be much less because the sun is low in the south.

Griffin (1959) and Neubauer et al. (1964), studied the effect of different paint colors on roof temperature. Their research included measurement of solar radiation and wall and roof temperatures for different orientations. Both Griffin and Neubauer et al. concluded that the east and west walls received more radiation and reached higher temperature than the north or south facing walls. The black and other dark-colored roofs became very hot, while white, light colors and shiny metals were much cooler. Light-colored shades, especially concrete walls, were effective in heat control.

The importance of size, shape, and orientation to reduce building solar heat gain in summer has been investigated and researched thoroughly by Neubauer et al. (1966, 1968a, 1968b, 1969a). Their research included building models of different shapes and sizes oriented in many directions. Results indicated that when a rectangular building was oriented east-west with large area exposed to the north and south, the interior air temperature of the building was considerably less than for the same shape rectangular building oriented north-south with large area exposed to the east and west. When a rectangular building oriented north-south had a light reflective roof, the benefit of the reflective roof was not significant compared to the large increase of solar radiation incident on the walls. Neubauer's work also focused on the effect of many different shaped model buildings such as quonsets, domes, cylinders, parallelepipeds, cubes, wedges, etc. The research was conducted under California summer conditions. Results indicated the dome to be significantly hottest, followed by the quonset, wedge, and cube.

Neubauer (1969b) conducted his research to study further the effect of shapes and orientation of houses on the interior temperature of the building. He found that a house facing south with roof overhangs had the thermal advantage of receiving the warm radiation of the sun in winter. The roof overhang above the south walls and windows was adequate for shading during summer months. His simple rule-of-thumb stated that "the south overhang should be about 2 percent of the latitude in degrees times the window height in inches." On building shapes, he mentioned that gable roofs with the major axis oriented in the north-south direction, and the hemispherical dome, were extremely hot shapes. The coolest buildings were the rectangular models with the east-west dimension about three or four times the north-south dimension.

Neubauer also studied other methods for reducing interior temperature during summer. One method was by tilting or leaning of the house toward the south, so that only the roof was exposed to the sun at noon. Another method was using a double roof with a white top surface. These methods were less effective on inside temperature compared with the effect of the orientation and the shape of the building.

Reece (1974) studied the effect of insulation on energy consumption in poultry houses. Two broiler houses were compared. The first had an overall U-value of 1.3 BTU/hr Ft^2 ^oF (7.38 w/m^2 ^oK), and was identified as "without insulation." The second had an overall U-value of 0.12 BTU/hr Ft^2 ^oF (0.68 w/m^2 ^oK). Under cold weather conditions, the heat lost through walls and ceiling of the first house was equal to the heat produced by birds, and no heat was available to heat the ventilating air and to remove the moisture produced by chickens. Thus, supplementary heat was required. In the second house, the heat lost through walls and ceiling was only about (15) percent of the heat produced by the chickens. What was left of this heat could raise the ventilating air temperature 30^o F (17^o C). The ventilation would also help in lowering the moisture content of air to 80 percent relative humidity. Reece concluded that insulation would be the best solution for maintaining higher temperatures and acceptable moisture levels in poultry buildings.

Hans et al. (1977) simulated the truss-frame house to study its thermal performance. The test conditions covered investigations on seven design variants. Six of them were oriented at 20° S-SW. The study included different numbers of glazed windows layers and different window to floor area ratios in each house. The seventh house was of the Arkansas energy saving house design at average orientation. Four of the six houses were of the truss-frame type, and the other two were of the Arkansas-frame type. Energy management and conservation appeared to be affected by the insulation level of the house.

Hans et al. reported that the fuel demand for similar designs and identical internal gain levels may vary by as much as 50 percent and more depending on such factors as air leakage control, solar gain utilization, and night protection for glass areas.

Buffington (1978) developed a computer program to simulate the heat extraction and addition rates of residential buildings for summer and winter. The effect of solar radiation on conduction was modeled according to information and data given in 1972 ASHRAE handbook of fundamentals by using the sol-air temperature for each wall orientation in the model in lieu of outside air temperatures. Two houses were compared. One of them called the low-energy house, in which the ceiling insulation was 17.8 cm of mineral wool, the wall insulation was 1.9 cm polystyrene, has the orientation east-west and the inside temperature was 25.5^{0} C. The second was the high-energy house with 8.9 cm mineral wool ceiling insulation, no wall insulation, north-south orientation, and 23.3^{0} C inside temperature. Some other features were also different between the houses. The data was for a summer day in Gaiensville, Florida. It was found that the heat extraction rate of the low-energy house was 69 percent less than the heat extraction rate of the high-energy house. It was illustrated that if any technique was used to reduce energy consumption in summer, it would be about as effective in conserving the energy required during winter. The heating system in the high-energy house required a capacity of about 13,000 watts greater than that of the low energy house.

Ceiling insulation of 17.8 cm reduced the heat extraction rate for the building by 21 percent compared to the no insulation. Wall insulation of 1.9 cm of polystyrene foam reduced the heat extraction by 4 percent.

The benefit of the east-west orientation compared to north-south orientation was a 7 percent decrease in the heat extraction required. The east-west orientation was also beneficial in reducing the heating requirement in winter.

Mahoney _et al_. (1978) conducted a study on solar pattern and air flow for different shapes of open front buildings. The first shape was the standard gable roof, 3/12 slope, with vent panels in the upper half of the south facing roof slope. The second shape had the ridge of building one third back from south entry, back slope 3/12, front slope

6/12. The third had the ridge one fourth back from south entry, back slope 3/12, and front slope 9/12. To study the air movement pattern, plexiglass models of the three shapes were constructed and placed in a smoke chamber. The roof panel openings used in the smoke chamber were determined by sun angle such that, it would allow optimum direct solar radiation. It was found that, buildings with roofs one fourth or one third back from the south front, and louvers in the entire south facing roof give better sun light patterns and solar drying potential than a gable roof with one half the south slope in roof louvers. Also the air movement at floor level was better for the two buildings with steep south sloped roofs as compared to a standard gable roof with roof louvers opened 30^{0} to 50^{0} to the horizontal.

Buffington and Skinner (1978) used computer simulation techniques to study the effects of solar radiation and wind velocity on heat gains and losses of an agricultural structure for four different orientations in seven different locations. Two building constructions with different wall and ceiling insulations were considered. The low insulation house was considered as a control. The second house with high insulation was called the low-energy house. It was concluded that, the east-west orientation yields the lowest seasonal heat loss in fall and winter. The other important conclusions were: (1) when a structure was well insulated and the doors were properly weather-stripped, both conduction and infiltration gains and losses were reduced compared with structures with less energy efficiency; (2) the variation in heat transfer was reduced as a function of orientation in the insulated, weatherstripped structure; (3)

the NE-SW, and the N-S orientations resulted in a high conduction heat gain during the spring and summer seasons, and a higher heat loss during the fall and winter seasons.

CHAPTER III

COMPUTER SIMULATION OF A POULTRY BUILDING

I. GENERAL CONSIDERATIONS

The positioning of buildings with respect to sun rays (that is, the earth-sun angular relationships) has long been studied. Building orientation needs to be considered in any building design, because it influences the amount of solar radiation received on the walls and roof of the building.

The shape and size of the building also play an important role in the design for best comfort. Mathematically, for buildings of similar shape and orientation, a small house is heated and cooled more readily by the sun than a large one. This is because of the higher ratio of building volume to surface area for the large house compared to the small one. A perfect cube has the lowest surface area to volume ratio compared to other square floor shapes of different heights. However, it seems impractical to design a cubic shaped building for animal housing.

To experimentally evaluate the effects of shape, size, building orientation, insulation, and ventilation rate on the inside temperature and heat gain or loss of buildings, research would involve constructing at least fifty buildings to include the above mentioned factors. Such experimental design and evaluation would be unbelievably expensive and time consuming. Simulation models for this case would be the best approach for evaluating the effect of each factor on building design.

A computer program was developed to simulate the various factors which affect the inside air temperature of buildings. The building was assumed to house 20,000 birds with constant width and height of 12.0 m and 3.5 m respectively. The factors considered were:

1. Area per bird
2. Slope of roof
3. Orientation of building
4. Building insulation
5. Ventilation rate

Each factor was varied keeping the rest constant. The flow chart of the main program, Figure 1, shows the simulation method used. The model computes average temperatures for day-time hours. All computer variables are identified in Appendix B.

II. PARAMETERS SIMULATED

Area Per Bird

The area per bird or the bird density was given careful attention, since it affected the sensible and latent heat produced by birds, and was the main heating source for the building during the winter months.

The current trend in designing poultry laying houses for reduced labor cost and increased production involves a very low bird density, (0.04 to 0.07 m^2/bird).

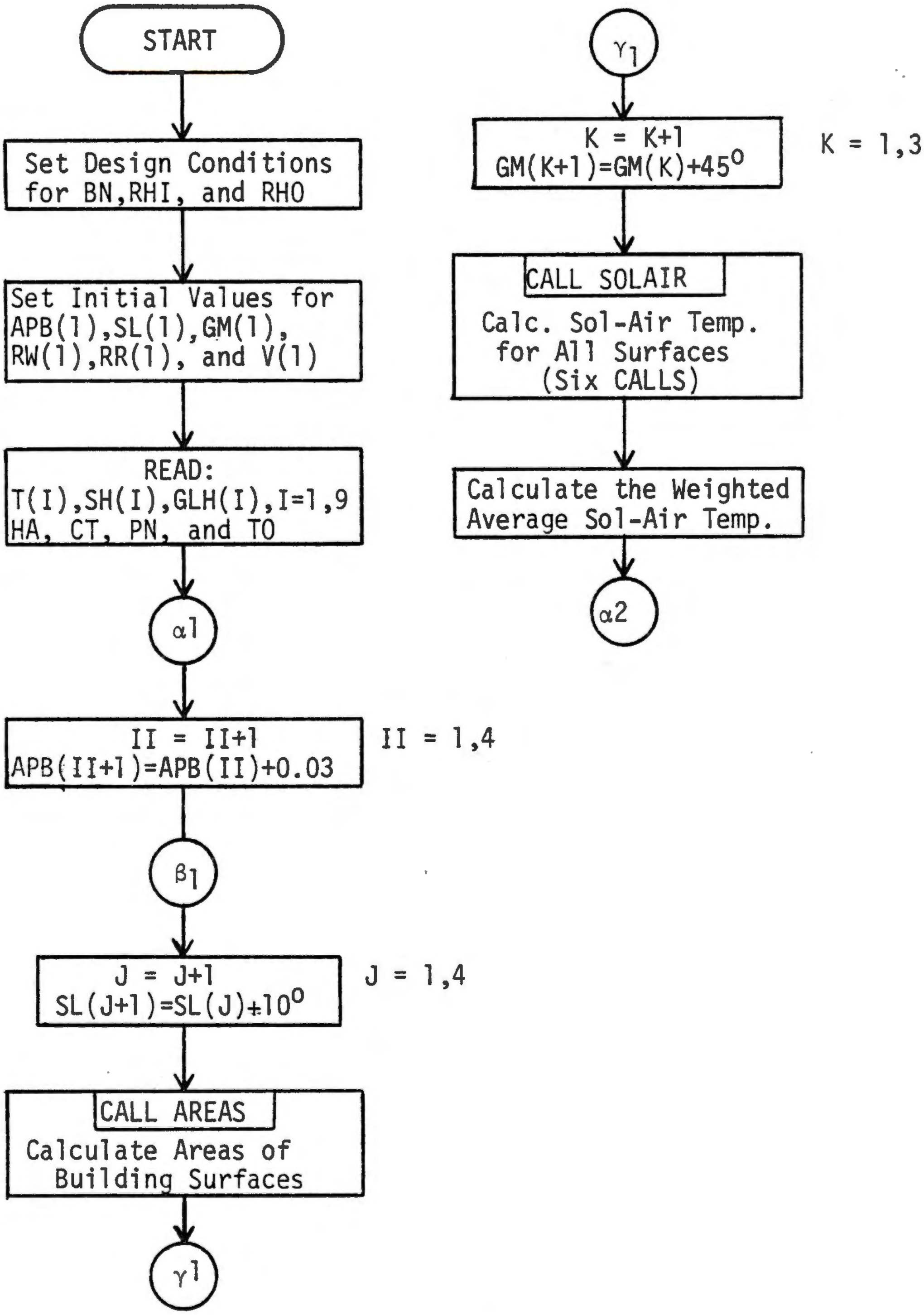

Figure 1. Flow Chart of the Main Program. All Variables are Explained in Appendix B.

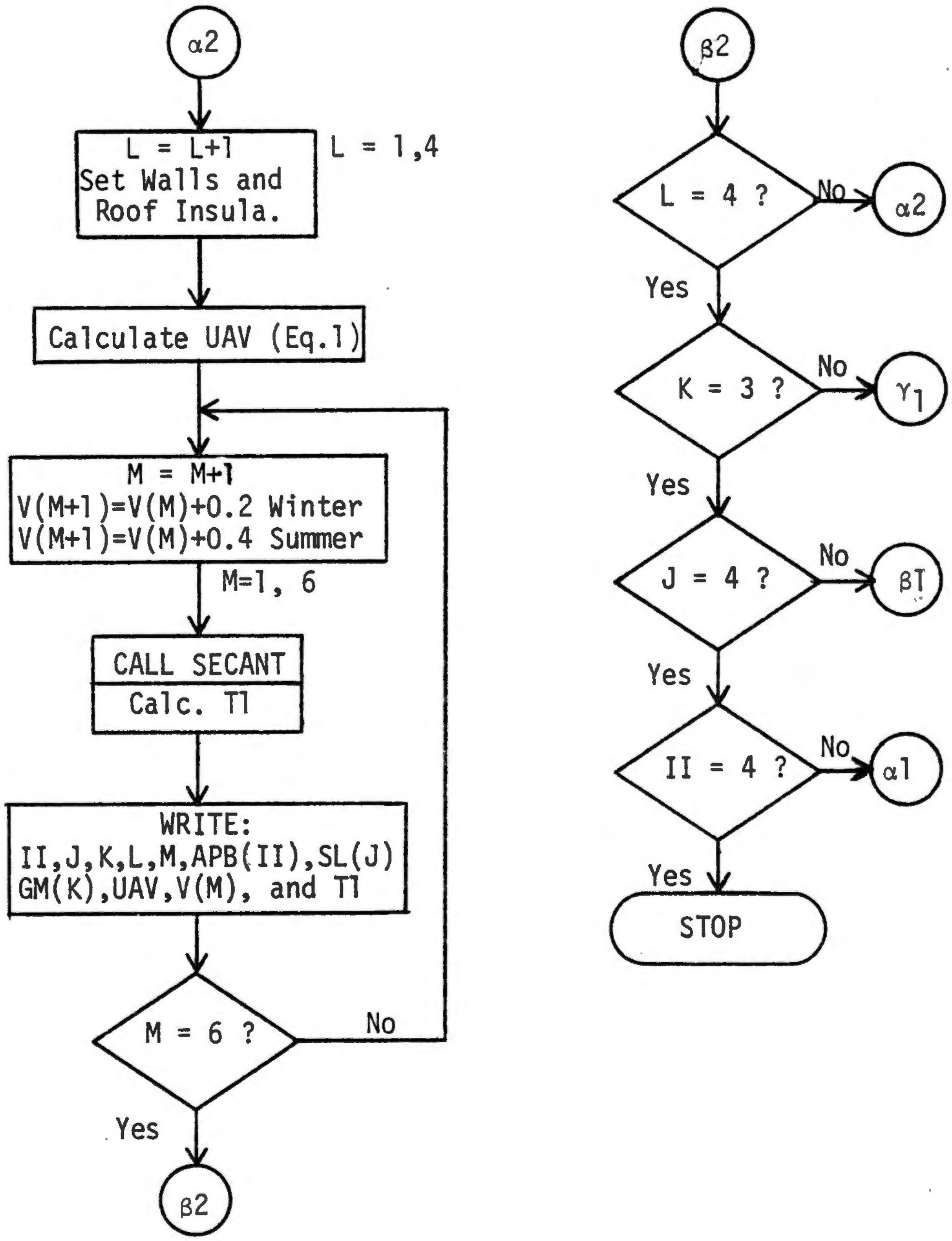

Figure 1. (Continued).

For the purposes of studying the effects of this factor on inside conditions for both winter and summer seasons, a range of 0.03 to 0.12 m^2/bird was considered.

Slope of Roof

Since the amount of solar radiation on any surface depends mostly on the angle at which the sun rays strike that surface, varying the roof slope would affect the interior conditions of the building. However, there is only a limited practical range for roof slope, because steep roofing design would involve high framing and construction cost. Also horizontal type roofing would require heavy and expensive beams for supporting large roof spans.

The minimum roof slope considered in this study was 10 degrees from horizontal. This slope was increased to a maximum of 40 degrees in steps of 10 degrees.

Building Orientation

It is very easy to determine the best orientation of a single surface for the minimum or maximum solar radiation. However, when all the surfaces for different building shapes and orientations need to be considered, the problem becomes very complicated, especially if the optimum conditions for year round seasons are to be determined. The orientation here is defined as the angle the major axis of the building makes with the south.

Two types of roofs were considered in this study. The first was the gable-type and the second was the shed-type. In the gable-type, three orientations were considered: (1) N-S orientation of major axis, (2) NE-SW orientation, and (3) E-W orientation. In the shed-type, five cases were considered: (1) N-S and roof facing east, (2) NE-SW with roof facing SE, (3) E-W with roof facing south, (4) NW-SE and roof facing SW, and (5) N-S with roof facing West. The above orientations for both types of roofing were considered to cover all important cases in farm buildings.

Building Insulation

Building insulation seems to be the most important factor affecting the energy consumption for heating and ventilation as well as the comfort of animals. Increasing wall and roof insulation helps in reducing the building heat gain in summer. It also conserves the heat produced by birds during winter, thus raising the temperature inside the building. Higher inside temperatures would allow for higher ventilation rates to control the moisture and ammonia concentration.

At the same time, it may be economically less efficient to use heavy insulation. Thus, it is very important to study this factor carefully to predict its performance under both summer and winter conditions.

Four different levels of building insulation were chosen. The insulation level (overall U-value) for buildings with different wall and roof insulation materials are listed in Table 1.

Ventilation Rate

Ventilation rate adjustment for the different outdoor and indoor conditions is the most critical factor in managing farm buildings. It

TABLE 1

THE OVERALL U-VALUES OF BUILDING FOR VARIOUS LEVELS OF WALLS AND ROOF INSULATION USED

Walls		Roof		U-Value[2] $w/m^2\ ^oK$	
R-Value[1] $m^2\ ^oK/w$	Wall Insulation Materials	R-Value[1] $m^2\ ^oK/w$	Roof Insulation Materials	Shed-Type	Gable-Type
0.22	Metal siding only	0.22	Metal roofing only	4.55	4.55
0.22	Metal siding only	0.92	2.54 cm glass fiber	1.75	1.50
0.86	2.54 cm expanded polystyrene, molded beads	0.92	2.54 cm glass fiber	1.15	1.10
0.86	2.54 cm expanded polystyrene, molded beads	1.62	5.08 cm glass fiber	0.80	0.75

[1]Outside surface resistance to heat flow was not included in determining R and U-values.

[2]The overall U-value of building was calculated using the equation:

$$UAV = ATOT/\ (RW(AW) + RR(AR)) \tag{1}$$

where:

ATOT = total surface area of building, m^2

RW and RR = resistance values for heat flow for walls and roof respectively, $m^2\ ^oK/w$

AW and AR = areas of walls and roof respectively, m^2

is not always correct to use higher ventilation rates to lower the inside temperature or control moisture level. The main factor involved here is the enthalpy difference between the inside and outside air. During summer months, the outside enthalpy of air sometimes gets higher than the inside enthalpy. In this case, it would not only waste energy to ventilate, but it will result in higher inside temperatures and possibly higher moisture levels.

Adjusting the thermostat for different weather conditions is important. This requires a better knowledge of how to operate and control the ventilation system. At least two thermostat settings are required during the year. Adjusting thermostats more than twice a year would be very beneficial for energy consumption and animal comfort. Professional guidance in this field is needed.

For the purpose of carrying out the theoretical analysis of this research, two different sets of ventilation rates (one for winter and one for summer conditions) were used. For winter, a minimum ventilation rate of 0.25 cubic meter per second per thousand birds was used. This minimum was increased to a maximum of 1.2 in steps of 0.15 to 0.2 m^3/sec-1000 bird. For summer, the minimum was 0.6, the maximum was 2.6, and a step size of 0.4 m^3/sec-1000 bird was used.

III. BUILDING AREAS

The standard widths and heights in the current design of poultry laying houses are about 12.0 m and 3.5 m respectively. These values were used in a subroutine developed to calculate the areas of the different building surfaces. Figure 2 is a flow chart of the subroutine AREAS used for the calculations. Figure 3 shows the dimensions and areas assigned to all building surfaces.

IV. SOLAR RADIATION ON TILTED SURFACES

Liu and Jordan (1962), developed a simple method for estimating the average daily radiation for each month of the year on surfaces facing the equator. Klein (1977) adapted that method and extended his work for the estimation of the average daily radiation for the month on surfaces east or west of south.

The method simply involves the determination of the overall ratio of total radiation on the tilted surface to that on a horizontal surface. The total radiation on the inclined surface can be found by using equation 2.

$$HT = RALL\ (HA) \tag{2}$$

where:

HT = total daily radiation on tilted surface, mega jouls per square meter (MJ/m^2)

HA = total daily radiation on horizontal surface, MJ/m^2

RALL = the overall ratio of daily average radiation on the inclined surface to that on a horizontal surface.

The above method was adapted in this research to determine the total monthly average daily solar radiation on building surfaces. Figure 4 shows the flow chart for the subroutine SOLAIR. This subroutine was developed to calculate RALL and HT for each month. These

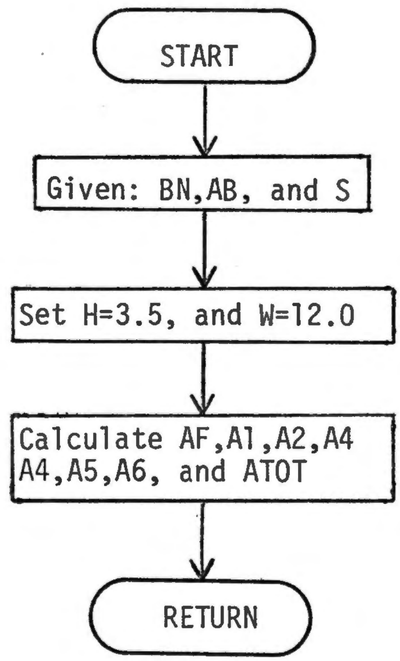

Figure 2. Flow Chart for the Subroutine AREAS. (A Subroutine to Calculate Building Surface Areas for Different Bird Densities and Roof Slopes.)

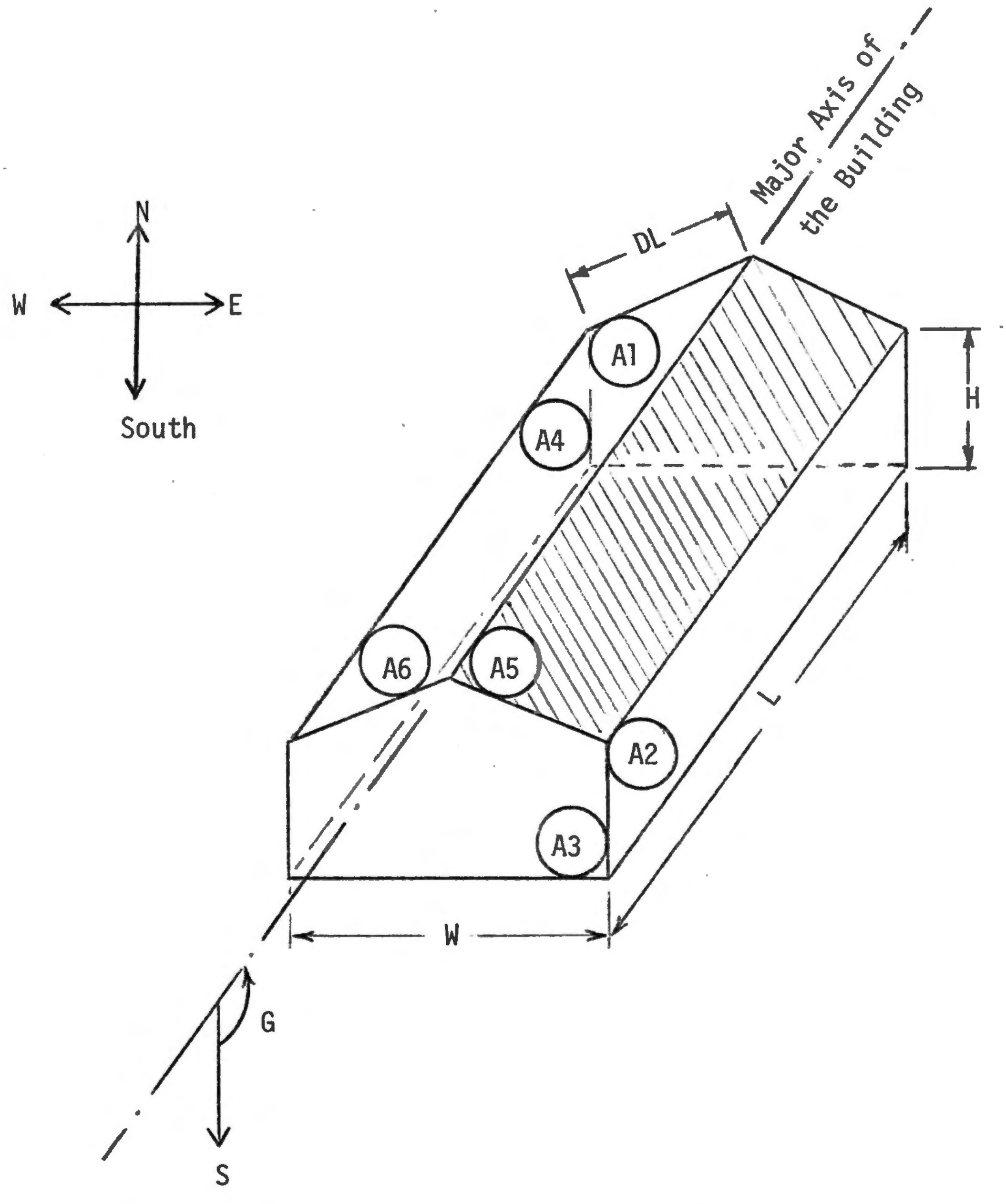

Figure 3. Building Dimensions and Areas Assigned to Different Surfaces.

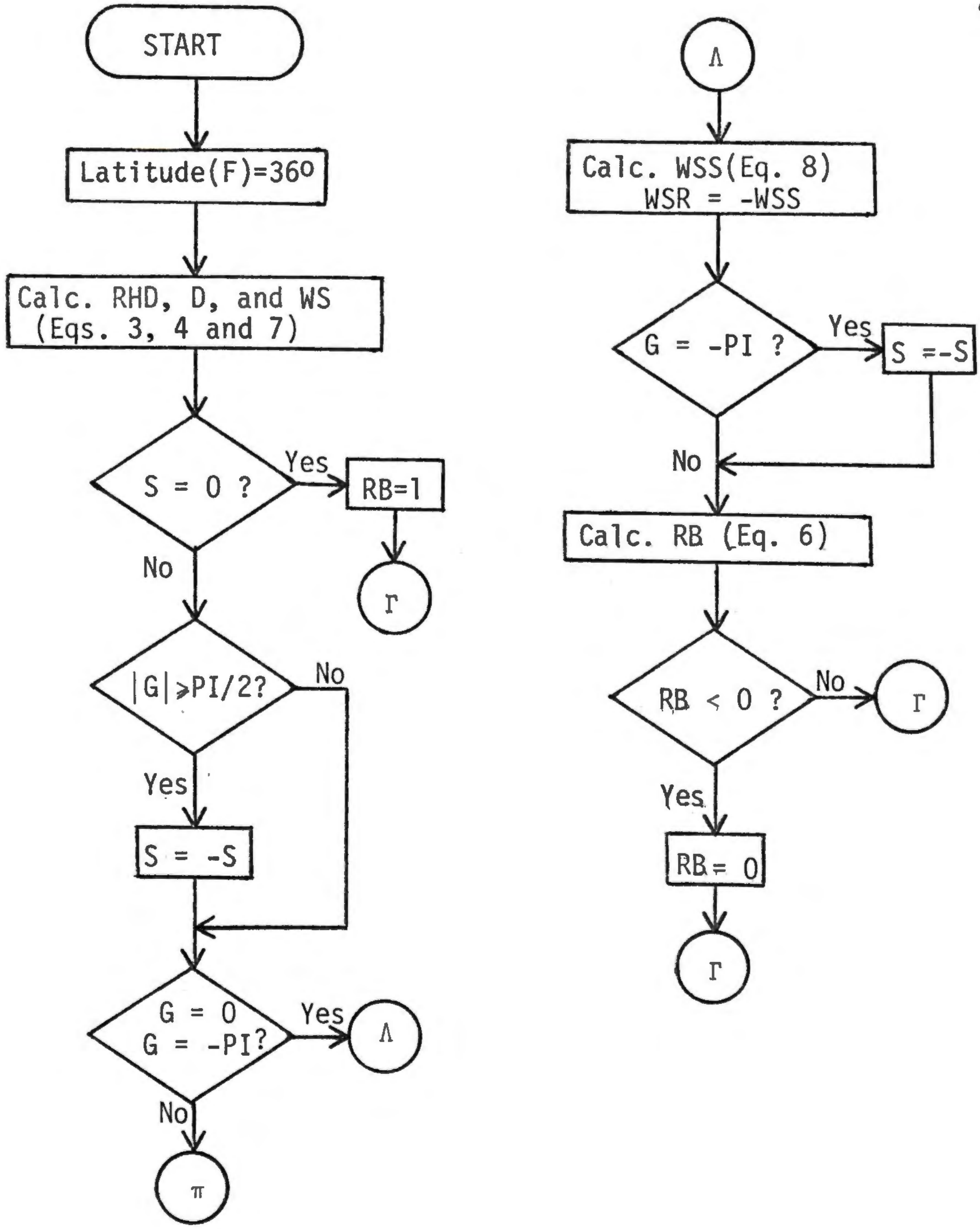

Figure 4. Flow Chart of the Subroutine SOLAIR. (A Subroutine to Compute the Monthly Average Daily Solar Radiation and the Sol-Air Temperature for a Given Surface.)

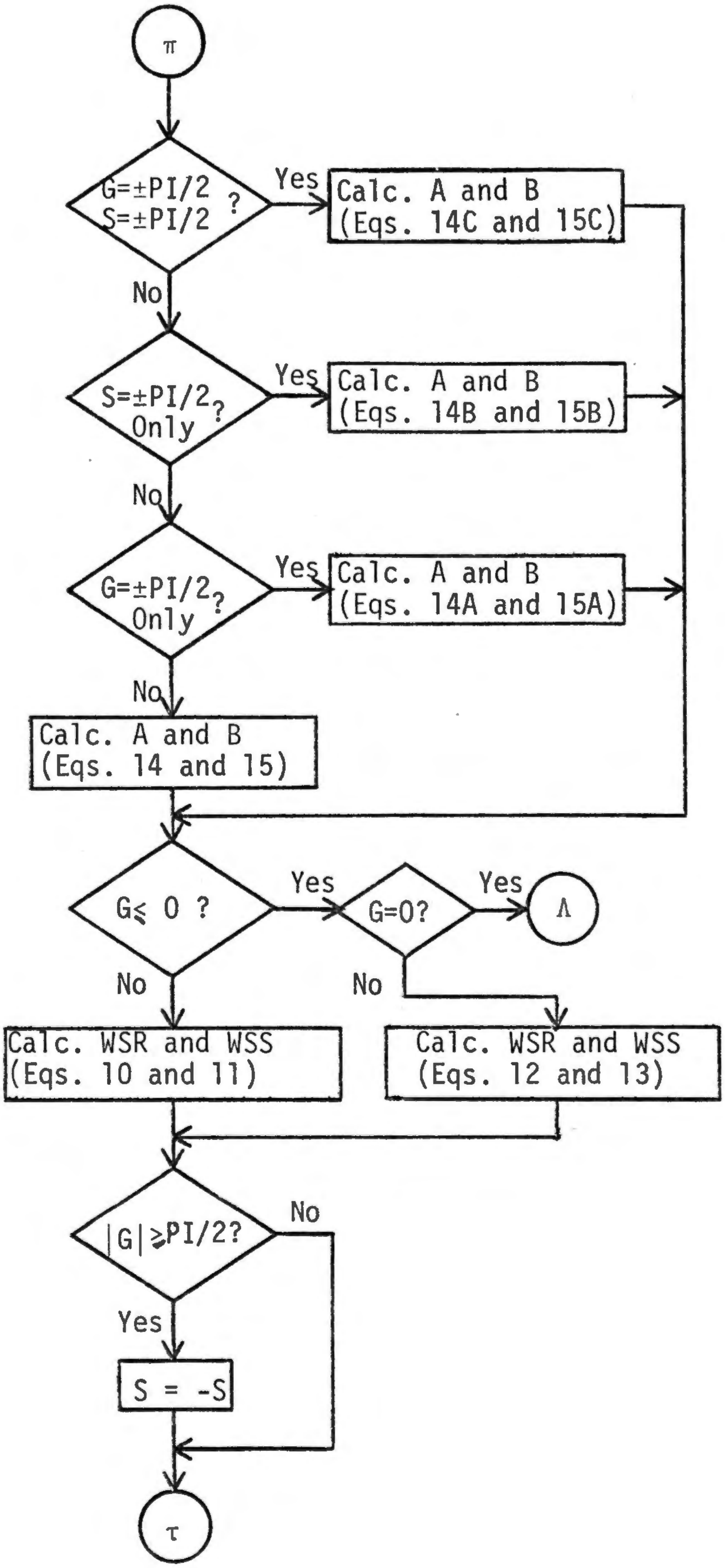

Figure 4. (Continued)

values were then used to calculate the sol-air temperature on various surfaces. The calculations were carried out following these steps:

1. Ratio of Diffuse Radiation to Total Radiation (RHD). Liu and Jordan (1962) developed a correlation equation for RHD in terms of the ratio of the monthly average daily total radiation to the extraterrestrial daily insolation (CT).

$$RHD = 1.390 - 4.027\ (CT) + 5.531\ (CT)^2 - 3.108\ (CT)^3 \qquad (3)$$

Data for CT in the above equation and HA in equation 2 are available for 171 cities in the United States (Beckman et al., 1977).

2. Declination of Sun. The declination angle was determined for the average day of each month using equation 4 below:

$$D = \frac{23.45\ \pi}{180} \quad (\mathrm{Sin} \quad (\frac{2\ \pi\ (284+PN)}{365})) \qquad (4)$$

where:

D = the declination angle of sun, radians

PN = the day of the year given for each month as recommended by Klein (1977) and listed in Table 2.

3. Ratio of Beam Radiation on Tilted Surfaces to that on a Horizontal Surface (RB). The following cases were considered.

Case 1: Horizontal Surface (slope, S = 0)

$$RB = 1.0 \qquad (5)$$

Case 2: Inclined Surface Facing South (surface azimuth angle, G = 0)

$$RB = (\mathrm{Cos}(F-S)\ \mathrm{Cos}(D)\ \mathrm{Sin}\ (WSS) + WSS\ \mathrm{Sin}(F-S)\mathrm{Sin}(D)) \div (\mathrm{Cos}(F)\ \mathrm{Cos}(D)\ \mathrm{Sin}(WS) + WS\ \mathrm{Sin}(F)\ \mathrm{Sin}(D)) \qquad (6)$$

TABLE 2

RECOMMENDED AVERAGE DAY FOR EACH MONTH, (KLEIN, 1977)

Month	Day of the Year	Date
January	17	January 17
February	47	February 16
March	75	March 16
April	105	April 15
May	135	May 15
June	162	June 11
July	198	July 17
August	228	August 16
September	258	September 15
October	288	October 15
November	318	November 14
December	344	December 10

where:

F = latitude, (taken equal to 0.628 radians (36^{o}) for Knoxville, Tennessee)

S = slope of surface from horizontal in radians, (positive if facing south, negative if facing north)

D = declination, radians

WS = sunset hour angle for horizontal surface, radians

WSS = sunset hour angle for tilted surfaces, radians

WS and WSS were determined using the following two equations:

$$WS = \arccos(-\tan(F)\tan(D)) \quad (7)$$

$$WSS = \text{Min}(WS, \arccos(\tan(F-S)\tan(D))) \quad (8)$$

Case 3: Tilted surfaces not facing south

$$\begin{aligned} RB = {} & ((\text{Cos}(S)\,\text{Sin}(D)\,\text{Sin}(F))\,(WSS-WSR) \\ & -(\text{Sin}(D)\,\text{Cos}(F)\,\text{Sin}(S)\,\text{Cos}(G))\,(WSS-WSR) \\ & +(\text{Cos}(F)\,\text{Cos}(D)\,\text{Cos}(S))\,(\text{Sin}(WSS) - \text{Sin}(WSR)) \\ & +(\text{Cos}(D)\,\text{Cos}(G)\,\text{Sin}(F)\,\text{Sin}(S)\,(\text{Sin}(WSS) - \text{Sin}(WSR)) \\ & -(\text{Cos}(D)\,\text{Sin}(S)\,\text{Sin}(G))\,(\text{Cos}(WSS) - \text{Cos}(WSR)))\div \\ & 2(\text{Cos}(F)\,\text{Cos}(D)\,\text{Sin}(WS) + WS\,\text{Sin}(F)\,\text{Sin}(D)) \end{aligned} \quad (9)$$

where:

G = surface azimuth angle in radians, (the zero point due south, east negative, and west positive)

WSR = sunrise hour angle on tilted surfaces, radians.

When G was negative, WSR and WSS were found using the following two equations:

$$WSR = -Min\ (WS,\ arcos\ (\frac{AB + SORT(A^2 - B^2 + 1)}{A^2 + 1})) \tag{10}$$

$$WSS = Min\ (WS,\ arcos\ (\frac{AB - SORT(A^2 - B^2 + 1)}{A^2 + 1})) \tag{11}$$

For G greater than zero, the following two equations were used:

$$WSR = -Min\ (WS,\ arcos\ (\frac{AB - SORT(A^2 - B^2 + 1)}{A^2 + 1})) \tag{12}$$

$$WSS = Min\ (WS,\ arcos\ (\frac{AB + SORT(A^2 - B^2 + 1)}{A^2 + 1})) \tag{13}$$

where:

$$A = \frac{Cos(F)}{Sin(G)tan(S)} + \frac{Sin(F)}{tan(G)} \tag{14}$$

$$B = tan(D)(\frac{Cos(F)}{tan(G)} - \frac{Sin(F)}{Sin(G)tan(S)}) \tag{15}$$

For G = ± 90 degrees (east or west facing surface) then,

$$A = \frac{Cos(F)}{Sin(G)tan(S)} \tag{14A}$$

$$B = -\frac{tan(D)Sin(F)}{Sin(G)tan(S)} \tag{15A}$$

For S = ± 90 degrees (vertical wall) then,

$$A = \frac{Sin(F)}{tan(G)} \tag{14B}$$

$$B = \frac{tan(D)Cos(F)}{tan(G)} \tag{15B}$$

If G = ± 90, and S = ± 90 (east or west facing vertical walls) then,

$$A = 0 \tag{14C}$$

$$B = 0 \tag{15C}$$

Equations 6 and 9 were derived by integrating the rate of the extraterrestrial radiation on tilted surfaces during the period when the sun is both above the horizon and in front of the surface. This integral was divided by the mean daily extraterrestrial radiation. For further information, refer to Liu and Jordan (1962), and Klein (1977).

4. Determination of the Overall Ratio of Total Radiation (Beam Plus Diffuse) on Tilted Surfaces to that on a Horizontal Surface (RALL). Solar energy text books recommend the following equation developed by Liu and Jordan (1962) to be used for the determination of RALL:

$$RALL = (1\text{-}RHD)(RB) + RHD\left(\frac{1 + \cos(S)}{2}\right) + \rho\left(\frac{1 - \cos(S)}{2}\right) \qquad (16)$$

where:

ρ = ground reflectance, (ρ = 0.2 for ground with no snow, and ρ = 0.7 when ground is covered with snow).

V. SOL-AIR TEMPERATURE

The sol-air temperature approach was used to take care of the incident solar radiation on building surfaces, radiant energy exchange with the sky and surroundings, and the convective heat exchange with outdoor air.

This method is presented in detail in the ASHRAE Handbook of Fundamentals 1972, Chapter 22, page 410. The equation used in ASHRAE to determine the sol-air temperature is:

$$t_e = t_o + \alpha\, I_t/h_o - \varepsilon\, \Delta R/h_o \qquad (17)$$

where:

t_e = sol-air temperature, degree Fahrenheit (^oF)

t_o = outdoor air temperature, ^oF

α = absorptance of surface for solar radiation

I_t = total solar radiation incident on surface, BTU/hr. sq. ft.

h_o = coefficient of heat transfer by radiation and convection at the outdoor surface, BTU/hr. sq. ft. ^oF

ε = hemispherical emittance of the surface

ΔR = the difference between the longwave radiation incident on the surface from the sky and surroundings, and the radiation emitted by a black body at outdoor air temperature, BTU/hr. sq. ft.

The following assumptions were made based on recommendations and data given in ASHRAE:

1. $\varepsilon = 0.9$
2. $h_o = 4.0$ BTU/hr. sq. ft. ^oF
   $= 22.7 \ w/m^2 \ ^oK$
3. recommended values for the absorptance α are 0.45 for light colored surface, and a maximum of 0.9 for a very dark surface.

An α -value of 0.45 was used.

4. recommended values of ΔR are zero and 21.0 BTU/hr. ft.^{2} for vertical and horizontal surfaces respectively.
5. to determine ΔR values for tilted surfaces, and to use the recommended values above, ΔR was assumed to be a function of the cosine of the slope of surface. Thus the term $\varepsilon \ \Delta R/h_o$ become equal to:

$$\frac{0.9 \times 21}{4.0} \ \text{Cos(S)}, \ ^oF = 2.63 \ \ \text{Cos(S)}, \ ^oC$$

6. $I_t = \frac{HT}{TM}$

where:

HT = total daily radiation, mega jouls per square meter (MJ/m^2)

TM = length of day, hr.

The length of day was determined using the following equation:

$$TM = 2\ (\frac{180}{\pi}\ \frac{WS}{C}) \qquad (18)$$

where:

WS = sunset hour angle, radians

C = constant for converting hour angle from degrees to hours, (C = 15 degrees/hr.)

7. the term $\frac{\alpha I_t}{h_o}$ becomes

$$\frac{\alpha I_t}{h_o} = \frac{\alpha HT}{h_o TM} = (0.45\ (HT,\ MJ/M^2)) \div ((4.0,\ BTU/hr\ ft^2\ {}^oF)$$

$$(0.020442\ \frac{MJ/m^2\ {}^oK}{BTU/hr\ ft^2\ {}^oF})\ (\frac{24\ WS}{\pi}))$$

therefore, $\frac{\alpha I_t}{h_o} = 0.72\ HT/WS$

Thus equation 17 in SI units become:

$$TS = TO + 0.72\ HT/WS - 2.63\ Cos(S) \qquad (19)$$

The above equation was used in the subroutine SOLAIR, Figure 4, page 23, to determine the sol-air temperature on tilted surfaces.

VI. SENSIBLE AND LATENT HEAT PRODUCTION ESTIMATION

Data for sensible and latent heat production of laying birds (White Leghorns), was taken from Figure 44 of ASAE Data (1975) and Converted to SI units. The weight of White Leghorn birds was assumed equal to 1.8 Kg. A simple interpolation subroutine (HEAT), was developed to determine the sensible and latent heat produced by birds at temperatures in the range -5 to 35^{o} C. A flow chart of the subroutine HEAT is shown in Figure 5. The following interpolation equations were used:

1. for sensible heat:

$$SH1 = SH(LL) + (SH(LL+1) - SH(LL))(TI - T(LL))/(T(LL+1)-T(LL)) \quad (20)$$

2. for latent heat:

$$GLH1 = GLH(MM) + (GLH(MM+1) - GLH(MM))(TI-T(MM))/(T(MM+1) - T(MM)) \quad (21)$$

where:

TI = temperature inside the building at which the sensible and latent heat need to be determined, ^{o}C

SH1 = sensible heat produced, Kw/1000 Kg of body weight of birds per hour

GLH1 = latent heat produced Kw/1000 Kg-hr.

SH(LL) and GLH(MM) are the sensible and latent heat data at the inside temperature T(LL). Table 3 contains the data used in the subroutine HEAT.

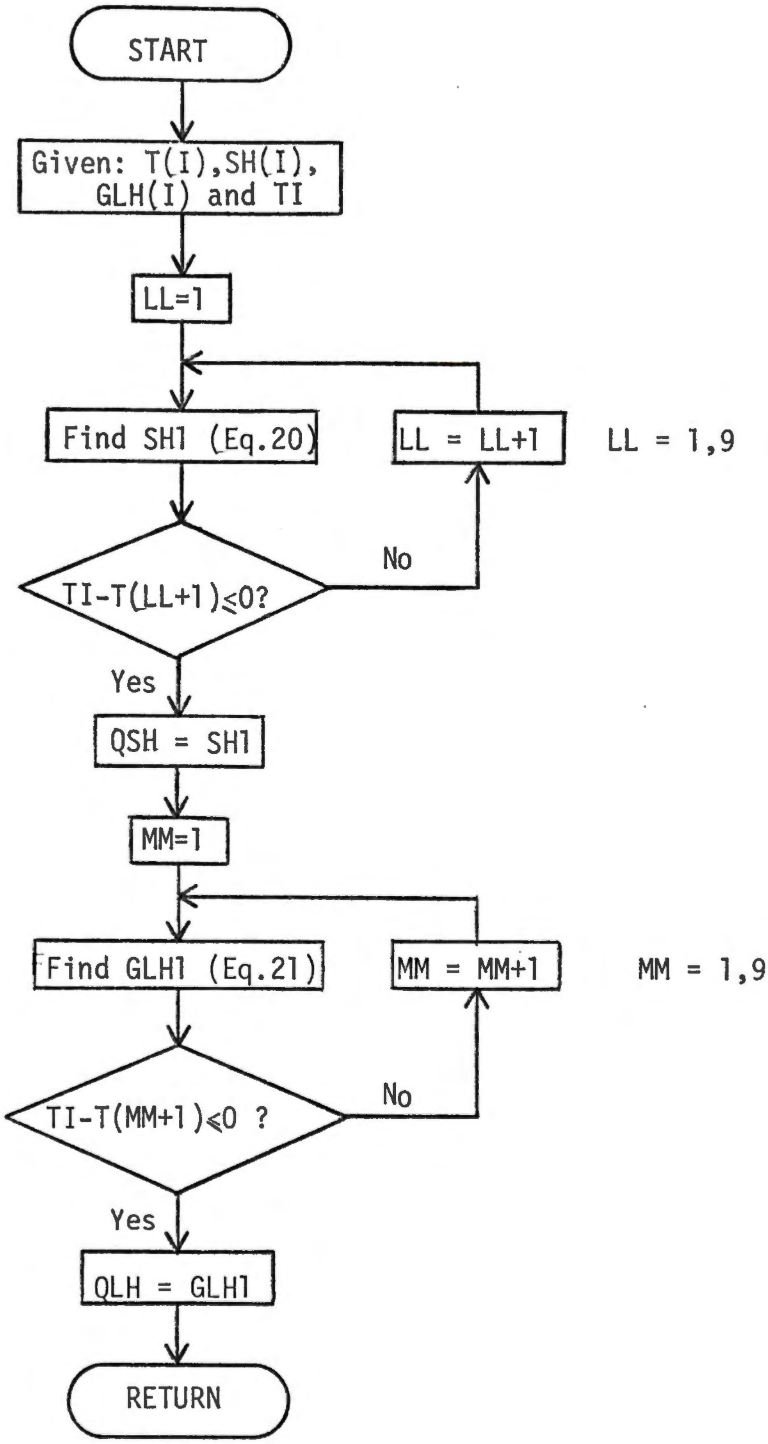

Figure 5. Flow Chart of the Subroutine HEAT. (An Interpolation Subroutine to Find Sensible and Latent Heat Values from an Array of These Values as a Function of Temperature.)

TABLE 3

SENSIBLE AND LATENT HEAT OF BIRDS FOR DIFFERENT INSIDE TEMPERATURES (ASAE DATA, 1975)

Inside Temperature °C	Sensible Heat Kw/1000 Kg- hr	Latent Heat Kw/1000 Kg- hr
-5.0	6.044	1.270
0.0	5.225	1.306
5.0	4.671	1.367
10.0	4.350	1.489
15.0	4.112	1.699
20.0	3.773	1.911
25.0	3.104	2.069
30.0	2.066	2.370
35.0	0.351	3.164

VII. HEAT BALANCE EQUATION

The three main elements that were considered in the heat balance equation were: (1) total heat production by birds (sensible and latent), (2) heat gained or lost by conduction through building walls and ceiling, and (3) heat gained or lost by ventilation.

A subroutine was developed to calculate the three elements previously mentioned for a given inside temperature. The inside relative humidity was taken equal 80 percent. Figure 6 is the flow chart of the subroutine FUNCT used for this purpose.

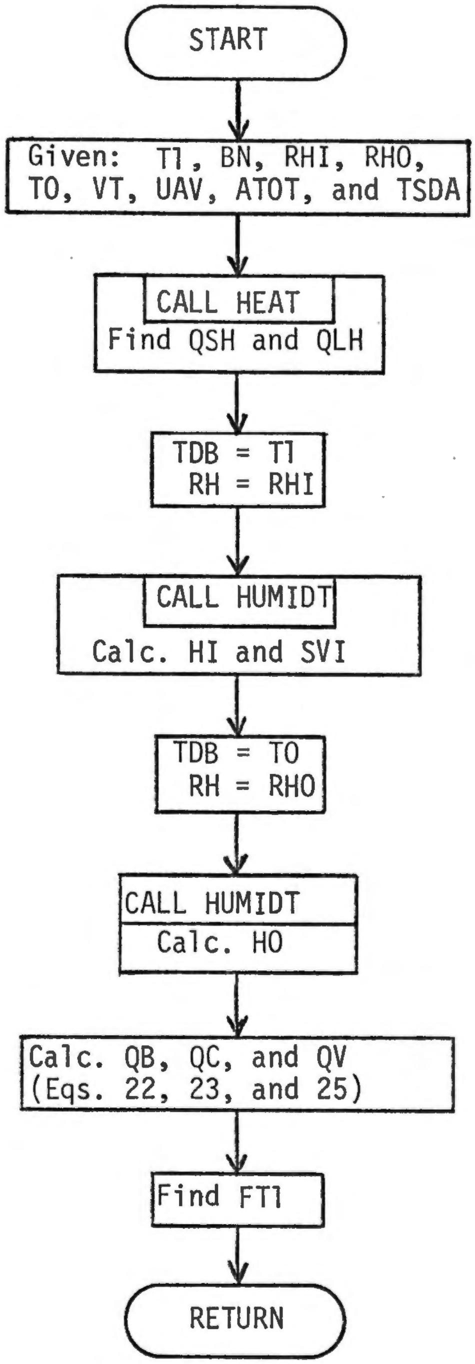

Figure 6. Flow Chart for the Subroutine FUNCT. (A Subroutine to Compute the Heat Produced by Birds and the Heat Gained or Lost by Ventilation and Conduction.)

<u>Sensible and Latent Heat</u>

The heat produced by birds was determined using the following equation:

$$QB = \frac{1.8\ BN}{1000}\ (QSH + QLH)\ (TM) \tag{22}$$

where:

QB = total heat produced by birds, Kwh

BN = bird number

QSH and QLH are the sensible and latent heat produced by birds calculated using the subroutine HEAT, Kw/1000 Kg.

TM = length of day as determined from equation 18.

<u>Conduction Heat Transfer</u>

The heat transferred by conduction through roof and walls was determined based on the sol-air temperature of the outside surface which takes into account the heat of solar radiation on building surfaces. This heat component was calculated using the following equation:

$$QC = \frac{UAV}{1000}\ (ATOT)(T1 - TSDA)\ (TM) \tag{23}$$

where:

QC = conduction heat through walls and roof, Kwh

UAV = the overall thermal conductivity of building excluding the coefficient of heat transfer of outside air to building, $w/m^2\ {}^oK$

T1 = temperature inside the building, ^oC

TSDA = weighted average sol-air temperature of building surfaces, ^oC

TSDA was determined using the equation:

$$TSDA = \frac{TSD1(A1) + TSD2\ (A2) + \ldots + TSD6(A6)}{ATOT} \tag{24}$$

where:

TSD1 through TSD6 are the sol-air temperature of building surfaces 1 through 6 (see Figure 3, page 22), ^{o}C.

A6 = 0, for shed type building

Heat for Ventilation

Based on the enthalpy difference between the inside and outside air, the heat lost or gained by ventilation (QV), was determined using the equation:

$$QV = VT(HI\text{-}HO)/SVI \tag{25}$$

where:

SVI = specific volume of air inside the building, m^3/Kg of dry air

HI = enthalpy of air inside the building, KJ/Kg of dry air

HO = enthalpy of air outside the building, KJ/Kg of dry air

VT = total air flow as determined from the equation:

$$VT = V\ (\frac{BN}{1000})\ (TM) \tag{26}$$

where:

V = ventilation rate, m^3/sec-1000 bird

The properties of air, i.e. the specific volume and the enthalpy of air inside and outside the building, were calculated using special subroutine (HUMIDT) developed by Wilhelm (1976). See Appendix A.

The heat flow in and out the building was modeled using the heat balance equation (equation 27). The three main elements of heat mentioned before should balance each other such that the equilibrium condition of equation 27 can be maintained.

$$QB - QV - QC = 0 \tag{27}$$

VIII. ITERATION PROCEDURE

A special subroutine (SECANT) was developed to iterate for the inside temperature T1. For any set of outside temperature, outside relative humidity, solar radiation, ventilation rate, and building insulation, the iteration, if it converges, would give an inside temperature that satisfies equation 27 (equilibrium condition). A flow chart of the subroutine SECANT is shown in Figure 7.

The secant method of iteration as described by Conte (1965), chapter 2, was used in this subroutine. This method is a modification of Newton's procedure of iteration. An iteration range of -5 to 35^{o} C was considered. The iteration equation was:

$$TX2 = (TX(FTX1) - TX1(FTX))/(FTX1 - FTX) \tag{28}$$

where:

TX2 = the new temperature to be used for the next iteration

TX and TX1 are the iteration range

For the first iteration TX and TX1 are the minimum and maximum possible temperatures inside the building (-5 and 35^{o} C respectively).

$$FTX1 = QB - QC - QV \tag{29}$$

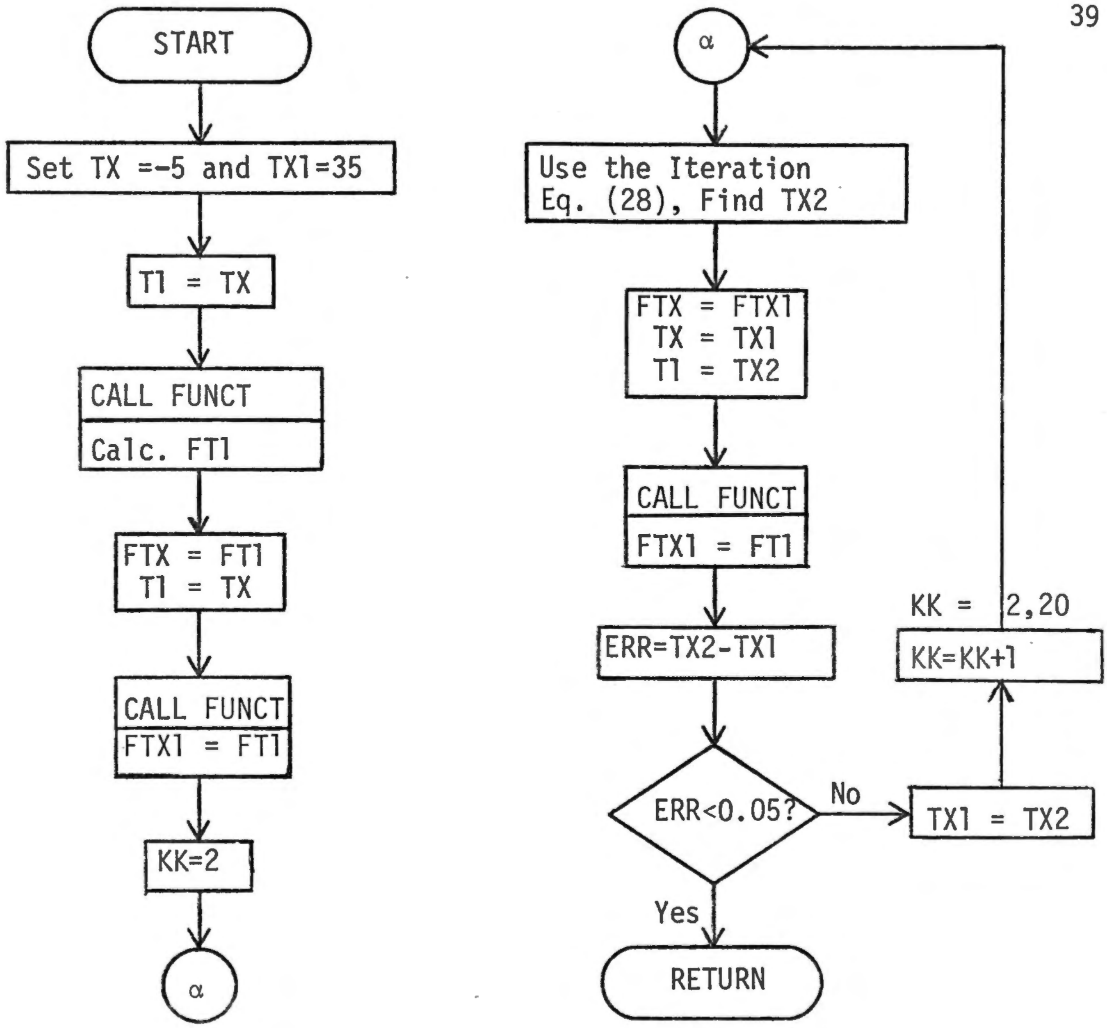

Figure 7. Flow Chart for the Subroutine SECANT. (A Subroutine Using The Secant Method of Numerical Solution to Solve for the Building Inside Temperature.)

The function FTX1 is the residual from the last iteration. The function FTX is the residual from the iteration previous to the last.

This subroutine gives the inside temperature within $\pm$ 0.05^{o} C.

CHAPTER IV

EXPERIMENTAL PROCEDURE

I. BUILDING SELECTION

To check the validity of the computer model, data were collected from three existing buildings. Two of the buildings chosen were near Knoxville, Tennessee. Data during summer and winter were collected from these two houses. The third house was located at the agricultural college of the University of Mosul, Iraq. Data for summer only were collected from the later location. Existing features of each of the three houses will be explained here.

The computer model developed in Chapter III was modified and used to predict the inside temperature for each hour of the day instead of the daily average inside temperature. The actual outside temperature and relative humidity, ventilation rate, and the solar radiation data were used in the model. The other observations used for each building are listed in Table 4.

Scott Egg Farm

The Scott Egg Farm was located near Friendsville, 40 Km to the south of Knoxville. The facility was a U-shape arrangement consisting of two houses with their major axis in the east-west direction. Eggs were collected on moving belts leading to the processing area between the two houses. Data were collected from the north house. Each house

TABLE 4

BUILDING OBSERVATIONS AND DATA USED IN THE ANALYSIS OF EXPERIMENTAL DATA

Item	Scott Egg Farm	White Egg Farm	Hammam Al-Allil Farm
1. Slope of roof, (S, radians)	0.245	0.376	0.250
2. Building Orientation, (G, radians)	$-\pi/2$	$-\pi/2$	$-\pi/2$
3. Overall U-Value, Excluding the Outside Surface Resistance (UAV, $w/m^2\ {}^oK$)	1.26	1.58	2.91
Winter Observations:			
4. Number of Birds, BN	34,000	17,570	----
5. Area per Bird, (APB, m^2)	0.050	0.080	----
6. Ground Reflectivity, ρ	0.2	0.7	----
7. CT[1], December	0.422	----	----
January	0.382	----	----
February	----	0.435	----
Summer Observations:			
8. Number of Birds, BN	32,000	17,570	1,200
9. Area per Bird, (APB, m^2)	0.053	0.080	0.350
10. Ground Reflectivity, ρ	0.2	0.2	0.2
11. CT, June	----	0.551	----
July	----	0.536	0.650
August	0.534	----	----

[1]CT = ratio of the monthly average daily total radiation to the extraterrestrial daily insolation (Beckman et al., 1977).

was 13.72 meters wide and 123.45 meters in length. Other details and dimensions of the house are shown in Figure 8.

Each building was designed to house a maximum of 36,000 birds in five cage sets with six aisles in the longitudinal direction. The actual number of birds was 34,000 during the winter of 1978-1979, and about 32,000 during the summer of 1979. Waste was collected below cages in a pit 1.8 m deep. The building insulation consisted of 2.54 cm thick expanded polystyrene, molded beads, in the walls and ceiling. The overall U-value of the house was determined to be 1.16 w/m^2 ^oK.

Twenty-six thermostatically controlled ventilators were built on the south facing wall below cage level. The diameter of the ring surrounding the ventilator fan was 90.0 cm. The thermostat settings during winter were such that only two ventilators would operate if the inside temperature dropped below 5^o C, and a maximum of 13 ventilators if the inside temperature exceeded 21.5^o C. During summer, all the ventilators would operate if the inside temperature was higher than 24^o C.

White Egg Farm

This farm was located 50 Km to the east of Knoxville. One of the newest laying houses was chosen. The house was designed for a maximum capacity of 18,000 bird. Birds were housed above a wire net covering the entire floor area. The house had two side aisles in the longitudinal direction. Eggs were collected from nests on two moving belts on the side of each aisle. The belts delivered eggs to the collection room at the front of the building. The house was 12.2 m

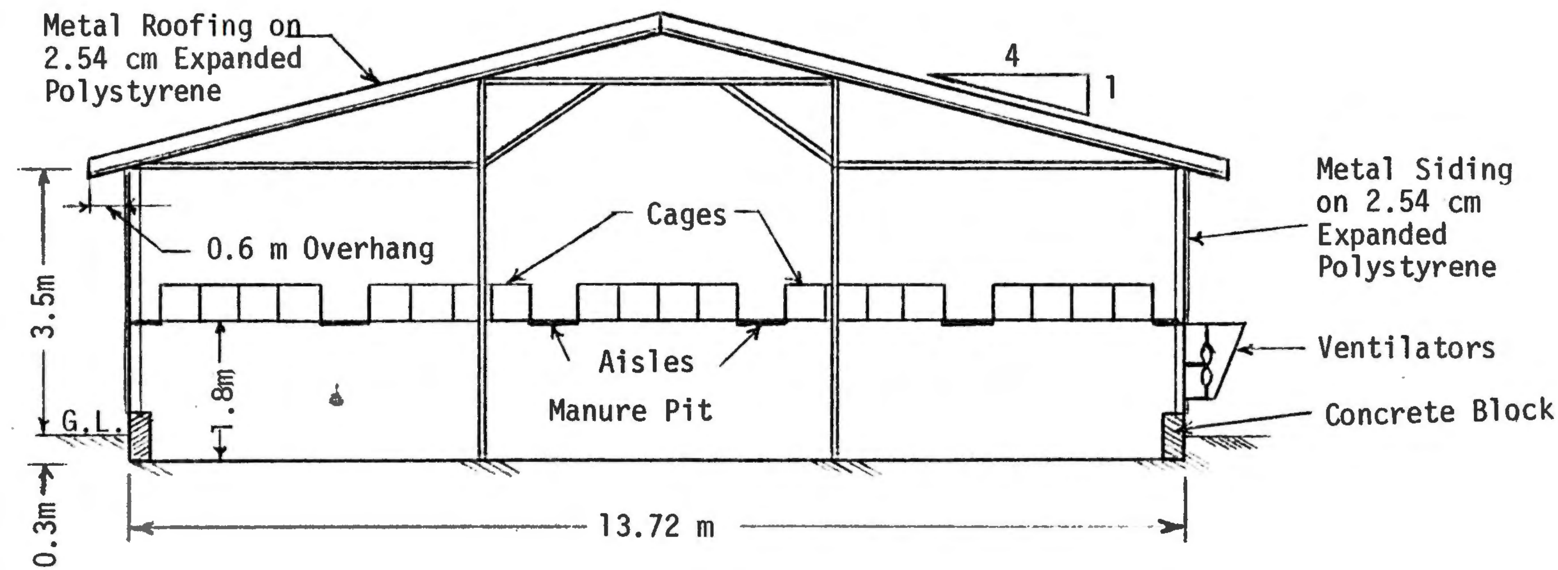

Figure 8. Cross-Section Through One of Scott Farm Houses.

wide and 115.2 m long with its major axis in the east-west direction. Ninety-one cm high curtains on wire net were built on the bottom of the south facing wall, and 46 cm high curtains were on the top of the north facing wall. Other dimensions and details of the building construction are shown in Figure 9. Manure was collected in a 1.8 m deep pit below the wire net. Ten small fans, five on each side, were installed in the longitudinal direction of the pit. These fans were not used to exhaust air, but only to dry manure.

The building was well insulated with 2.54 cm expanded polystyrene for walls, and 2.54 cm glass fiber insulation for the ceiling. The overall U-value of the building was determined to be 1.37 $w/m^2\ {}^oK$. This U-value was higher than that for Scott farm house because of the large curtains areas which had a very high thermal conductivity.

The ventilation system consisted of eleven thermostatically controlled ventilators built on the south facing wall. The ventilators were set to operate during summer only. Two of them were set to operate at temperatures above 26.5^o C. The rest operated if the inside temperature exceeded 24.5^o C. Ventilators number one and eleven were smaller than the others and were installed to ventilate the manure pit. The small ventilators had a diameter of 61 cm. The larger ventilators had a diameter of 104 cm.

Hammam Al-Allil Farm

This farm was located on the agricultural campus of the University of Mosul, Iraq. The climate in this area is semi-arid.

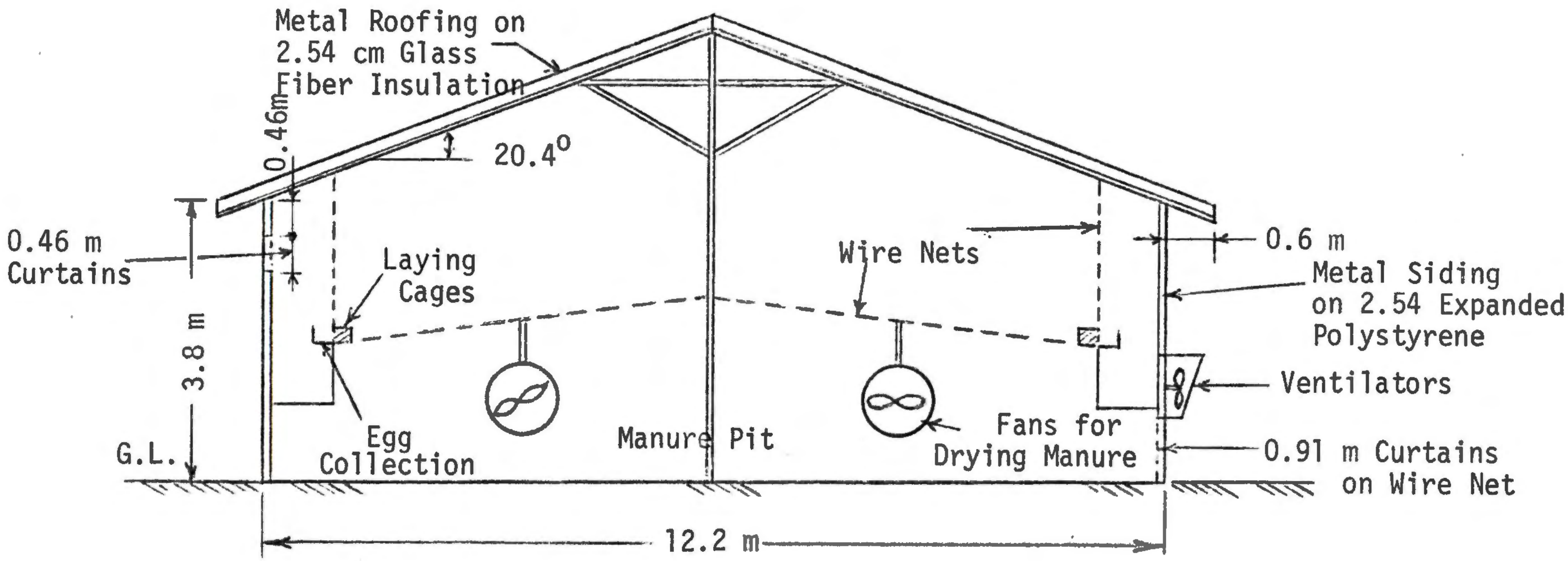

Figure 9. Cross-Section Through White Egg Farm House.

A floor pen type house was chosen to provide different conditions from the houses previously mentioned. The house was 10.0 meters wide and about 42.0 meters long, with a 10 percent window to floor area. The overall U-value of this house was determined to be 2.58 w/m^2-^oK. Two drip type evaporative coolers were provided. Each had a capacity of 2.36 m^3/sec (5000 cfm). The house contained about 1,200 Rhode-Island birds. It was oriented such that its major axis was in the east-west direction.

II. INSTRUMENTATION

Temperature Measurement

A temperature recorder using copper constantan thermocouples was used to measure the dry bulb, wet bulb, and black globe temperatures at selected locations in the buildings. These measurements were taken at 1-hour intervals.

Thermocouples were installed at two cross sections of the building to measure the inside temperature. Temperature measurements were taken at three locations in each section. One near the ceiling, the second at the center and the third in the manure pit below the cages.

The outside temperature was measured using four thermocouples. Measurements were taken at two different locations on each long side of the building. The inside and outside wet bulb temperatures were measured by using wet wicks inserted in plastic bottles filled with distilled water. The plastic bottles were placed near the ventilators so that air movement near the wick could be provided. The water level in the plastic bottles was checked periodically and distilled water was added to keep its level above the bottom of the wick.

Temperatures of walls and ceiling were measured by installing twenty thermocouples in different locations inside and outside all building surfaces. Location of all thermocouples inside and outside the building are shown in Figure 10. One thermocouple was used to measure the temperature of a black globe installed at the top of the roof.

Relative Humidity

Hygrothermographs were installed to measure the inside relative humidity at two different locations in the building. A third unit, was used to measure the outside relative humidity.

For temperatures below zero ^{o} C, the water in the plastic bottles froze. This resulted in erroneous measurements of the wet bulb temperature. Hygrothermograph data were more dependable during freezing periods and were used in later analysis.

Solar Radiation

A continuous measurement of total radiation (direct + diffuse) on horizontal surfaces was taken using a pyranometer and a strip chart recorder. Diffuse radiation could only be measured by shading the pyranometer. The recorder gave a continuous graph for the total radiation in calories/cm^2 - min.

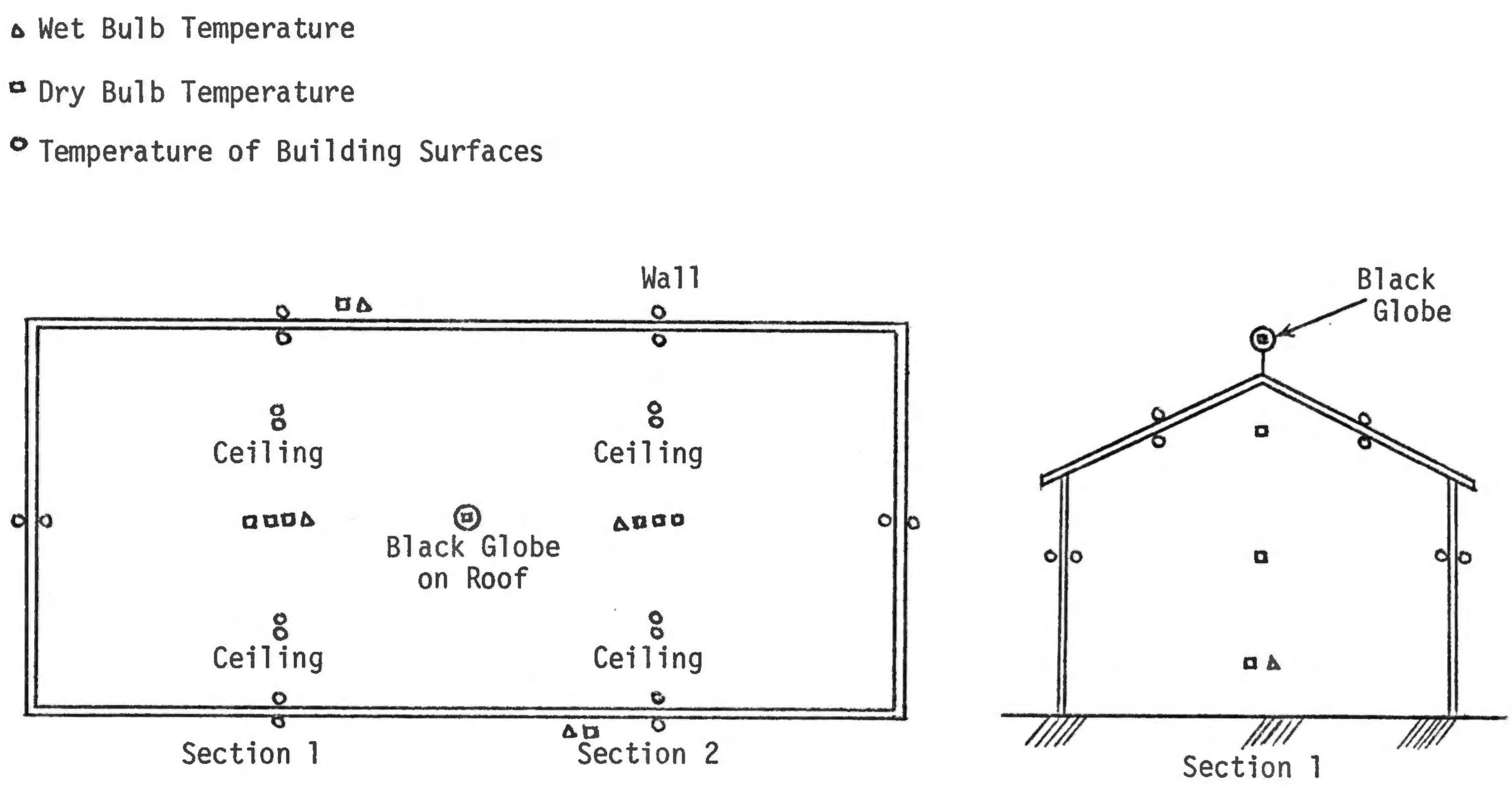

Figure 10. A Map Showing Location of Thermocouples Inside and Outside the Building.

A hand held solar meter using a photo cell was also used to take instantaneous measurements of radiation, and to provide verification of accuracy for both sensors.

Hourly total radiation was found by integrating the area under the curve for each hour of the day. Figure 11 shows the pyranometer installed on leveled table in Scott farm. The figure also shows one of the hygrothermographs and the recorders used for temperatures and total radiation measurements.

Air Flow Rate

Air velocity through ventilators and open curtains was measured using an air velocity meter. The meter used a hot wire anemometer probe which provided sensetivity over a wide range of flow rates. It consisted of a telescopic probe with a sensing element at its end. The meter could also be used to measure the dry bulb temperature of air.

III. DATA COLLECTION

Environmental Conditions for the Experiment

Data were collected from Scott farm during the winter of 1978-1979, and the summer of 1979. During winter the outside temperature fell to -10^{0} C, but no snow was encountered. For the purpose of determining the diffuse radiation, the ground reflectivity in equation 16 was assumed equal to 0.2 for bare ground.

From White Egg Farm, data were collected during winter and summer of 1979. About 10 cm of snow accumulated on the ground and building

Figure 11. Instruments Used to Measure and Record Temperatures, Solar Radiation, Relative Humidity, and Wet Bulb Temperature. The Pyranometer and Hygrothermograph are in the Foreground. Other Recording Equipment is Located in the Shelter Near the Fans. Note the Black Globe Sensor on Top of the Building.

roof during the winter part of the experiment. The ground reflectivity during this period was assumed equal to 0.7.

Data were collected from Hammam Al-Allil experiment station in the summer of 1978. Solar radiation was measured for one full day using the hand held solar meter. Instruments for other measurements were not available. The inside and outside temperatures and relative humidities were measured using two hygrothermographs installed for this purpose.

Ventilation Rate Data

The ventilators at both the Scott and White farms were set to operate at specific inside temperatures. The thermostat settings were not the same for all ventilators. Thus, at different ranges of inside temperatures, the number of ventilators operating changed. Also for different number of ventilators operating, the air flow rate through each ventilator was different. Air velocities through the cross sectional area for different number of ventilators operating were measured. The ventilation rates for different inside temperature ranges were calculated. Ventilation rates for both Scott and White farms during winter and summer were determined.

Scott Egg Farm. Table 5 contains the air velocity data and shows the method used to determine the ventilation rates for different number of ventilators operating at Scott's farm.

TABLE 5

VENTILATION RATE DETERMINATION IN SCOTT EGG FARM DURING WINTER AND SUMMER

Inside Temperature °C	No. of Ventilators	Air Velocity m/sec	Total Ventilation[1] m^3/sec	Ventilation Rate[2] m^3/sec-1000 bird
Winter Ventilation				
≤ 5.0	2	5.12	6.5	0.19
≤ 11.8	3	4.75	9.1	0.27
≤ 17.5	5	4.11	13.1	0.39
≤ 19.7	9	3.40	19.5	0.57
> 19.7	13	3.15	26.0	0.76
Summer Ventilation				
≤ 24.0	21	2.73	36.5	1.14
> 24.0	23	2.73	40.0	1.25

[1]Total Ventilation = No. of ventilators x air velocity x A

where A = cross sectional area of the 0.9 diameter ventilator,

$A = 0.636\ m^2$

[2]Ventilation Rate = $\frac{\text{Total Ventilation}}{\text{BN}} \times 1000$

where BN = 34,000 bird during winter and, BN = 32,000 bird during summer.

<u>White Egg Farm</u>. No artificial ventilation was provided during winter in this building. However, the curtains on the north facing wall were open. Air velocities through openings were measured. The average velocity was about 0.4 m/sec. The ventilation rate was estimated to be 0.26 m^3/sec - 1000 bird. The house was provided with nine ventilators of cross-sectional area of 0.85 m^2, and two small ventilators for the manure pit one of which was idle. The cross-section area of the small ventilators was 0.292 m^2.

The thermostats were set such that, seven large and one small ventilator would operate if the inside temperature was less than 26.5^{o} C. For temperatures higher than 26.5^{o} C all ventilators were operated. Air velocities through the small and large ventilators were measured. Table 6 contains the air velocities and ventilation rate for each case.

TABLE 6

VENTILATION RATE DETERMINATION FOR WHITE EGG FARM DURING SUMMER

Inside Temperature ^{o}C	No. of Ventilators	Air Velocity m/sec	Total Air Flow m^3/sec	Ventilation Rate m^3/sec-1000 bird
$\leq$ 26.5	7 large ventilators	3.76		
	1 small ventilator	3.60	23.4	1.33
> 26.5	9 large ventilators	3.50		
	1 small ventilator	3.54	27.8	1.58

Hammam Al-Allil Farm. No artificial ventilation was provided. Data were collected during summer when the outside temperature reached 50^{o} C for part of the day. The inside temperature was about 10^{o} C less than the outside temperature during that period. The air flow rate through windows was estimated based on wind velocity to be 6.0 m^3/sec-1000 bird.

IV. ANALYSIS OF DATA

All data measurements were made on the half-hour to represent the one hour period, (e.g., measurements at 10:30 a.m. represented the average values for the period 10:00 a.m. to 11:00 a.m.). The actual inside temperature was determined by averaging the temperature measurements in the two sections of the building. The average wet bulb temperature measurements were also determined. Computer subroutines developed by Wilhelm (1976) were used to determine the inside and outside relative humidities. Relative humidity data from the hygrothermographs were used during freezing period as a substitute for the relative humidity found from the wet bulb temperature measurements.

CHAPTER V

RESULTS AND DISCUSSION

I. RESULTS OF THE COMPUTER MODEL

Two different building shapes were considered in developing the computer model. These were: (1) gable-type house, and (2) shed-type house. Two extreme weather conditions were also considered. Weather data for January and July were used to represent the coolest and hottest months of the year respectively.

The daily average inside temperature of the building was predicted for the above four factors using different values for the environmental factors. The analysis of the effect of each factor on the inside temperature was conducted while all other factors were kept constant. A typical value currently used in building design was selected for each factor to be used as a constant. These constant values were as follows:

1. Area per bird (APB) = 0.06 m^2
2. Slope of roof (S) = 20 degree from horizontal
3. Building Orientation (G) = -90^o, i.e. east-west orientation (with roof facing south for shed-type building)
4. Ventilation rate (V)
   a. Winter ventilation, V = 0.4 m^3/sec-1000 bird
   b. Summer ventilation, V = 1.4 m^3/sec-1000 bird

5. Building insulation or insulation value

   a. Wall resistance, RW = 0.22 m^2 $^oK/w$ (No insulation)

   b. Roof resistance, RR = 0.92 m^2 $^oK/w$

These insulation values resulted in an overall U-value of approximately 1.5 w/m^2 ^oK for gable-type roof and 1.75 w/m^2 ^oK for shed-type roof, (for more details, see Table 1, page 18).

Area Per Bird

Figures 12, 13, and 14 represent the relationship between the inside temperature in a gable-type roof and the area per bird for the winter and summer conditions. The lines in each figure represent different levels of insulation. The inside temperature was significantly affected by the area per bird. For a constant ventilation rate of 0.4 m^3/sec-1000 bird, the inside temperature during winter increased as the area per bird decreased. Figures 12 and 13 indicated that for low insulation level, i.e. high overall U-value, a rapid increase in inside temperature took place as the area per bird decreased. The total decrease in temperature for a decrease of the area per bird from 0.12 to 0.03 m^2 was a function of the overall U-value of building. A maximum increase of about 3.0^o C resulted for a U-value of 4.55 w/m^2 ^oK. As shown in Figure 13, the inside temperature during night-time dropped to about 6^o C when an area per bird of 0.12 m^2 was used.

During summer, very little decrease in inside temperature resulted from decreasing the area per bird. The only significant decrease was for building with very low insulation.

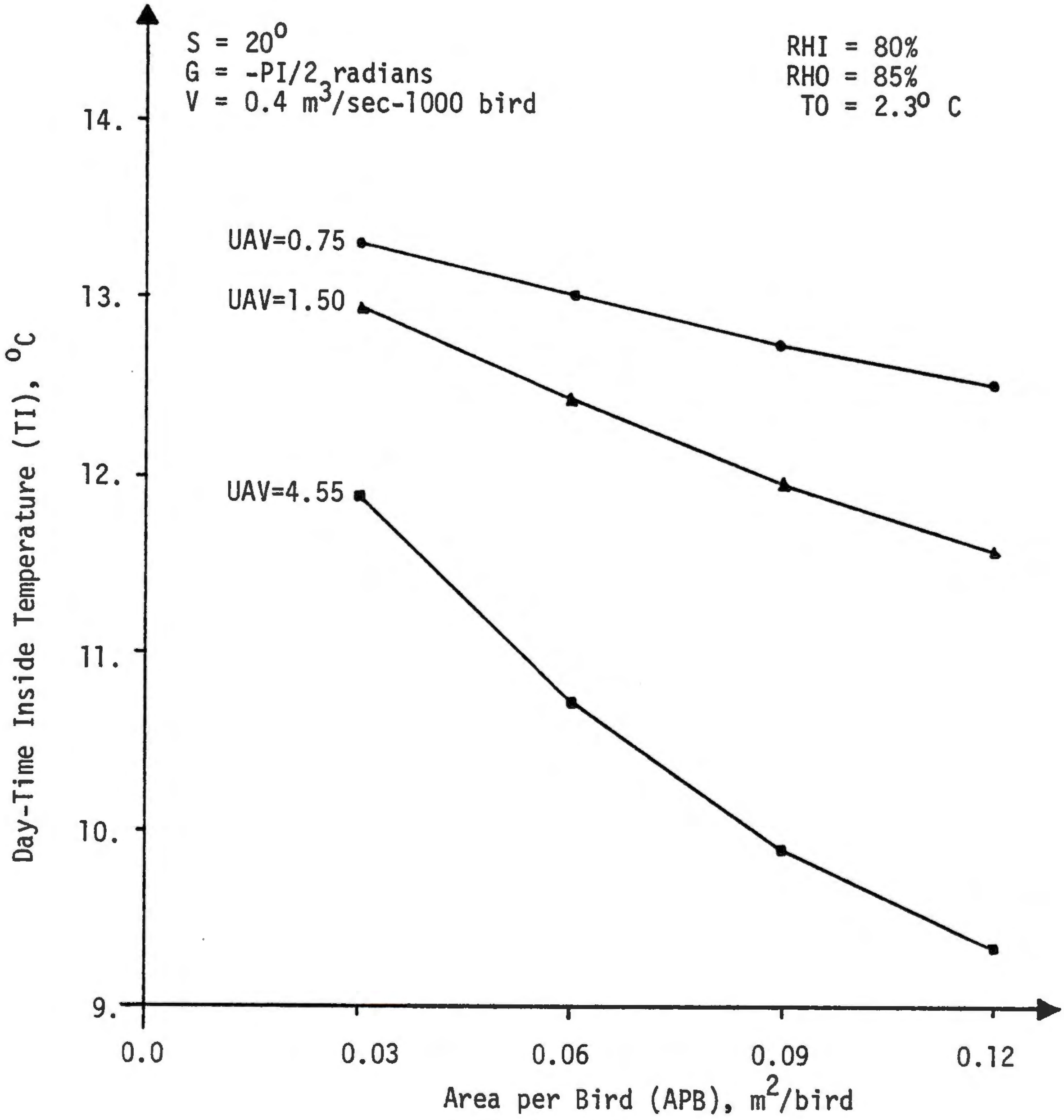

Figure 12. The Average Day-Time Inside Temperature as a Function of the Area per Bird for Different Insulation Levels During Winter (Gable-Type Roof).

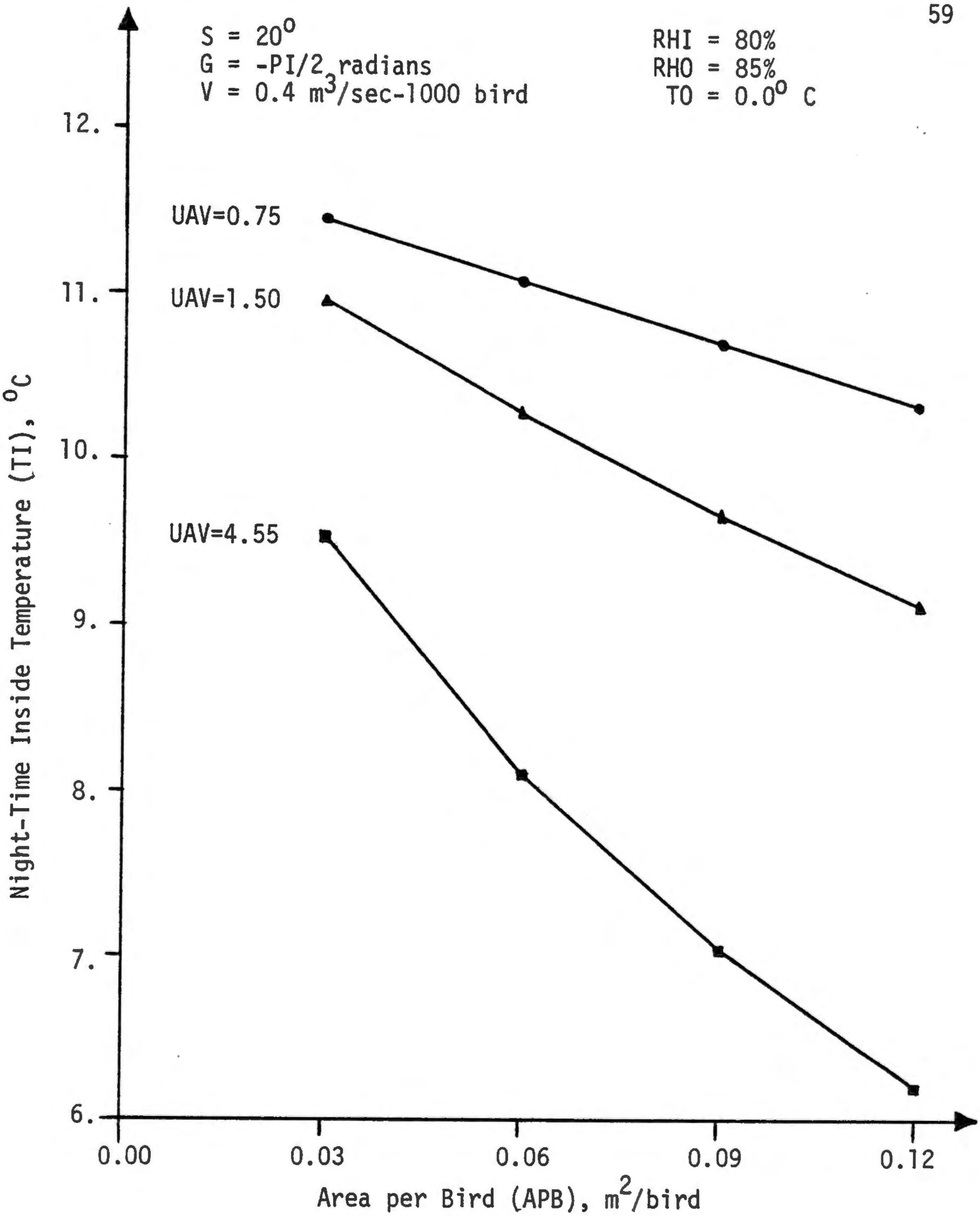

Figure 13. The Average Night-Time Inside Temperature as a Function of the Area per Bird for Different Insulation Levels During Winter (Gable-Type Roof).

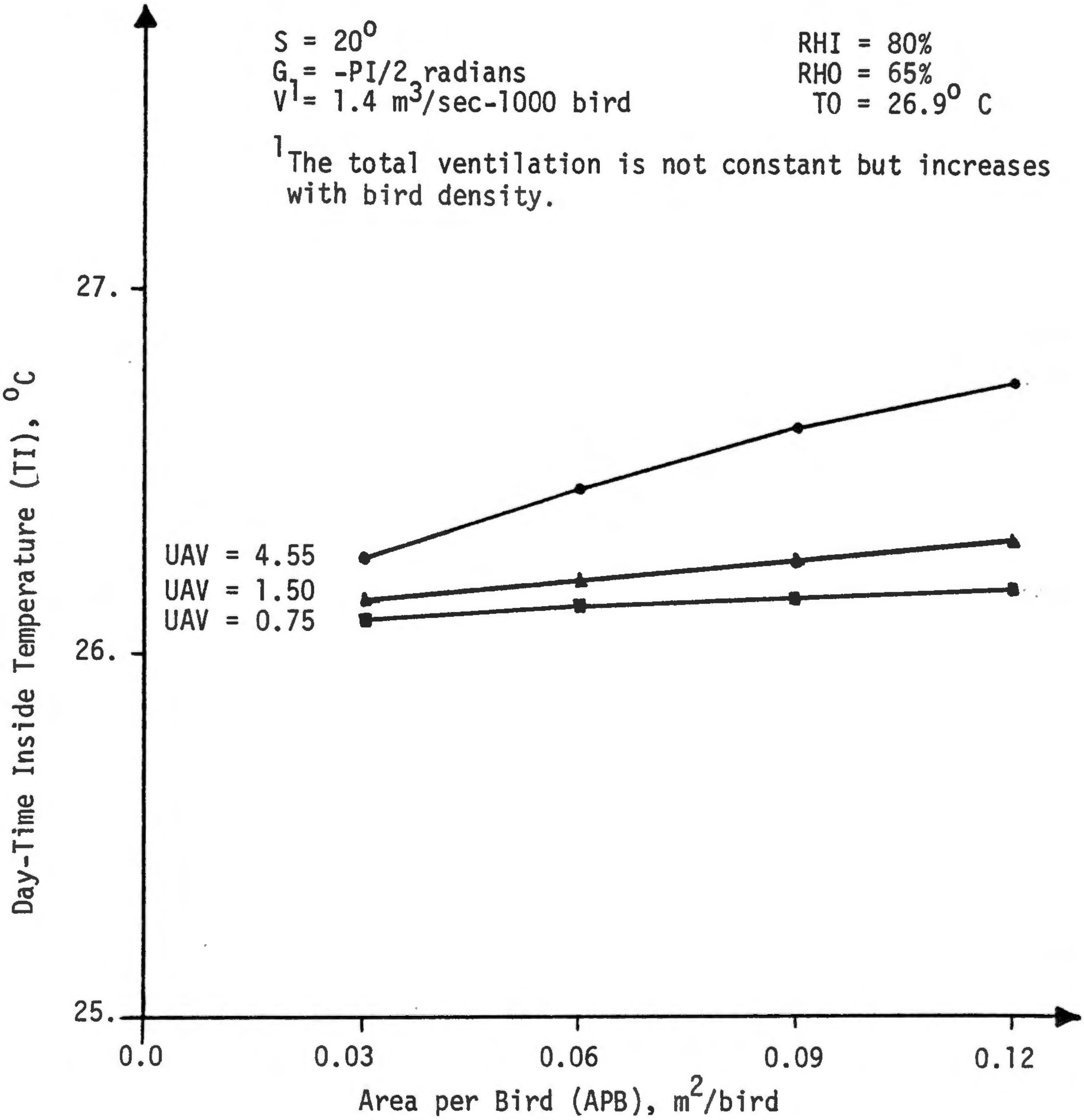

Figure 14. The Average Day-Time Inside Temperature as a Function of the Area per Bird for Different Insulation Levels During Summer (Gable-Type Roof).

The total surface area of the building decreased as the area per bird decreased. This resulted in less heat transfer by conduction and higher inside temperatures were obtained. For the same reason, the inside temperature during summer was lower for low area per bird (Figure 14). The results will differ if the ventilation rate and/or outside environmental conditions are changed. However, the trends shown should not change greatly unless conditions are such that the inside temperatures reach near lethal levels for the birds.

For the shed-type roof, the area per bird had the same effect on the inside temperature during both summer and winter conditions as for a gable-type roof.

Slope of Roof

Graphs for the effect of roof slope on inside temperature during winter for three levels of insulation are shown in Figure 15. In both shed and gable-type roofs, the inside temperature increased as the roof slope decreased. For the same slope, the effect was more significant with the shed-type roof than for the gable-roof. There were two apparent reasons for this difference: (1) compared to the gable-roof, the total surface area for a shed-type building increases significantly with steeper slopes. This allows greater heat loss through the larger wall areas, (2) the ratio of the roof area to the total surface area in a gable-type roof is higher than that for a shed-type. This resulted in a higher overall U-value for shed-type building and consequently higher amounts of heat lost through walls and ceiling.

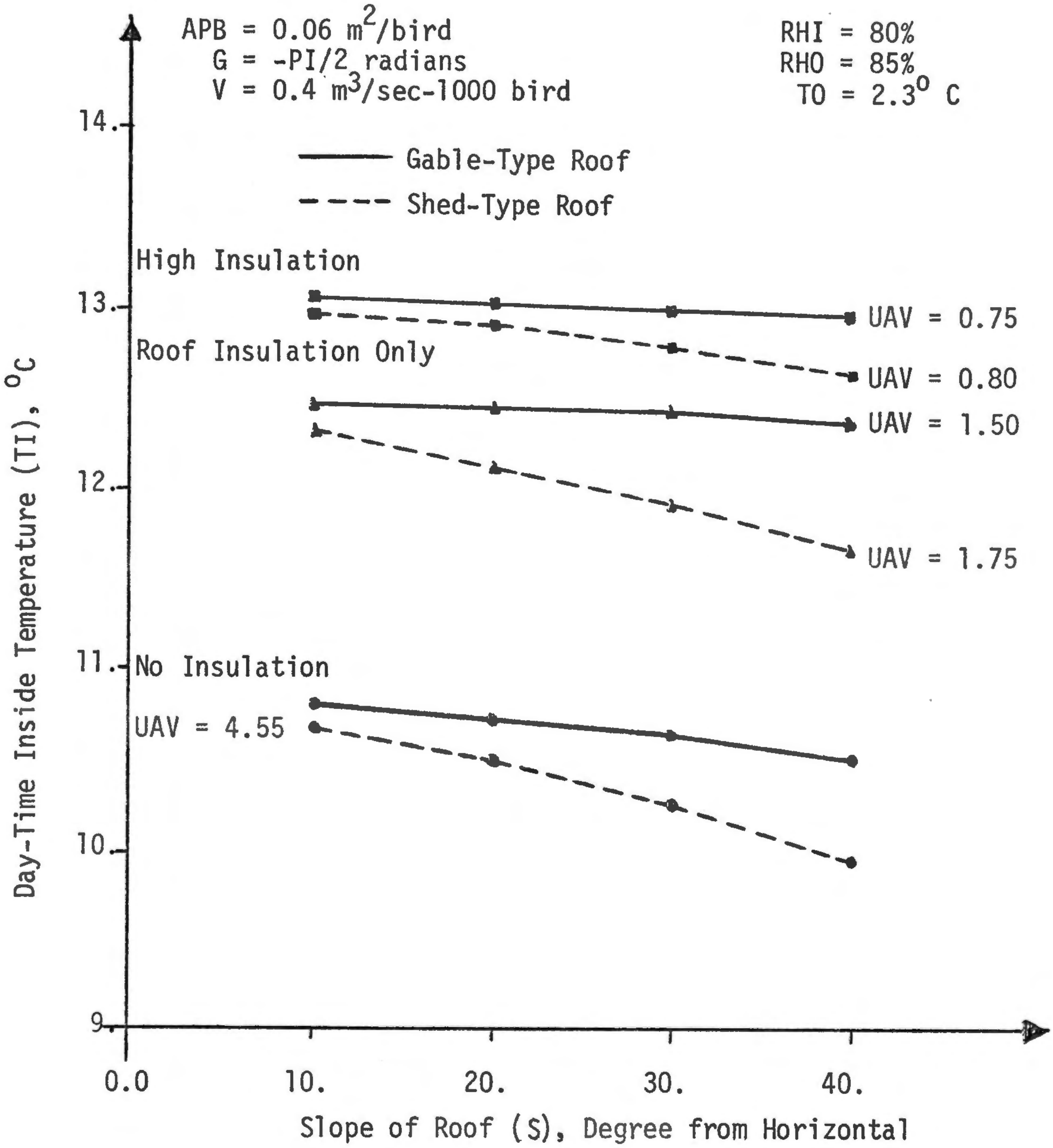

Figure 15. The Average Day-Time Inside Temperature as a Function of the Roof Slope for Different Levels of Insulation in a Shed and a Gable-Type Roofs (Winter).

During summer, the inside temperature was slightly increasing as the roof became steeper. Graphs shown in Figure 16 are for both shed and gable-type roofs and for two levels of insulation. The effect of slope was not statistically significant. However, for the same roof slope, the inside temperature was higher for the shed-type house. This was caused by the same factors, mentioned above, which resulted in lower temperature in a shed-type house during winter.

Building Orientation

In the shed-type house, the building orientation did not show any statistically significant effect on inside temperature. However, the computer results indicated that the best orientation to give higher inside temperature during winter and lower inside temperature during summer was east-west with roof facing south. These results are shown in Figures 17 and 18 for high and low values of roof slope.

In gable-type house, the building orientation (G) indicated a significant effect on inside temperature during summer only. Actually, the maximum change of inside temperature as a result of changing building orientation was negligable (e.g. + 0.06 ^{o}C when $G = -\pi$). Also, the computer results indicated that the best orientation for higher inside temperature during winter and lower inside temperature during summer was the east-west direction of the major axis.

Building Insulation

The computer results for the effect of building insulation on inside temperature are shown in Figures 19, 20 and 21. These figures

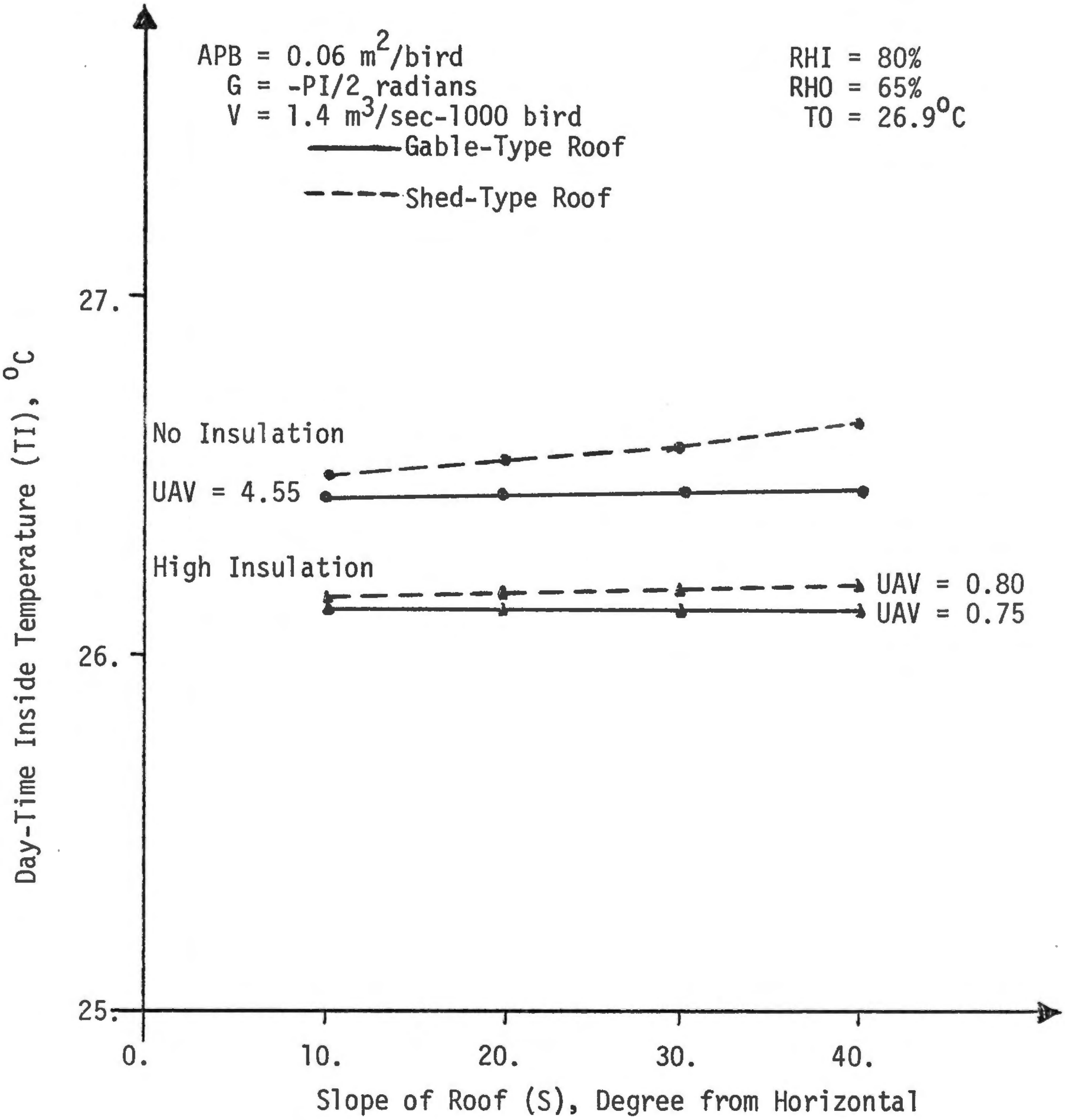

Figure 16. The Average Day-Time Inside Temperature as a Function of the Roof Slope for Different Levels of Insulation in a Shed and a Gable-Type Roofs (Summer).

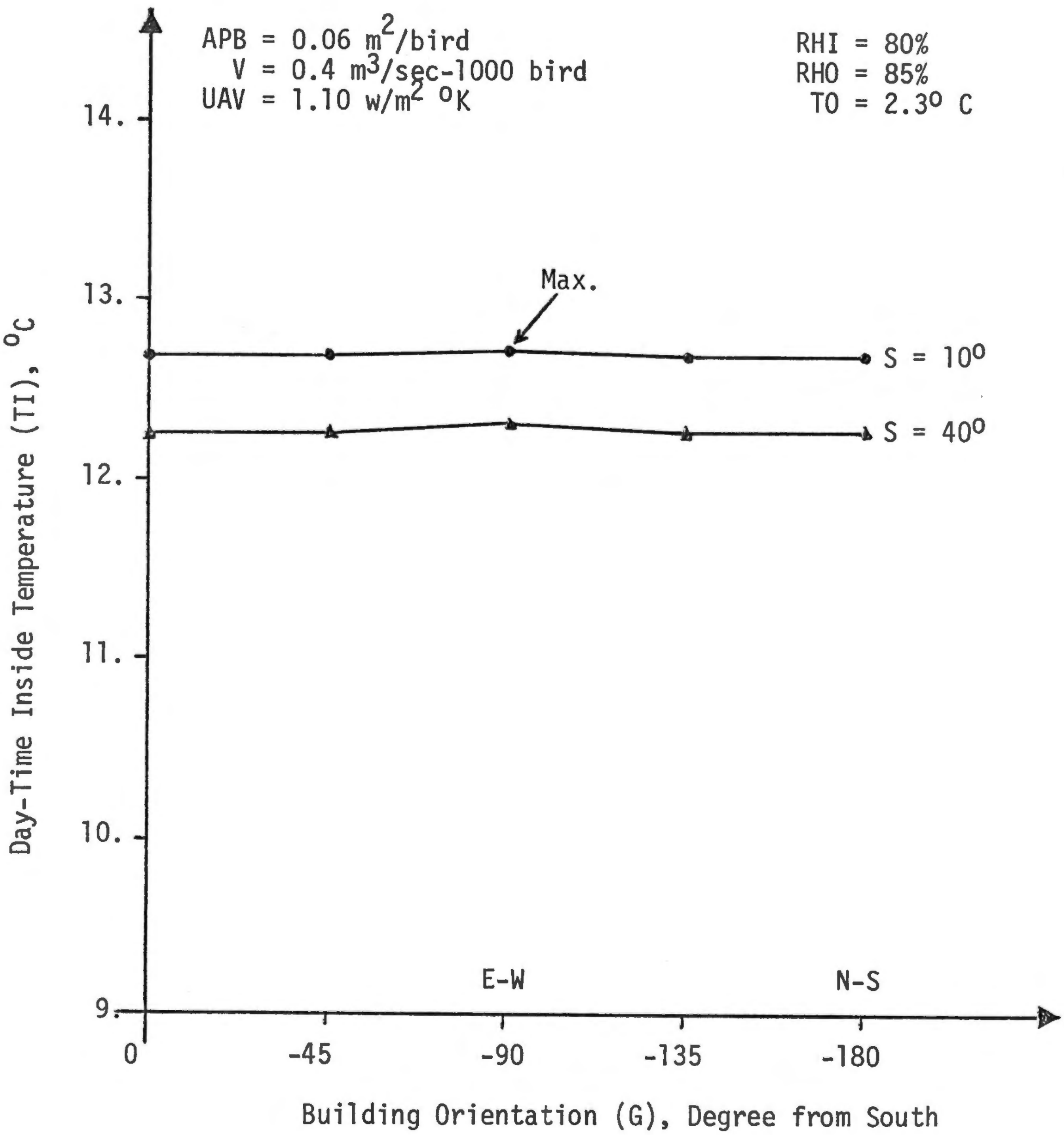

Figure 17. The Average Day-Time Inside Temperature as a Function of the Building Orientation for Two Different Roof Slopes in a Shed-Type House (Winter).

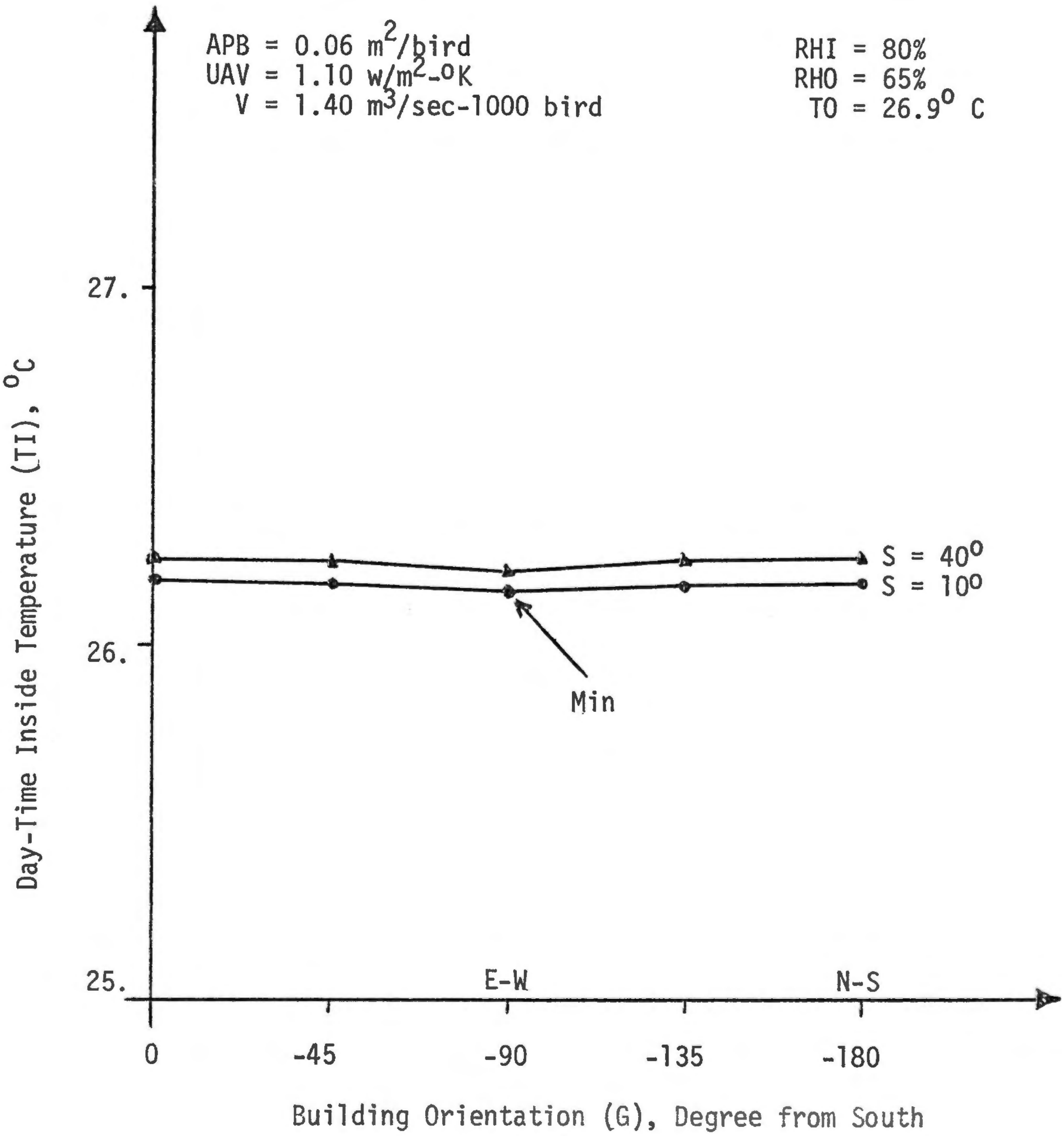

Figure 18. The Average Day-Time Inside Temperature as a Function of the Building Orientation for Two Different Roof Slopes in a Shed-Type House (Summer).

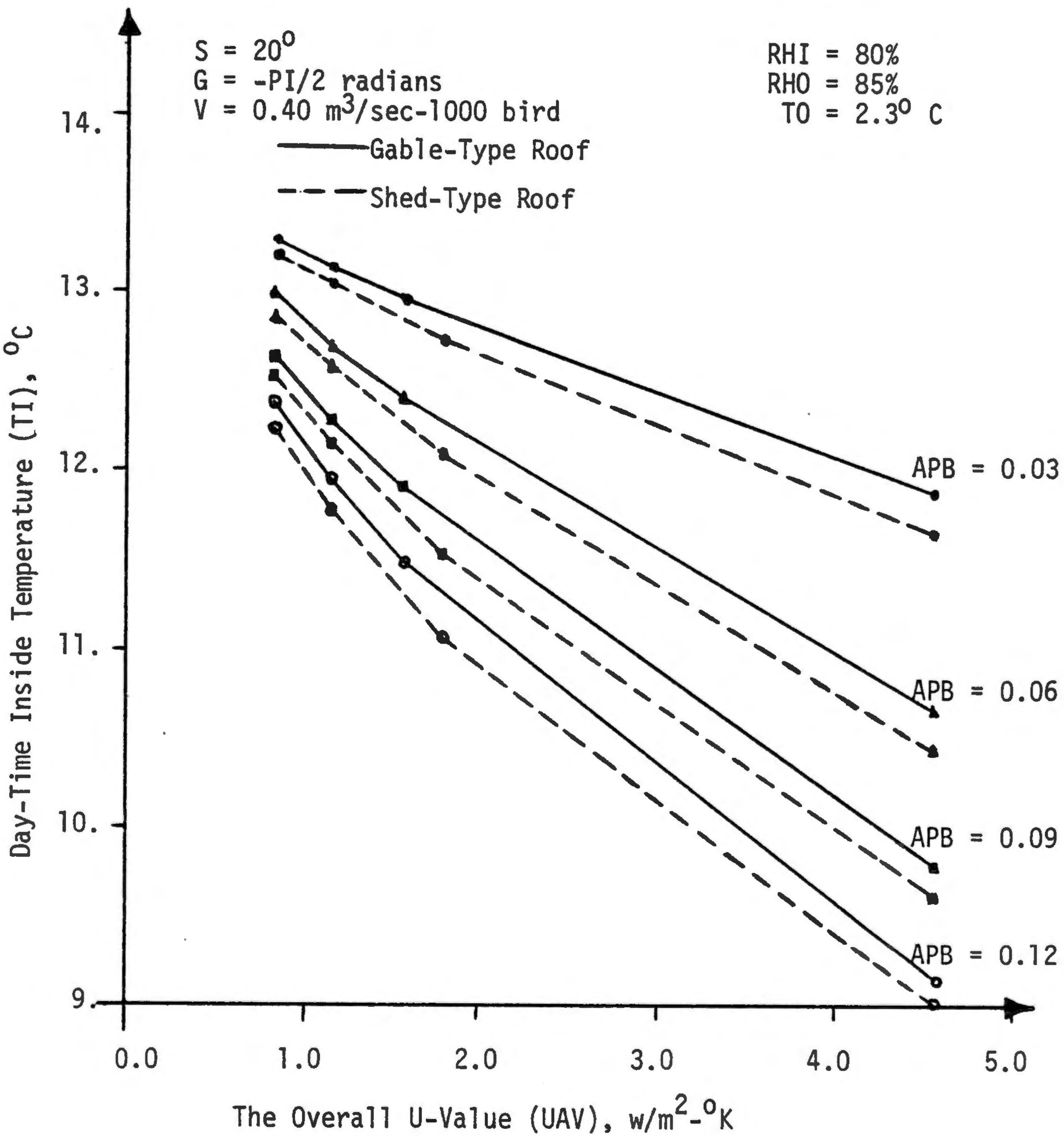

Figure 19. The Average Day-Time Inside Temperature as a Function of the Building Insulation (UAV) for Different Areas per Bird in a Shed and a Gable-Type Roofs During Winter.

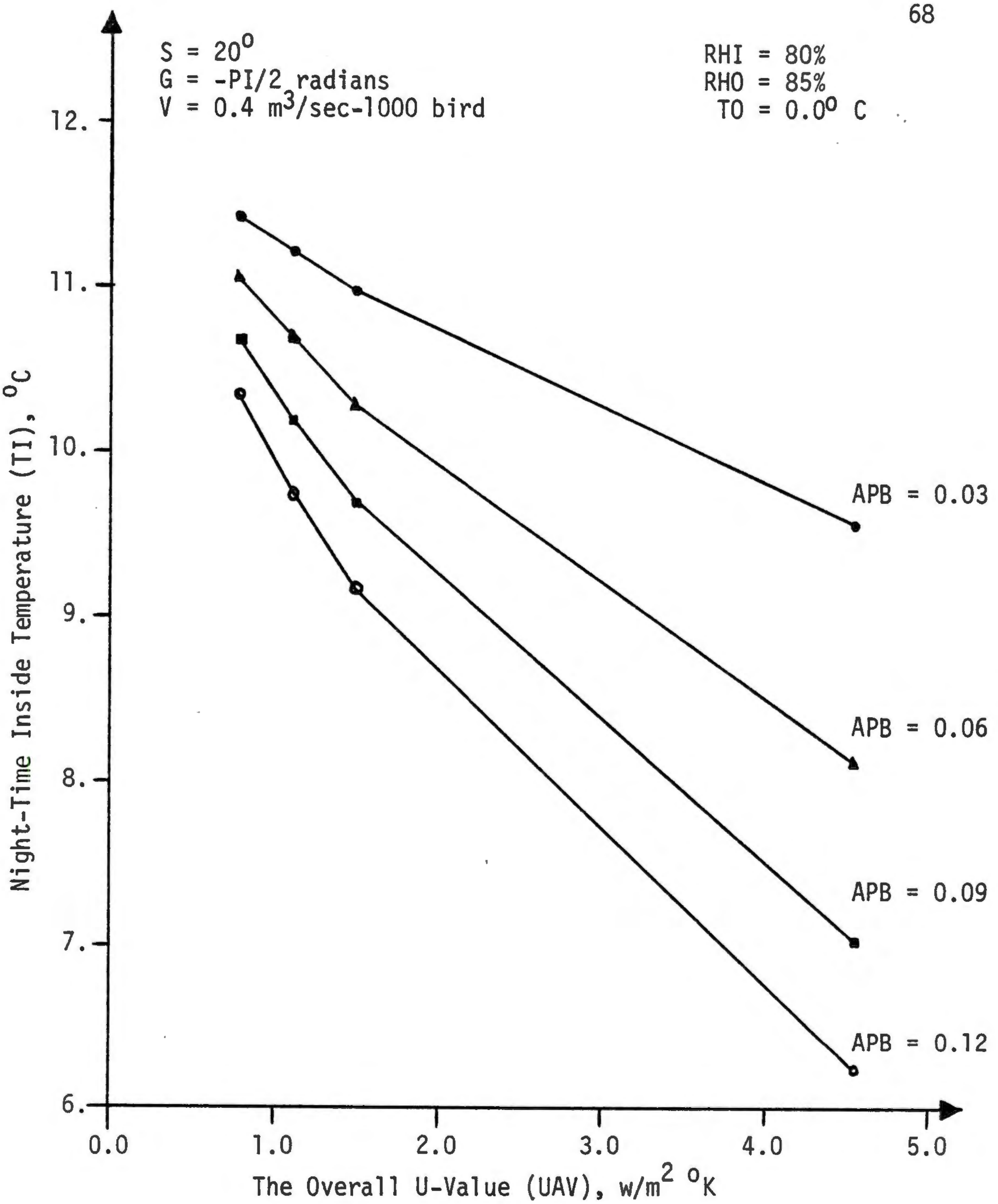

Figure 20. The Average Night-Time Inside Temperature as a Function of the Building Insulation (UAV) for Different Areas per Bird in a Gable-Type Roof During Winter.

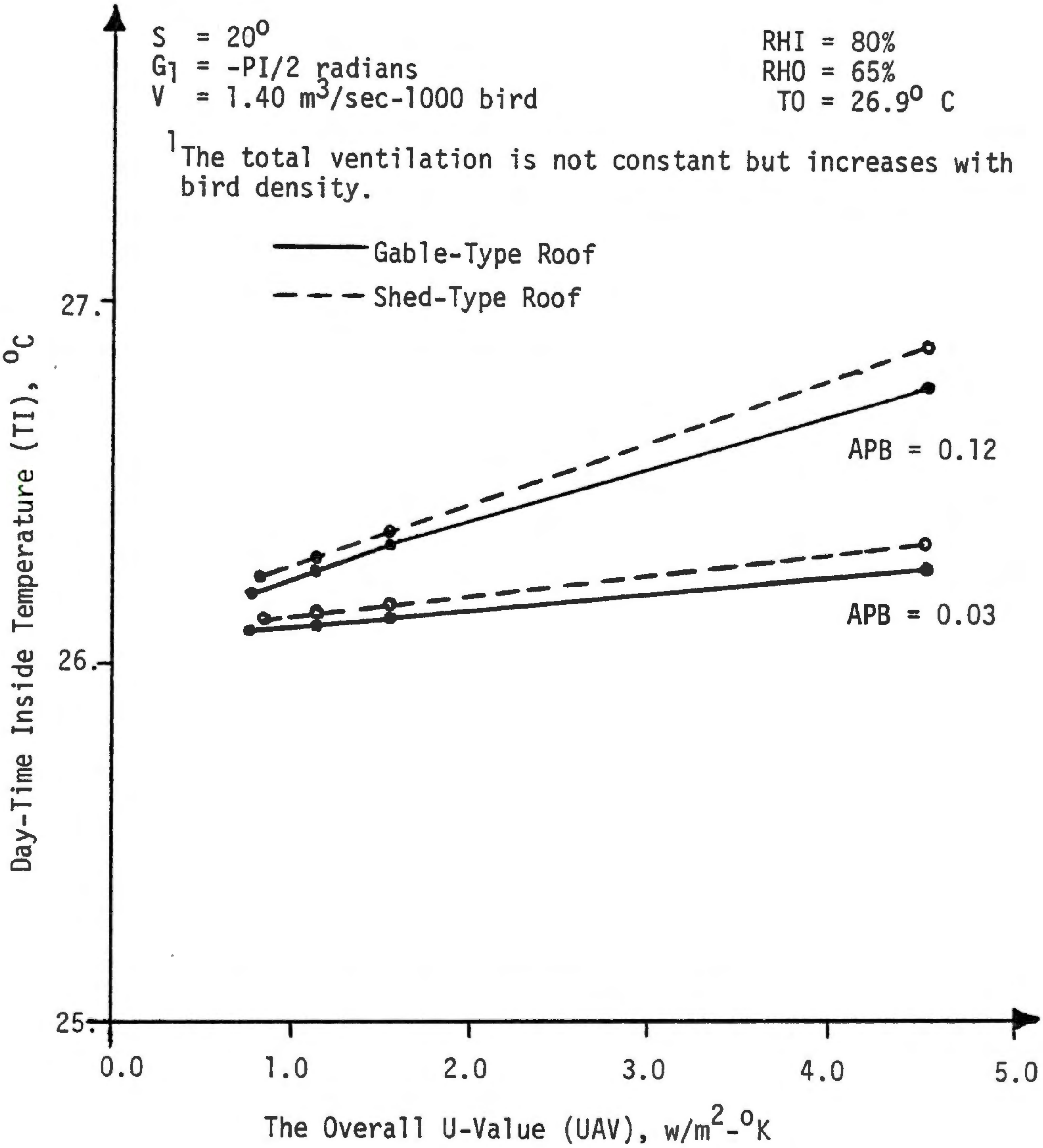

Figure 21. The Average Day-Time Inside Temperature as a Function of the Building Insulation (UAV) for Different Areas per Bird in a Shed and a Gable-Type Roofs During Summer.

indicated that building insulation had a significant effect on inside temperature.

Winter Conditions. Figures 19 and 20, pages 67 and 68, represent results obtained for the effect of the overall U-value (UAV), on inside temperature for different area per bird during day-time and night-time respectively. A constant ventilation rate of 0.4 m^3/sec-1000 bird was used to produce the graphs. It is clearly shown that: (1) increasing the insulation level, i.e. decreasing UAV, resulted in higher inside temperatures, and (2) the effect of insulation increased when UAV was less than about 1.8 $w/m^2\ {}^oK$.

Two other results were obtained from Figure 19, page 67: (1) For the same insulation level, the shed-type house was cooler than the regular house (gable-roof). The difference in inside temperature was very small and negligable when compared to other effects. This was caused by the larger surface area of the shed-type house resulting in higher heat loss by conduction. (2) Building insulation was more effective when higher areas per bird were used.

Summer Conditions. As shown in Figure 21, the inside temperature was a linear function of the building insulation. The inside temperature decreased as the building insulation increased. The effect of insulation on inside temperature was much lower than its effect during winter.

The inside temperature in the shed-type house was slightly higher than that for regular house. This was caused by the larger roof area facing south which received higher amounts of solar radiation compared to the regular house.

Effectiveness of Insulation. Table 7 contains the insulation levels used in the computer model and the insulation effectiveness expressed in terms of the difference between the inside and the outside temperature for each insulation level.

Results from Table 7, Figure 19, page 67 and Figure 20, page 68, show that an insulation value (UAV) of 1.0 to 1.5 w/m^2 ^oK would be sufficient to maintain an average inside temperature above 8^o C during the day and night. This result is for regions where the outdoor monthly average temperature would not fall below zero ^oC.

Ventilation Rate

The ventilation rate was the most significant factor affecting inside temperature. Figures 22, 23, and 24 contain graphs of the computer simulation results. The graphs represent the inside temperature as a function of the ventilation rate for three levels of insulation. The same pattern of results for the effect of the ventilation rate on inside temperature was obtained for both gable-type and shed-type houses.

Winter Ventilation. The most critical factors in winter ventilation are the ammonia concentration and humidity level inside the building. A constant relative humidity of 80 percent was considered in this analysis. Figures 22 and 23 indicate that, higher inside temperatures

TABLE 7

THE INSULATION EFFECTIVENESS[1] FOR DIFFERENT LEVELS OF INSULATION

Insulation Level	UAV[2] w/m^2 °C	TI[3] °K	TI-TO °C
1. No insulation	4.55	10.7	8.4
2. Low insulation (roof insulation only)	1.50	12.4	10.1
3. Medium insulation	1.10	12.7	10.4
4. High insulation	0.75	13.0	10.7

[1]The insulation effectiveness expressed in terms of the difference between the inside and the outside temperatures. Where, the outside temperature (TO) = 2.3° C.

[2]UAV = Values for the different insulation levels were taken from Table 1, page 18.

[3]Values of the inside temperature (TI) for the different insulation levels were taken from results of the computer model.

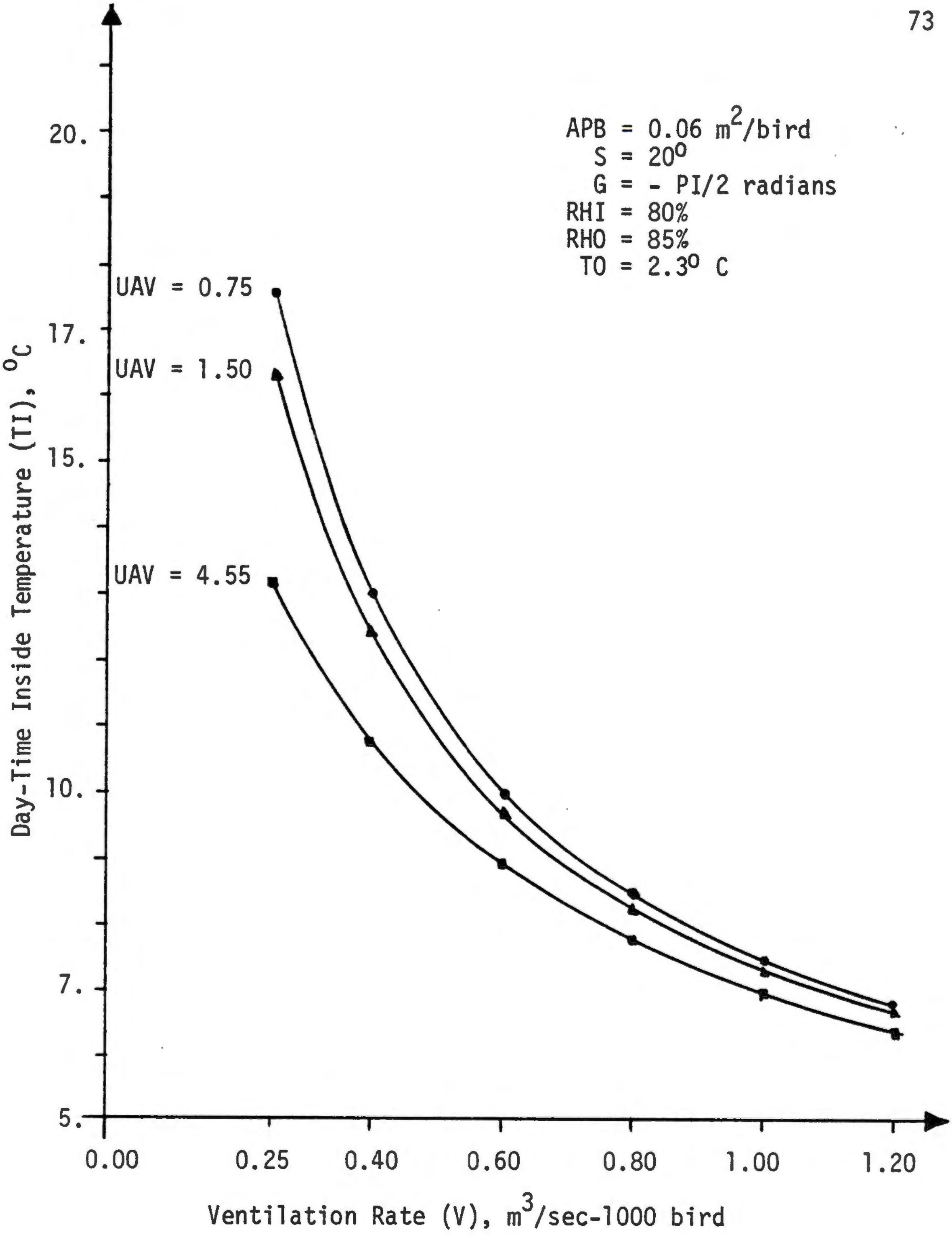

Figure 22. The Average Day-Time Inside Temperature as a Function of the Ventilation Rate for Different Levels of Insulation in a Gable-Type Roof During Winter.

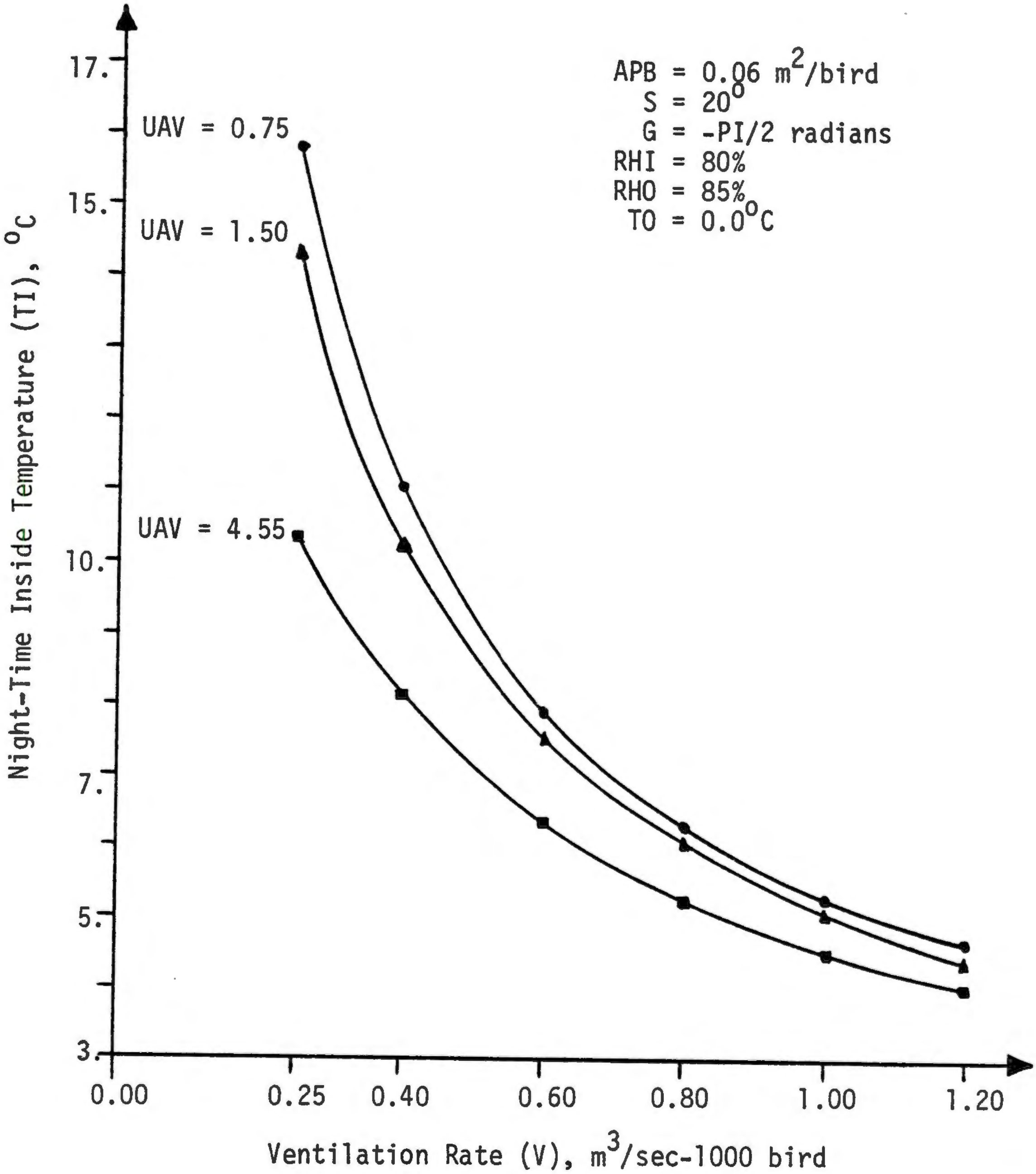

Figure 23. The Average Night-Time Inside Temperature as a Function of the Ventilation Rate for Different Levels of Insulation in a Gable-Type Roof During Winter.

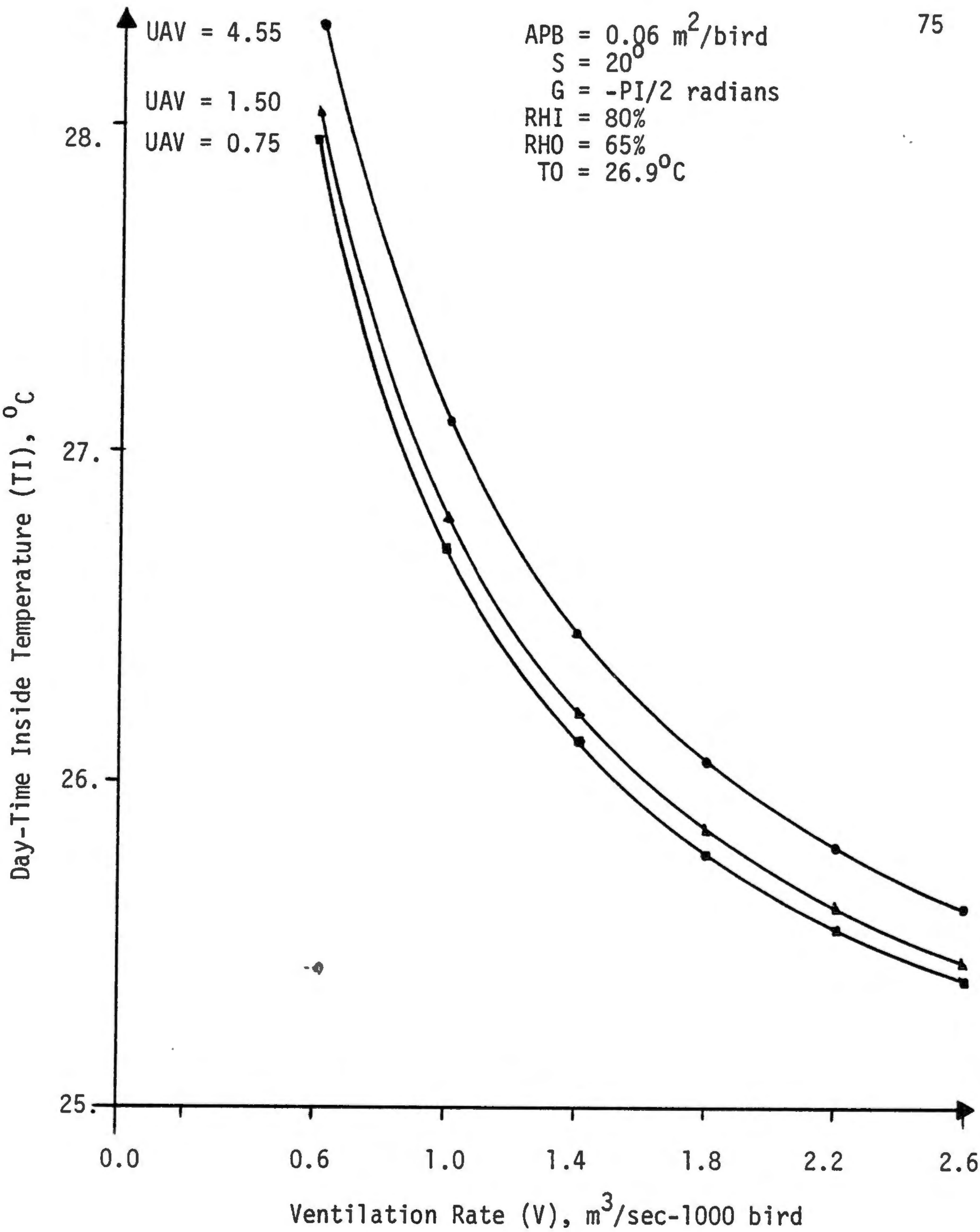

Figure 24. The Average Day-Time Inside Temperature as a Function of the Ventilation Rate for Different Levels of Insulation in a Gable-Type Building During Summer.

could be maintained by using low ventilation rates. The inside temperature may drop below 5^{o} C if ventilation rates higher than 1.0 m^3/sec-1000 bird are used. Ventilation rates in the range of (0.25-0.4) m^3/sec-1000 bird are required to remove harmful gases and lower the ammonia concentration. Within this range the inside temperature was 8 to 13^{o} C depending on the overall U-value of the building. There is no need for artificial heating in regions where the average monthly temperature is above 0^{o} C. Results also indicated that ventilation was more effective in lowering the inside temperature in buildings with low levels of insulation. For the same ventilation rate (0.25-0.4 m^3/sec-1000 bird), 3 to 4^{o} C difference in inside temperature existed between buildings with an overall U-value of 1.5 $w/m^2\ {}^{o}K$ or less and buildings with no insulation. Therefore, higher ventilation rates can be used to maintain the desired inside temperature and control humidity if the building is well insulated. Figures 22 and 23, pages 73 and 74, also indicated that for high ventilation rates, the effect of different insulation levels on inside temperature would be minimal.

For two reasons, ventilation rates higher than 0.6 m^3/sec-1000 bird are not recommended:

a. The inside temperature drops below 8^{o} C and artificial heating would be needed.

b. More energy would be consumed on ventilation.

Summer Ventilation. Figure 24 contains graphs for the inside temperature as a function of the ventilation rate for three levels of insulation.

The most significant factor that should be considered in discussing the ventilation rate is the energy consumption for ventilation. For the given summer conditions, the computer results as plotted in Figure 24, page 75, indicated that ventilation could lower the inside temperature a maximum of 4^{o} C. This temperature reduction can be obtained by using ventilation rates of 2.6 m^3/sec-1000 bird or higher. About 80 percent of this reduction was obtained by using a ventilation rate of 1.5 m^3/sec-1000 bird. Doubling this ventilation would result in doubling the energy consumption. However, not more than 1^{o} C reduction in inside temperature can be obtained by doubling the ventilation.

The graphs also indicated a small difference in inside temperature (0.3^{o} C) existed between a highly insulated building and building with no insulation.

II. STATISTICAL ANALYSIS OF THE COMPUTER RESULTS

Computer results for the two types of buildings under summer and winter conditions were analysed using linear correlation procedures. The inside temperatures were assumed to depend on the area per bird (APB), slope of roof (S), building orientation (G), the overall building U-value (UAV), and the ventilation rate (V).

Preliminary analysis of the computer results indicated that the inside temperature could be considered as a linear function of all the environmental factors noted above except the ventilation rate.

It was found that the ventilation rate should be included as both a linear and a logarithmic term. Thus, the general model chosen to study the effects of each variable on the inside temperature (TI) was:

$$TI = F\ (APB,\ S,\ G,\ UAV,\ V,\ LogV) \tag{30}$$

Results for the shed and gable type houses were analysed separately. The results were based on an inside relative humidity equal to 80 percent and weather data for Knoxville, Tennessee.

Gable-Type Building

The best general linear model under the day-time winter weather conditions was:

$$TI = 3.26-11.51\ APB - 0.23\ S + 0.004\ G - 0.43\ UAV + 5.7\ V - 21.08\ LogV \tag{31}$$

$$r = 0.9761$$

The building orientation (G) in the above model was not significant. As a result, this factor was dropped producing the resulting equation:

$$TI = 3.22 - 11.51\ APB - 0.23\ S - 0.43\ UAV + 5.70\ V - 21.08\ LogV \tag{32}$$

$$r = 0.9761$$

At night, the above equation takes the form:

$$TI = 1.60 -15.44\ APB - 0.37\ S - 0.58\ UAV + 5.73\ V - 21.15\ LogV \tag{33}$$

$$r = 0.9689$$

The area per bird (APB), S, UAV, V, and LogV in the above two equations were all significant ($P<0.001$).

The general linear model for this type building under the summer conditions was:

$$TI = 25.46 + 2.75\ APB + 0.05\ S - 0.02\ G + 0.11\ UAV + 1.00\ V - 7.28\ LogV \quad (34)$$

$r = 0.9961$

All the factors in the above model were significant ($P<0.001$); however, the numerical values of the slope and orientation terms were very small for any value of these two factors. Thus, these two factors were dropped from the general model and equation 34 was simplified to:

$$TI = 25.54 + 2.75\ APB + 0.11\ UAV + 1.00\ V - 7.28\ LogV \quad (35)$$

$r = 0.9959$

Shed-Type Building

The general linear model for this shape building under the winter conditions was:

$$TI = 4.39 - 13.02\ APB - 0.67\ S - 0.0005\ G - 0.46\ UAV + 4.90\ V - 19.06\ LogV \quad (36)$$

$r = 0.9690$

The orientation was not significant in the above model. The slope and other factors were significant ($P<0.001$). The orientation term in the above model was dropped and equation 36 became:

$$TI = 4.39 - 13.02\ APB - 0.67\ S - 0.46\ UAV + 4.90\ V - 19.06\ LogV \quad (37)$$

$r = 0.9690$

Under the summer conditions, the building orientation was not significant. The resulting model for this case was:

$$TI = 25.44 + 3.52\ APB + 0.20\ S + 0.13\ UAV - 0.98\ V - 7.29\ LogV \quad (38)$$

$r = 0.9945$

The roof slope in the shed-type building indicated a higher effect on inside temperature compared with its effect in the gable-type building. The overall U-value was more significant under the winter conditions than under the summer conditions.

The Analysis of the Effect of the Ventilation Rate

The logarithmic function of the ventilation rate was found to be the most significant factor affecting the inside temperature. The following equation represent the inside temperature as a function of LogV for a gable-type building under the summer conditions.

$$TI = 27.07 - 4.18 \, \text{Log}V \qquad (39)$$

$$r = 0.9410$$

From the last equation, an inside temperature of 26^{o} C is obtained by using a ventilation rate of 1.5 m^3/sec-1000 bird. By doubling the ventilation rate, the inside temperature would become 25^{o} C. This result shows that it is an energy waste to use high ventilation rates during summer.

III. ANALYSIS OF EXPERIMENTAL DATA

Experimental data for the inside and outside temperatures, the sol-air temperature, and the difference between the actual and predicted inside temperatures are shown in Figures 25 through 29. Figures 25 through 28 contain data for five days collected from Scott and White farms during winter and summer respectively. Figure 29 contains data collected from Hammam Al-Allil farm for one summer day.

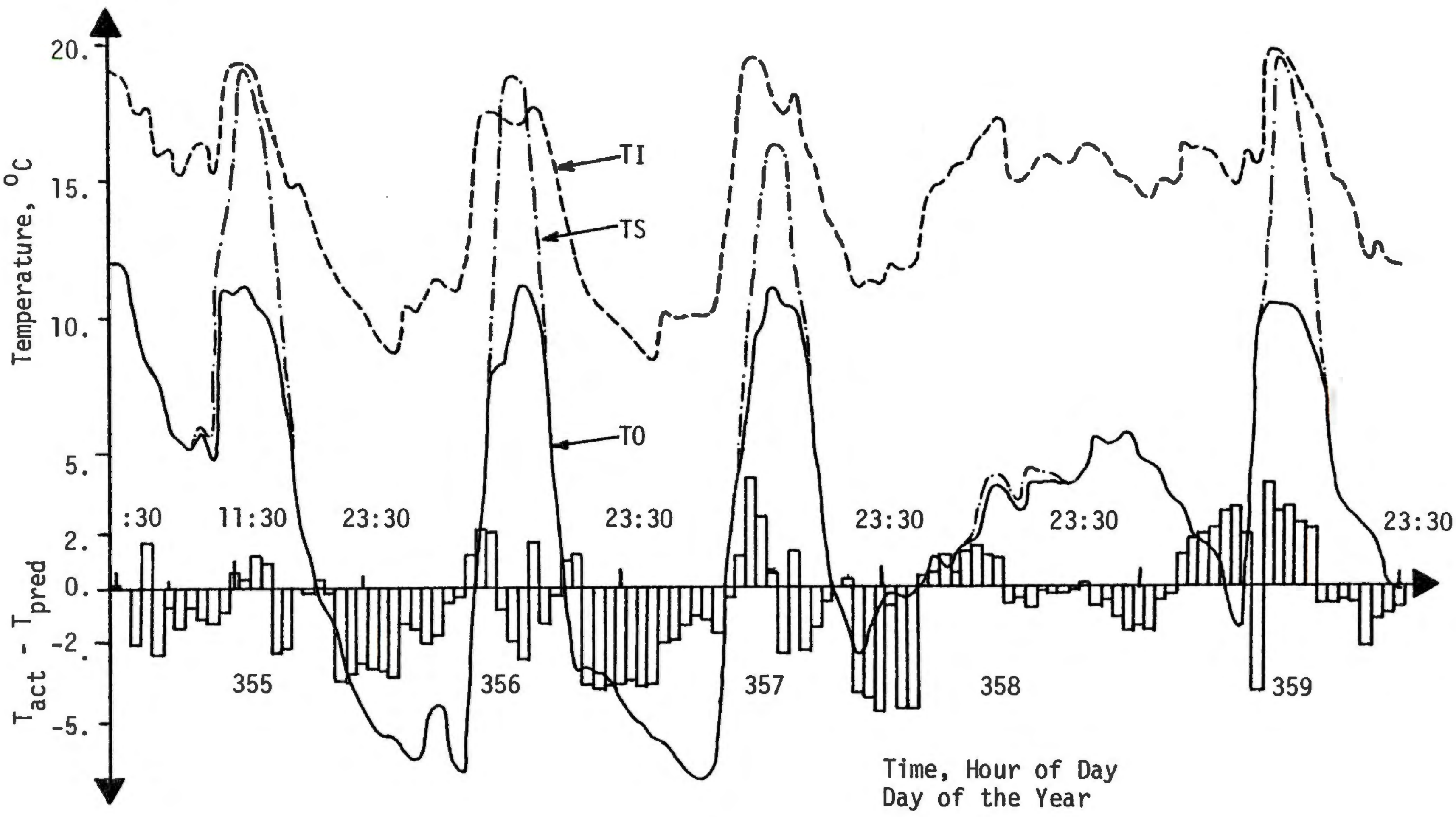

Figure 25. Graphs for the Inside and Outside Temperatures, the Sol-Air Temperature, and the Difference Between the Actual and Predicted Inside Temperature, (Scott Egg Farm, Winter).

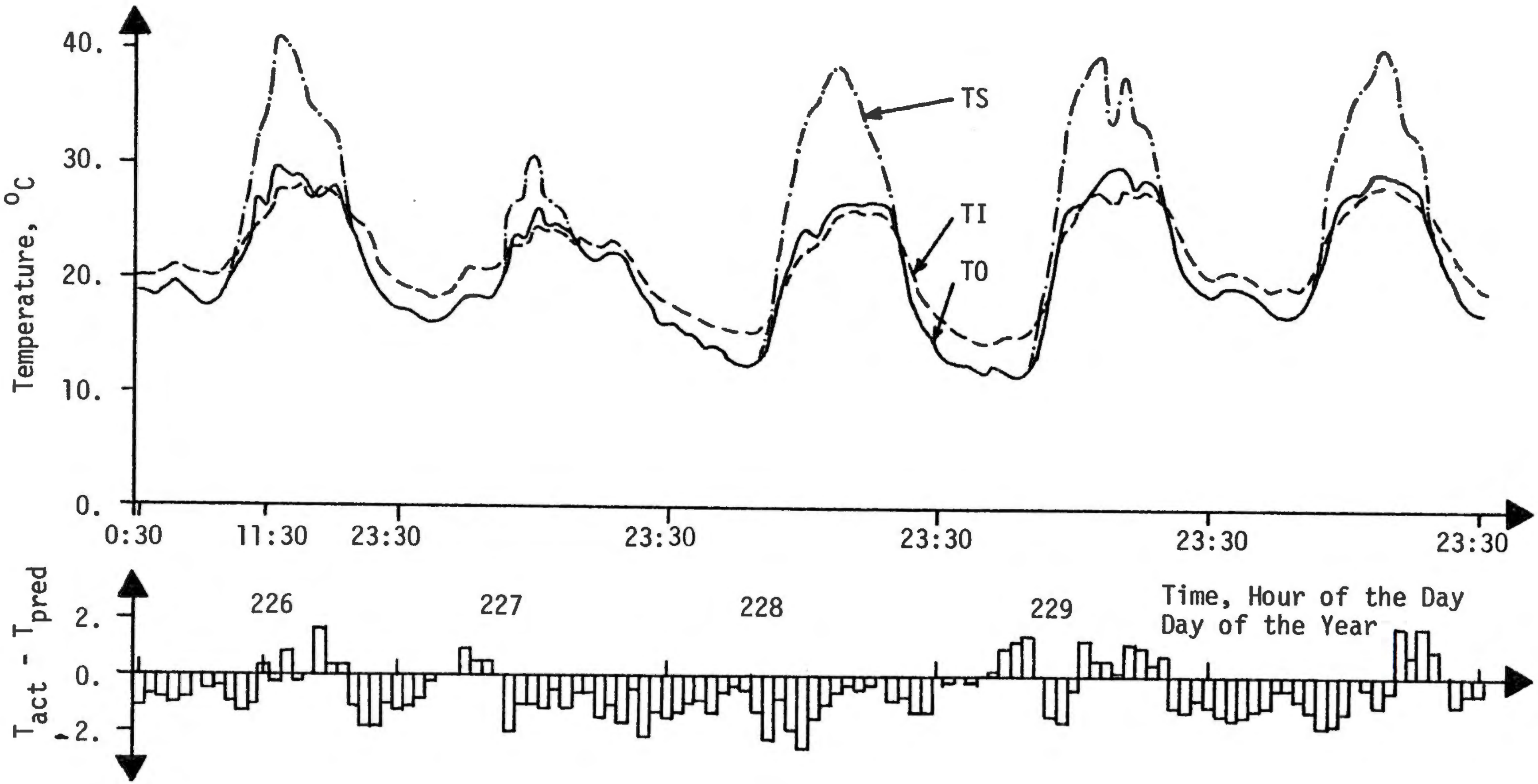

Figure 26. Graphs for the Inside and Outside Temperatures, the Sol-Air Temperature, and the Difference Between the Actual and Predicted Inside Temperatures, (Scott Egg Farm, Summer).

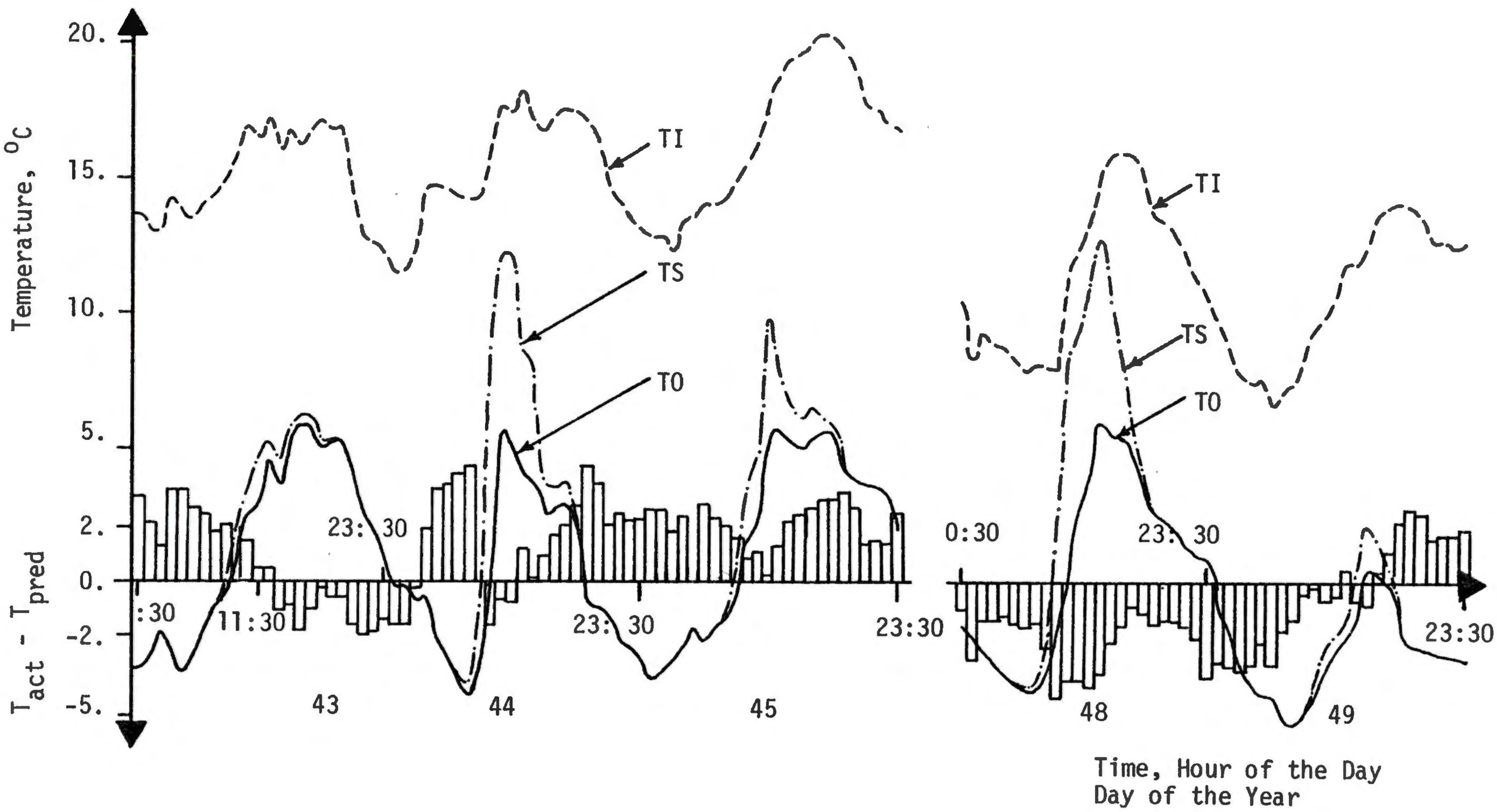

Figure 27. Graphs for the Inside and Outside Temperatures, the Sol-Air Temperature and the Difference Between the Actual and Predicted Inside Temperatures, (White Egg Farm, Winter).

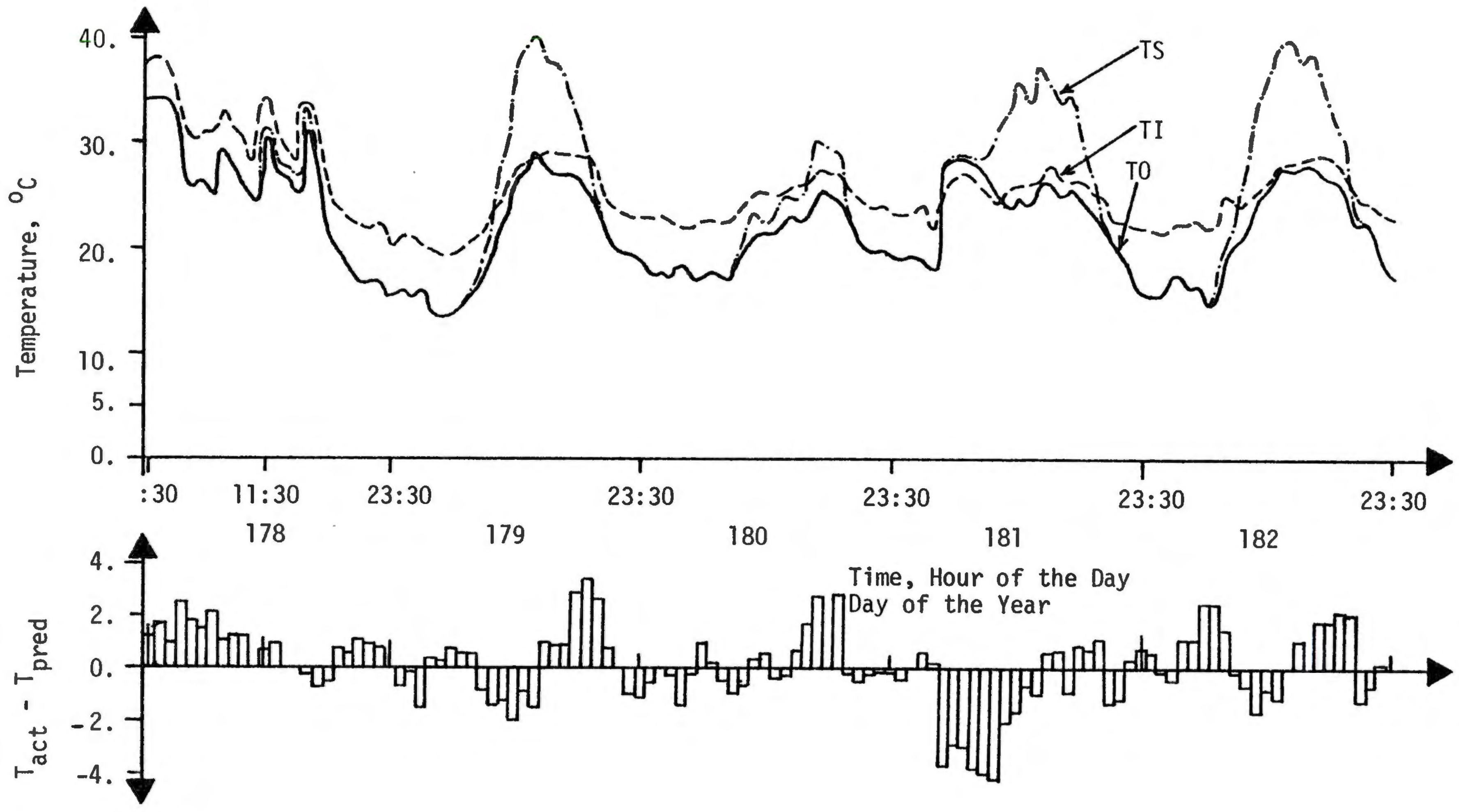

Figure 28. Graphs for the Inside and Outside Temperatures, the Sol-Air Temperature, and the Difference Between the Actual and Predicted Inside Temperatures, (White Egg Farm, (Summer).

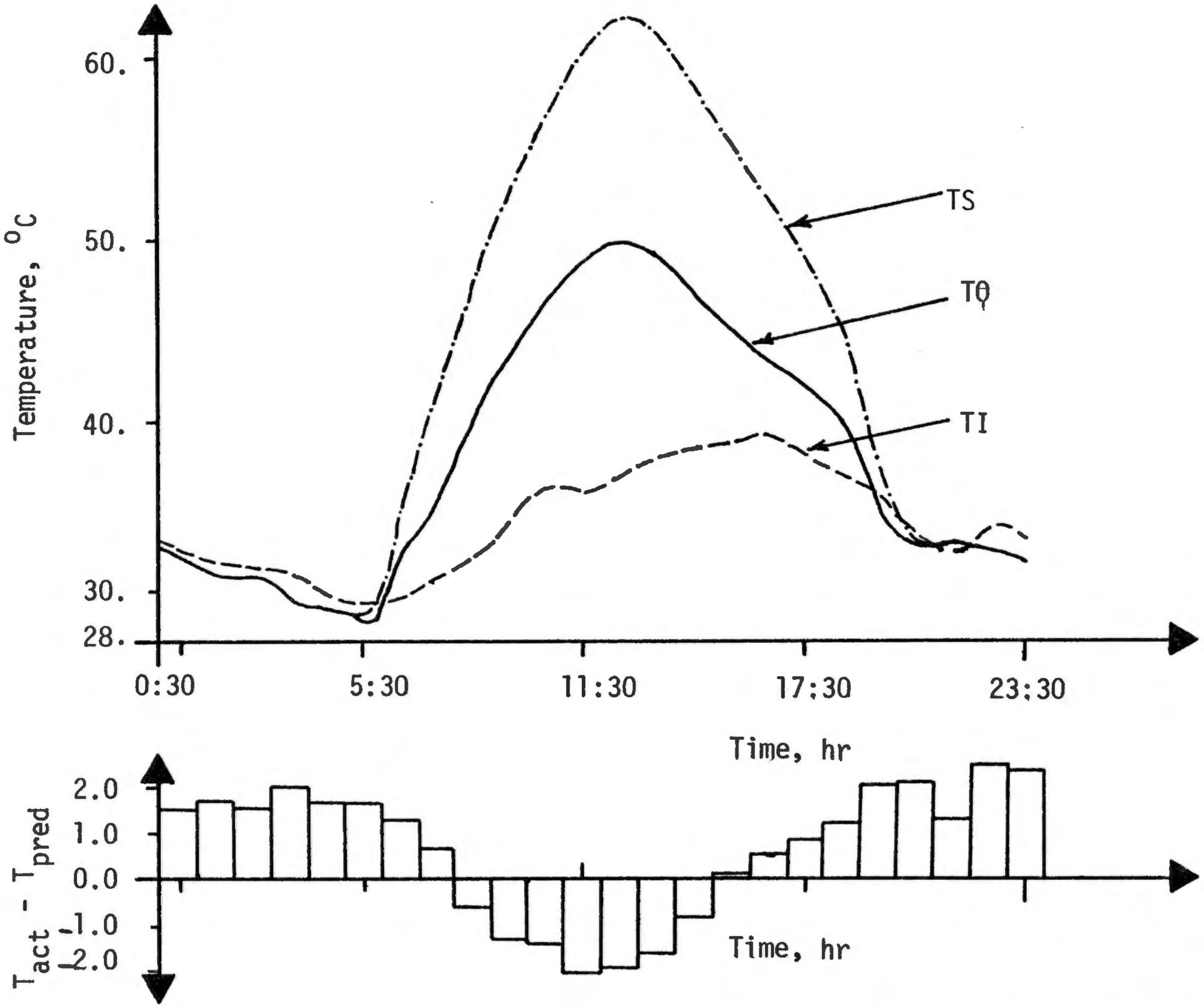

Figure 29. Graphs for the Inside and Outside Temperatures, the Sol-Air Temperature, and the Difference Between the Actual and Predicted Inside Temperatures, (Hammam Al-Allil Farm).

Scott Egg Farm

The average absolute difference between the predicted and the actual temperatures was 1.58^{0} C for the winter part of the experiment. This error was attributed to: (1) air flow rate through openings which is very difficult to measure or estimate, (2) evaporated drinking water, and (3) inaccurate wet bulb temperature measurements. The average inside and outside temperatures during winter (January) were 14.5^{0} C and 2.0^{0} C respectively. No harmful oders were noticed in this building. An average inside temperature of 14.5^{0} C indicates that: (1) the building was very well thermaly designed, and (2) thermostats were adjusted to allow for correct ventilation rates.

During summer (August), the average temperature inside the building was 25.3^{0} C. The average outside temperature was lower than the inside by 1.1^{0} C. This indicated that the ventilation rate (about 1.2 m^{3}/sec-1000 bird) was enough to remove the sensible and latent heat produced by birds. The average difference between the actual and predicted inside temperatures was 0.98^{0} C which is considered very good. A histogram for the hourly difference is shown in Figure 26, page 82.

White Egg Farm

In this building, no ventilation was provided during winter. The average inside and outside temperatures for the period when data were collected were 14.4^{0} C and 1.6^{0} C respectively. Bad odors of high ammonia concentration were noticed. The building was well insulated (UAV = 1.37 $w/m^{2}\ {}^{o}K$). Therefore, artificial ventilation could have been provided to lower the ammonia concentration.

The average difference between the actual and predicted inside temperatures was 1.68^{o} C. This was attributed to the inaccurate measurements of air flow through the uncontrolled opening of curtains and the unaccounted air flow through leakages.

During summer, the average inside and outside temperatures were 25.7^{o} C and 22.3^{o} C respectively. This 3.4^{o} C difference indicated that the ventilation rate was less than needed to remove all the sensible and latent heat produced by birds. The average difference between the actual and predicted inside temperatures was 1.18^{o} C. This was attributed to the unaccounted air flow through open curtains and doors on the side of the building.

<u>Hammam Al-Allil Farm</u>

Data were collected from this farm during the summer only. Graphs for the collected data and a histogram for the difference between the hourly actual and predicted inside temperatures are shown in Figure 29, page 85. Solar radiation data were collected for one day only. Thus only one day's data were used for the analysis. The average difference between the actual and predicted inside temperatures was 1.45^{o} C. This difference was attributed to: (1) Erroneous measurement of the inside relative humidity, and (2) the inaccurate estimation of the air flow rate through open windows.

One hygrothermograph was hanged from ceiling to measure the inside relative humidity. This hygrothermograph did not give correct relative humidity measurements because it was not installed at the level of the birds. Also, not many hygrothermographs were available so that temperatures and relative humidities could be measured at different building locations.

To correct the relative humidity data, it was assumed that all the moisture produced by birds (8 Kg/hr) during the day hours evaporated, and that only 60 percent of this moisture evaporated during the night.

The actual average inside and outside temperatures for the 24 hour period were 34.5^{0} C and 38.1^{0} C respectively. No artificial ventilation was provided. The building insulation was low (2.58 $w/m^{2}\ ^{0}K$). The inside temperature could have been lowered to 30^{0} C or less if the two drip-type evaporative coolers were operated.

IV. ANALYSIS OF THE COMPUTER MODEL

The average difference between the actual measurements and the predicted values of the inside temperature was $\pm 1.3^{0}$ C. Two types of errors apparently caused this difference: (1) Experimental errors caused by the inaccurate measurement of the wet-bulb temperature and the air flow rate. (2) Errors in the computer model: (a) The heat capacity of the walls and ceiling was not considered in the model. This may result in a lag for solar heating of building. (b) Evaporated portion of drinking water during day hours in summer resulted in cooling the building. (c) No provision was taken to account for the back radiation of the roof and walls after the sunset (i.e. the sol-air temperature was assumed equal to the outside air temperature). This may not be correct, the sol-air temperature may drop below the air temperature. The measured black-globe temperature indicated that also. This error would cause the predicted temperature to be higher than the actual temperature during night hours - a difference noted in Figures 25 and 26, pages 81 and 82.

The analysis of the experimental data indicated that the average difference between the actual and predicted inside temperatures was lower in Scott farm compared to that for White farm. The building in Scott farm was of the closed type house (without windows) and the air leakage was very small. The White farm building had curtains which were accidently open during winter, and the airflow rate could not be measured accurately.

Exact measurement of all the factors noted would eliminate the experimental error and reduce the total average difference between the actual measurements and predicted results.

CHAPTER VI

SUMMARY AND CONCLUSIONS

I. SUMMARY

Computer simulation techniques were used to study the effect of certain environmental factors on the energy consumption in poultry laying houses. The environmental factors simulated were: (1) the area per bird, (2) slope of roof, (3) building orientation, (4) building insulation, and (5) the ventilation rate. The other purpose of this study was to evaluate and determine the insulation requirement in poultry laying houses.

Two building shapes were considered: (1) shed-type building and (2) gable-type building. The analysis were conducted for both summer and winter conditions. Weather data of January and July for Knoxville, Tennessee, were used to represent the coolest and hottest months of the year.

The important goal in the computer simulation was to reach an optimum inside temperature during summer and winter by considering various combinations of the environmental factors noted before. Results of the computer model were analysed using the Statistical Analysis System developed by Barr et al. (1979).

To check the validity of the computer model and to study the thermal behavior of poultry buildings, data were collected from three existing buildings. Two of the buildings were near Knoxville, Tennessee, and the third was located at the Agricultural College, Mosul, Iraq.

In each of the buildings near Knoxville, thirty-three thermocouples were installed to measure the wet and dry bulb temperatures at different locations inside and outside the building. Solar radiation data on a horizontal surface were recorded using a pyranometer and recorder. All the measurements were recorded hourly. Simple instruments were used to collect data from the third building.

The computer model was used to predict the temperature inside the building using the measured data. The actual and predicted inside temperatures were compared for each hour. Results of the computer model were within an average error of about $\pm 1.3^{o}$ C when compared with the experimental measurements.

II. CONCLUSIONS

Based on results of the computer simulation and the comparison between the predicted results and actual data, the following conclusions were reached:

1. Reducing the area per bird resulted in less building surface area exposed to the outside conditions, thus higher inside temperature during winter and lower inside temperature during summer could be obtained.

2. Reducing roof slope resulted in higher inside temperatures during winter and slightly lower inside temperatures during summer caused by the reduced total surface area of the building.

3. The building orientation had no significant effect on the inside temperature, however, the best orientation to receive higher amounts of radiation during winter and lower radiation during summer was the east-west direction of the major axis. For the shed-type building, the best orientation was the east-west with a south facing roof.

4. The building insulation proved to have a significant effect on the temperature inside the building. Increasing the insulation would help to maintain higher inside temperature during winter and lower inside temperature during summer.

5. For regions where the monthly average outdoor temperature is above 0^{o} C an overall building U-value of 1.0 to 1.5 $w/m^{2}\ ^{o}K$ would maintain an average inside temperature above 8^{o} C, and no artificial heating would be needed.

6. Under the same environmental conditions, the inside temperature was slightly lower in shed-type buildings during winter and slightly higher during summer when compared with a gable-type house. This was caused by the larger volume and building surface area of the shed-type house for the same house dimensions.

7. For the Knoxville weather conditions, an inside temperature above 8^{o} C can be maintained if a ventilation rate in the range of 0.25 to 0.40 m^{3}/sec-1000 bird were used. This ventilation rate is acceptable for controlling the moisture level and the ammonia concentration inside the building.

8. Using high ventilation rates (more than 1.5 m^3/sec-1000 bird) during summer would not be effective in reducing the temperature inside the building. Thus, high ventilation rates would result in wasting energy on the ventilation system.

9. Windowless poultry buildings proved to be better than buildings with windows for providing optimum inside conditions during summer and winter.

10. Results of the computer simulation were valid with the exceptions of experimental measurement errors, and the unavoidable errors in setting up the computer model.

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LITERATURE CITED

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APPENDIXES

APPENDIX A

COMPUTER SIMULATION MODEL

This appendix contains the computer program that was developed as a simulation model of a poultry laying house. Five variables were considered: (1) area per bird, (2) slope of roof, (3) orientation of building, (4) insulation of walls and roof, and (5) the ventilation rate. Both winter and summer were considered. July was chosen as the most critical month during the hot summer season. January was chosen for the winter season. Two building shapes were considered: the shed and the gable type buildings. The subroutines were developed to determine the inside temperature in a gable-type house under summer conditions for different values of the variables mentioned above. Slight changes were needed for other cases.

```
      ****************      MAIN PROGRAM      ***************

      COMMON PI,AB,S,G,HA,CT,PN,TO,AF,A1,A2,A3,A4,A5,A6,ATOT,BN,TS,TI
     2 ,T(10),SH(10),GLH(10),QSH,QLH,WS,T1,FT1,VT,TM,RHI,RHO,UAV,TSDA
      DIMENSION APB(10),RW(10),RR(10),SL(10),GM(10),V(10)
C
      PI=2.*ARSIN(1.)
C     ASSUME NO. OF BIRDS TO BE HOUSED = 20,000
      BN=20000.
C     SET THE INSIDE RELATIVE HUMIDITY (RHI) = 80 PERCENT
      RHI=80.0
C     SET THE OUTSIDE RELATIVE HUMIDITY (RHO) EQUAL 85 PERCENT FOR THE
C     WINTER AND EQUAL TO 65 PERCENT FOR THE SUMMER
      RHO=65.0
C     SET INITIAL VALUES FOR THE AREA PER BIRD (APB), SLOPE OF ROOF (SL),
C     BUILDING ORIENTATION (GM), TOTAL WALL RESISTANCE (RW), TOTAL ROOF
C     RESISTANCE (RR), AND THE VENTILATION RATE (V)
      APB(1)=0.03
      SL(1)=PI/18.0
      GM(1)=-PI
      RW(1)=0.22
      RR(1)=0.22
C     USE AN INITIAL VALUE FOR THE VENTILATION RATE V(1)=0.25 FOR WINTER
C     AND V(1)=0.6 FOR THE SUMMER
      V(1)=0.60
C     READ INTERPRETATION DATA FOR THE SENSIBLE HEAT (SH), AND THE LATENT
C     HEAT (GLH) PRODUCED BY CHICKEN FOR DIFFERENT INSIDE TEMPERATURE (T)
      DO 20 I=1,9
      READ(5,10) T(I),SH(I),GLH(I)
   10 FORMAT(F4.1,2F6.1)
   20 CONTINUE
      READ(5,100)HA,CT,PN,TO
  100 FORMAT(F5.2,1X,F5.3,1X,2F5.1)
```

MAIN PROGRAM (CONTINUED)

```
      DO 500 II=1,4
C     USE THE INITIAL VALUE OF THE AREA PER BIRD APB(1)= 0.03 SQUARE
C     METER/BIRB, ADD AN INCREMENT OF 0.03
      APB(II+1)=APB(II)+0.03
      DO 500 J=1,4
C     USE THE INITIAL VALUE OF THE SLOPE SL(1)=10.0 DEGREES FROM HORIZAN-
C     TAL, ADD AN INCREMENT OF 10.0 DEGREES
      SL(J+1)=SL(J)+PI/18.
      S=SL(J)
      AB=APB(II)
      CALL AREAS
C     CALCULATE AREA OF WALLS, AND ROOFS
      DO 500 K=1,3
C     STARTING FROM THE NORTH-SOUTH (N-S) ORIENTATION GM(1)=-180.0 DEGREE
C     USE AN INCREMENT OF 45.0 DEGREES SO THAT THE SECOND ORIENTATION
C     WOULD BE NE-SW, THE THIRD ORIENTATION E-W, AND SO ON
      GM(K+1)=GM(K)+PI/4.
C     CALCULATE THE SOL-AIR TEMPERATURE FOR ALL THE BUILDING SURFACES
      G=GM(K)
      S=PI/2.
      CALL SOLAIR
C     CALCULATE THE SOL-AIR TEMPERATURE ON BUILDING SURFACE NO.1 (TSD1)
      TSD1=TS
      G=GM(K)+PI/2.
      S=PI/2.
      CALL SOLAIR
C     CALCULATE THE SOL-AIR TEMPERATURE ON BUILDING SURFACE NO.2 (TSD2)
      TSD2=TS
      G=GM(K)+PI
      S=PI/2.
      CALL SOLAIR
```

MAIN PROGRAM (CONTINUED)

```
C     CALCULATE THE SOL-AIR TEMPERATURE ON BUILDING SURFACE NO.3 (TSD3)
      TSD3=TS
      IF(GM(K).GT.-1.57) GO TO 200
      G=GM(K)+3.*PI/2.
      GO TO 201
  200 G=GM(K)-PI/2.
  201 S=PI/2.
      CALL SOLAIR
C     CALCULATE THE SOL-AIR TEMPERATURE ON BUILDING SURFACE NO.4 (TSD4)
      TSD4=TS
      G=GM(K)+PI/2.
      S=SL(J)
      CALL SOLAIR
      TSD5=TS
C     CALCULATE THE SOL-AIR TEMPERATURE ON BUILDING SURFACE NO.5 (TSD5)
      IF(GM(K).GT.-1.57) GO TO 300
      G=GM(K)+3.*PI/2.
      GO TO 301
  300 G=GM(K)-PI/2.
  301 S=SL(J)
      CALL SOLAIR
C     CALCULATE THE SOL-AIR TEMPERATURE ON BUILDING SURFACE NO.6 (TSD6)
      TSD6=TS
C     CALCULATE THE WEIGHTED AVERAGE SOL-AIR TEMPERATURE
      TSDA=(TSD1*A1+TSD2*A2+TSD3*A3+TSD4*A4+TSD5*A5+TSD6*A6)/ATOT
      DO 500 L=1,4
C     USE THE INITIAL VALUES OF THE TOTAL WALL AND ROOF RESISTANCES, SET
C     THE OTHER VALUES ACCORDING TO TABLF 1.
      IF(L.GE.2) GO TO 310
      RW(L+1)=RW(L)
      GO TC 320
```

MAIN PROGRAM (CONTINUED)

```
  310 RW(L+1)=0.86
  320 IF(L.EQ.3) GO TO 330
      RR(L+1)=0.92
      GO TO 340
  330 RR(L+1)=1.62
  340 UAV=ATOT/(RW(L)*(A1+A2+A3+A4)+RR(L)*(A5+A6))
      TM=24.0*WS/PI
      DO 500 M=1,6
C     USE THE INITIAL VALUE FOR THE VENTILATION RATE V(1), ADD AN INCR-
C     EMENT OF 0.20 IF IT IS WINTER, OR 0.40 IF IT IS SUMMER
      V(M+1)=V(M)+0.4
      VT=V(M)*(BN/1000.)*TM
C     USE THE SECANT METHOD TO DETERMINE THE INSIDE TEMPERATUE (T1)
      CALL SECANT
C     WRITE ALL THE VARIABLES AND THE CORESPONDING INSIDE TEMPERATURE T1
      WRITE(6,400) II,J,K,L,M,APB(II),SL(J),GM(K),UAV,V(M),T1
  400 FORMAT(5I5,6F12.3)
  500 CONTINUE
      STOP
      END
```

SUBROUTINE AREAS

```
      SUBROUTINE AREAS
      COMMON PI,AB,S,G,HA,CT,PN,TO,AF,A1,A2,A3,A4,A5,A6,ATOT,BN,TS,TI
     2 ,T(10),SH(10),GLH(10),QSH,QLH,WS,T1,FT1,VT,TM,RHI,RHO,UAV,TSDA
C
C     GIVEN THE AREA PER BIRD (AB), THE NUMBER OF BIRDS TO BE HOUSED (BN)
C     ,THE SLOPE OF ROOF (S), THE BUILDING HIGHT (H), AND THE WIDTH (W),
C     THIS SUBROUTINE CALCULATES THE FLOOR AREA (AF), THE ATTIC HIGHT
C     (AH), AND ALL THE AREAS OF THE BUILDING SURFACES (A1 THROUGH A6)
C     FOR SHED TYPE ROOF, THE ATTIC HIGHT AH=W*TAN(S) AND A6=0.0
      H=3.5
      W=12.0
      AF=AB*BN
      AH=W*TAN(S)/2.
      DL=SQRT((W/2.)**2+AH**2)
      A1=H*W+0.5*AH*W
      A2=H*AF/W
      A3=A1
      A4=A2
      A5=DL*AF/W
      A6=A5
C     FIND THE TOTAL SURFACE AREA OF THE BUILDIND (ATOT)
      ATOT=A1+A2+A3+A4+A5+A6
      RETURN
      END
```

SUBROUTINE SOLAIR

```
      SUBROUTINE SOLAIR
      COMMON PI,AB,S,G,HA,CT,PN,TO,AF,A1,A2,A3,A4,A5,A6,ATOT,BN,TS,TI
     2 ,T(10),SH(10),GLH(10),QSH,QLH,WS,T1,FT1,VT,TM,RHI,RHO,UAV,TSDA
C
C     FOR GIVEN ORIENTATION AND SLOPE OF SURFACE,THIS SUBROUTINE CALCULATES
C     THE MOTHLY AVERAGE DAILY SOLAR RADIATION AND THE SOL-AIR TEMPERATURE
C     FOR THAT SURFACE
C     LATITUDE FOR KNOXVILLE, TENNESSEE = 36 DEGREE NORTH
      F=36.*PI/180.
C     DETERMINE THE RATIO OF THE DIFFUSE RADIATION TO TOTAL RADIATION (RHD)
      RHD=1.39-4.03*CT+5.53*(CT**2.)-3.11*(CT**3.)
      RHB=1.-RHD
C     CALCULATE THE DECLINATION ANGLE OF SUN (D)
      D=(23.45*PI/180.)*SIN(2.*PI*((284.+PN)/365.))
C     DETERMINE THE SUNSET HOUR ANGLE ON HORIZONTAL SURFACE (WS)
      WS=ARCOS(-TAN(F)*TAN(D))
      SNG=SIN(G)
      ASNG=ABS(SIN(G))
      ABSG=ABS(G)
      ABSS=ABS(S)
      IF(ABSS.LE.0.0) GO TO 62
      IF(ABSG.GT.1.575) S=-S
      IF(SNG.EQ.0.0) GO TO 35
      IF(ABSS.GT.1.57.AND.ASNG.GT.0.9999) GO TO 26
      IF(ABSS.GT.1.57) GO TO 25
      IF(ASNG.GT.0.9999) GO TO 24
C     CALCULATE THE VALUE OF A AND B FOR THE GIVEN ORIENTATION AND SURFACE SLOPE
   21 A=COS(F)/(SIN(G)*TAN(S))+SIN(F)/TAN(G)
      B=TAN(D)*(COS(F)/TAN(G)-SIN(F)/(SIN(G)*TAN(S)))
      GO TO 27
   24 A=COS(F)/(SIN(G)*TAN(S))
```

SUBROUTINE SOLAIR, (CONTINUED)

```
      B=-TAN(D)*SIN(F)/(SIN(G)*TAN(S))
      GO TO 27
   25 A=SIN(F)/TAN(G)
      B=TAN(D)*COS(F)/TAN(G)
      GO TO 27
   26 A=0.0
      B=0.0
   27 U=A*B
      V=SQRT(1.+A**2-B**2)
   29 W=1.+A**2
      X=ARCOS((U+V)/W)
      Y=ARCOS((U-V)/W)
      IF(G)30,35,40
C     DETERMINE THE SUNRISE AND SUNSET HOUR ANGLES (WSR AND WSS RESPECTIVELY)
   30 WSR=-AMIN1(WS,Y)
      WSS=AMIN1(WS,X)
      GO TO 60
   35 Z=ARCOS(-TAN(F-S)*TAN(D))
      WSS=AMIN1(WS,Z)
      WSR=-WSS
      GO TO 61
   40 WSR=-AMIN1(WS,X)
      WSS=AMIN1(WS,Y)
   60 IF(ABSG.GT.1.572) S=-S
C     CALCULATE THE RATIO OF BEAM RADIATION ON TILTED SURFACES NOT FACING
C     SOUTH TO THAT ON A HORIZONTAL SURFACE (RB)
      RB1=(COS(S)*SIN(D)*SIN(F))*(WSS-WSR)
      RB2=(SIN(D)*COS(F)*SIN(S)*COS(G))*(WSS-WSR)
      RB3=(COS(F)*COS(D)*COS(S))*(SIN(WSS)-SIN(WSR))
      RB4=(COS(D)*COS(G)*SIN(F)*SIN(S))*(SIN(WSS)-SIN(WSR))
      RB5=(COS(D)*SIN(S)*SIN(G))*(COS(WSS)-COS(WSR))
```

SUBROUTINE SOLAIR (CONTIUED)

```
      RB6=2.*(COS(F)*COS(D)*SIN(WS)+WS*SIN(F)*SIN(D))
      RB=(RB1-RB2+RB3+RB4-RB5)/RB6
      IF(RB.LT.0.0) RB=0.0
      GO TO 70
   61 IF(ABSG.GT.1.572) S=-S
C     CALCULATE RB FOR SURFACES FACING SOUTH
      RB1P=COS(F-S)*COS(D)*SIN(WSS)+WSS*SIN(F-S)*SIN(D)
      RB2P=COS(F)*COS(D)*SIN(WS)+WS*SIN(F)*SIN(D)
      RB=RB1P/RB2P
      IF(RB.LT.0.0) RB=0.0
      GO TO 70
   62 RB=1.0
   70 BRAD=RHB*RB
      DRAD=RHD*(1.+COS(S))/2.
C     ASSUME REFLECTIVITY CF GROUND = 0.2
C     DETERMINE THE OVERALL RATIO OF SOLAR RADIATION ON TILTED SURFACES
C     TO THAT ON A HORIZONTAL SURFACE (RALL)
      RALL=BRAD+DRAD+0.2*(1.-COS(S))/2.
      HT=HA*RALL
C     DETERMINE THE SOL-AIR TEMPERATURE FOR THE GIVEN SURFACE
      TS=TO+0.72*HT/WS-2.63*COS(S)
      IF(TS.LT.TO) TS=TO
      RETURN
      FND
```

SUBROUTINE SECANT

```
      SUBROUTINE SECANT
      COMMON PI,AB,S,G,HA,CT,PN,TO,AF,A1,A2,A3,A4,A5,A6,ATOT,BN,TS,TI
     2 ,T(10),SH(10),GLH(10),QSH,QLH,WS,T1,FT1,VT,TM,RHI,RHO,UAV,TSDA
C
C     THIS SUBROUTINE USES THE SECANT METHOD OF ITERATION TO DETERMINE
C     THE INSIDE TEMPERATURE (T1) AT WHICH EQUILIBRIUM TAKES PLACE
      TX=-5.0
      TX1=35.0
      T1=TX
      CALL FUNCT
      FTX=FT1
      T1=TX1
      CALL FUNCT
      FTX1=FT1
      DO 20 KK=2,20
      TX2=(TX*FTX1-TX1*FTX)/(FTX1-FTX)
      FTX=FTX1
      TX=TX1
      T1=TX2
      CALL FUNCT
      FTX1=FT1
      ERR=ABS(TX2-TX1)
C     IF THE INSIDE TEMPERATURE BECOMES WITHIN AN ABSOLUTE ERROR OF 0.05,
C     THEN STOP
      IF(ERR.LT.0.05) GO TO 30
      TX1=TX2
   20 CONTINUE
      WRITE(6,25)
   25 FORMAT('*** DID NOT CONVERGE ***')
   30 RETURN
      END
```

SUBROUTINE FUNCT

```
      SUBROUTINE FUNCT
      COMMON PI,AB,S,G,HA,CT,PN,TO,AF,A1,A2,A3,A4,A5,A6,ATOT,BN,TS,TI
     2 ,T(10),SH(10),GLH(10),QSH,QLH,WS,T1,FT1,VT,TM,RHI,RHO,UAV,TSDA
C
C     GIVEN: (1) BIRD NO. (BN), (2) SENSIBLE AND LATENT HEAT (QSH AND
C     QLH), (3) THE INSIDE AND THE OUTSIDE TEMPERATURES (T1 AND TO),
C     (4) THE INSIDE AND THE OUTSIDE RELATIVE HUMIDITIES (RHI AND RHO),
C     (5) THE BUILDING OVERALL THERMAL CONDUCTIVITY (UAV), (6) THE TOTAL
C     BUILDING SURFACE AREA (ATOT), AND (7) THE TOTAL VENTILATION (VT),
C     THIS SUBROUTINE CALCULATES: (1) THE HEAT PRODUCED BY BIRDS (QB),
C     (2) THE HEAT FOR VENTILATION (QV), AND (3) THE CONDUCTION HEAT
C     TRANSFER (QC)
C     ASSUME WT. OF BIRD=1.8 KG
      TI=T1
      CALL HEAT
      TDB=T1
      RH=RHI
      CALL HUMIDT(TDB,RH,ENTH,SPVOL)
C     CALCULATE THE PROPERTIES OF AIR INSIDE THE BUILDING
      HI=ENTH
      SVI=SPVOL
      TDB=TO
      RH=RHO
      CALL HUMIDT(TDB,RH,ENTH,SPVOL)
C     CALCULATE THE PROPERTIES OF AIR OUTSIDE THE BUILDING
      HO=ENTH
      QB=(1.8*BN/1000.)*(QSH+QLH)*TM
      QV=VT*(HI-HO)/SVI
      QC=UAV*ATOT*(T1-TSDA)*TM/1000.
      FT1=QB-QV-QC
      RETURN
      END
```

SUBROUTINE HEAT

```
      SUBROUTINE HEAT
      COMMON PI,AB,S,G,HA,CT,PN,TO,AF,A1,A2,A3,A4,A5,A6,ATOT,BN,TS,TI
     2 ,T(10),SH(10),GLH(10),QSH,QLH,WS,T1,FT1,VT,TM,RHI,RHO,UAV,TSDA
C
C     THIS SUBROUTINE INTERPOLATES BETWEEN GIVEN VALUES OF SENSIBLE AND
C     LATENT HEAT TO FIND THE SENSIBLE HEAT (QSH) AND THE LATENT HEAT
C     (QLH) IN KW/1000 KG OF BODY WEIGHT OF BIRDS FOR ANY GIVEN TEMP-
C     ERATURE (TI)
      DO 50 LL=1,9
C     DETERMINE THE SENSIBLE HEAT (QSH)
      SH1=SH(LL)+(SH(LL+1)-SH(LL))*(TI-T(LL))/(T(LL+1)-T(LL))
      IF(TI-T(LL+1)) 51,51,50
   50 CONTINUE
   51 QSH=SH1
      DO 60 MM=1,9
C     DETERMINE THE LATENT HEAT (QLH)
      GLH1=GLH(MM)+(GLH(MM+1)-GLH(MM))*(TI-T(MM))/(T(MM+1)-T(MM))
      IF(TI-T(MM+1)) 62,62,60
   60 CONTINUE
   62 QLH=GLH1
      RETURN
      END
```

SUBROUTINE HUMIDT

```
      SUBROUTINE HUMIDT(TDB,RH,ENTH,SPVOL)
C
C     GIVEN TEMPERATURE AND RELATIVE HUMIDITY, THIS SUBROUTINE CALCULATES
C     THE OTHER PARAMETERS NEEDED FOR PSYCHROMETRIC ANALYSIS
C     INPUT PARAMETERS ARE DRY BULB TEMPERATURE (TDB) IN DEG C AND
C     RELATIVE HUMIDITY IN PERCENT
C     ENTH = ENTHALPY, JOULES PER GRAM OF DRY AIR
C     RH = RELATIVE HUMIDITY IN DECIMAL FORM
C     SPVOL = SPECIFIC VOLUME, CUBIC METERS PER KILOGRAM OF DRY AIR
C       ** REFERENCE, WILHELM (1976) **
      PATM = 101.325
      P = PATM
      R = 0.28705
C     CALCULATE SATURATION VAPOR PRESSURE FOR DRY BULB TEMPERATURE
      T = TDB + 273.16
      IF(T.GT.273.16) GO TO 10
      PSDB = EXP(24.2779 - 6238.64/T - 0.344438*ALOG(T))
      GO TO 20
   10 PSDB = EXP(-7511.52/T + 89.63121 + 0.02399897O*T - 1.1654551E-5*(
     2 T**2) - 1.2810336E-8*(T**3) + 2.0998405E-11*(T**4) - 12.150799*
     3 ALOG(T))
C     CALCULATE PROPERTIES AT DESIRED STATE POINT
   20 RH = RH/100
      PW = RH*PSDB
      W = 0.62198*PW/(P-PW)
      ENTH = 1.006*TDB + W*(2501+1.775*TDB)
      SPVOL = R*T*(1+1.6078*W)/P
      RETURN
      END
```

APPENDIX B

LIST OF SYMBOLS

Symbol	Definition
AB	Floor area per bird as used in subroutine AREAS, m^2/bird
AF	Floor area of building, m^2
AH	Attic Height, m
APB or APB(II)	Floor area per bird as used in the main program, m^2/bird
AR	Area of roof, m^2
ATOT	Total surface area of building, m^2
AW	Total area of walls, m^2
A1 through A6	Area of wall No. 1 through No. 6 as shown in Figure 3, page 22, m^2
BN	Number of birds to be housed
CT	Ratio of the monthly average daily total radiation to the extraterrestrial daily insolatuion
D	The declination of sun, radians
DIF	Difference between the actual and predicted inside temperatures (T_{act}-T_{pred})
DL	Hypotenuse of roof, m
ENTH	Enthalpy of air, KJ/Kg of dry air
F	Latitude, radians

FTX	The residual of the iteration equation previous to the last in subroutine SECANT
FTX1 or FT1	The residual of the last iteration in subroutine SECANT
G or GM(K)	The surface azimuth angle, that is, the angle the surface makes with south, (the zero point due south, east negative, and west positive, radians)
GLH1	Interpolation value of the latent heat produced by birds at the inside temperature T1, Kw/1000 Kg of body weight per hour
GLH(I)	Latent heat produced by birds, Kw/1000 Kg of body weight
h_o	Coefficient of heat transfer by radiation and convection at the outdoor surface, BTU/hr. sq ft. ^oF
H	Height of building, m
HA	Total daily radiation on horizontal surface, MJ/m^2
HI	Enthalpy of air inside the building, KJ/Kg Dry Air
HO	Enthalpy of air outside the building, KJ/Kg Dry Air
HT	Total daily radiation on tilted surface, MJ/m^2

I_t	Total solar radiation incident on surface BTU/hr. sq ft.
L	Length of building, m
PATM	Atmospheric pressure, KPa
PI	π
PN	The day of the year given to represent each month
PW	Saturation pressure, KPa
QB	Total daily heat production by birds, Kwh
QC	Total daily heat transfer through building surfaces, Kwh
QLH	Hourly latent heat production of birds, Kw/1000 Kg of body weight
QSH	Hourly sensible heat production of birds, Kw/1000 Kg of body weight
QV	Total daily heat gained or lost by ventilation, Kwh
r	The correlation coefficient
R	Gas constant for air, KJ/Kg ^{o}K
RALL	Overall ratio of daily average radiation on inclined surface to that on horizontal surface
RB	Ratio of beam radiation on tilted surface to that on horizontal surface

RH	Relative humidity, percent
RHD	The ratio of the monthly average daily diffuse radiation to the monthly average daily total radiation
RHI	Relative humidity of air inside the building, percent
RHO	Relative humidity of air outside the building, percent
RR or RR(L)	Total resistance of roof to heat flow excluding outside surface resistance, m^2 $^oK/w$
RW or RW(L)	Total resistance of wall to heat flow excluding outside surface resistance, m^2 $^oK/w$
R-Value	Resistance Value of walls or ceiling, m^2 $^oK/w$
S or SL(J)	Slope of roof, radians
SH1	Interpolation value of the sensible heat produced by birds at the inside temperature TI, Kw/1000 Kg of body weight per hour
SH(I)	Sensible heat produced by birds at the inside temperature T(I), Kw/1000 Kg of body weight
SPVOL	Specific volume of air, m^3/Kg of dry air
SVI	Specific volume of air inside the building, m^3/Kg of dry air
T_{act}	Actual measured temperature inside the building, ^oC

TDB	Dry bulb temperature, ^oC
T(I)	Inside temperature as used in the interpolation subroutine HEAT
TI or T1	Temperature inside the building, ^oC
TM	Total hours from sunrise to sunset, hr
TO or t_o	Daily average outside temperature for the month, ^oC
T_{pred}	Predicted inside temperature, ^oC
TS or t_e	Sol-air temperature as determined from the subroutine SOLAIR, ^oC
TSDA	Weighted average sol-air temperature of building surfaces, ^oC
TSD1 through TSD6	Sol-air temperature of building surfaces A1 through A6
TX and TX1	Temperatures for the iteration range in the subroutine SECANT, ^oC
TX2	The temperature to be used for the next iteration, ^oC
UAV	Overall U-value of building excluding the coefficient of heat transfer from air to outside surface, $w/m^2\ ^oK$
VT	Total ventilation during the day time hours, m^3
V(M)	Ventilation rate, m^3/sec-1000 bird
W	Width of building, m

WS	Sunset hour angle on horizontal surface, radians
WSR	Sunrise hour angle on tilted surfaces, radians
WSS	Sunset hour angle on tilted surfaces, radians
α	Absorptance of surface for solar radiation
ε	Hemispherical emittance of the surface
ΔR	The difference between the long wave radiation incident on the surface from the sky and surroundings, and the radiation emitted by a black body at outdoor air temperature, BTU/hr. sq. ft.

VITA

Nazar J. Alias was born in Mosul, Iraq, on July 27, 1950. He graduated from Al-Mustakbal High School in June 1968. In September of that year, he entered the University of Mosul where he graduated in June of 1972 with a Bachelor of Science degree in Agricultural Engineering. He received the honor of being the first in his department and the third in his college among graduates of that year. During July of 1972 he became a member of the Iraqi Engineers Union. In October of that year he entered the Iraqi Army and served as a soldier for one year and as a Second Lieutenant for six months. In March 1974, he was employed as an assistant engineer by the College of Engineering, University of Mosul.

In 1974 he was granted a full scholarship from the Iraqi Government to study for the M.S. and Ph.D. degrees in the United States. He entered The University of Tennessee in the fall of 1975 and received the M. S. degree in Agricultural Engineering in the spring of 1977.

He is married to Shatha K. Ameen and has a son three years old.