Production and Environmental Simulations for Livestock Housing

Mark Allen Diesch

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PRODUCTION AND ENVIRONMENTAL SIMULATIONS
FOR LIVESTOCK HOUSING

by

Mark A. Diesch

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in Agricultural
Engineering, South Dakota
State University
1987
PRODUCTION AND ENVIRONMENTAL SIMULATIONS
FOR LIVESTOCK STRUCTURES

This thesis is approved as a creditable and independent investigation by a candidate, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Donell P. Froehlich
Thesis Advisor

Dr. Mylo A. Hellickson
Head of Major Department

Date
DEDICATION

This thesis is dedicated to my mother. Her guidance, sacrifice, strength, and love paved my way through the graduate program. Rest in peace.

MAD
ACKNOWLEDGEMENT

I wish to express my gratitude to Dr. Donell P. Froehlich for guiding efforts and a supportive atmosphere for innovation throughout the course of this study.

The author also wishes to express his appreciation to the entire Agricultural Engineering faculty and staff for assistance and cooperation during this research.

Special appreciation is extended to Dr. Mylo A. Hellickson for his advice, guidance, and assistance throughout undergraduate and graduate study.

Deepest gratitude is expressed to the author's family for their assistance and encouragement throughout this candidacy.

MAD
# TABLE of CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION and OBJECTIVES</td>
<td>1</td>
</tr>
<tr>
<td>LITERATURE REVIEW</td>
<td>5</td>
</tr>
<tr>
<td>Environmental Factors</td>
<td>5</td>
</tr>
<tr>
<td>Animal Housing</td>
<td>10</td>
</tr>
<tr>
<td>State-Of-The-Art Livestock Environmental Models</td>
<td>14</td>
</tr>
<tr>
<td>MATHEMATICAL ANALYSIS and COMPUTER SIMULATION</td>
<td>17</td>
</tr>
<tr>
<td>Simulation Description</td>
<td>17</td>
</tr>
<tr>
<td>Outdoor Climatic Data</td>
<td>19</td>
</tr>
<tr>
<td>Sol-Air Temperature</td>
<td>20</td>
</tr>
<tr>
<td>Animal Heat and Moisture Production</td>
<td>23</td>
</tr>
<tr>
<td>Structural Heat and Moisture Production</td>
<td>24</td>
</tr>
<tr>
<td>Steady-Periodic Heat Exchange Through Wall and Roof Surfaces</td>
<td>25</td>
</tr>
<tr>
<td>Ventilation/Infiltration Heat and Moisture Exchange</td>
<td>27</td>
</tr>
<tr>
<td>Heat and Moisture Exchange with Floor</td>
<td>29</td>
</tr>
<tr>
<td>Simulation Solution</td>
<td>32</td>
</tr>
<tr>
<td>Computer Simulation Structure</td>
<td>33</td>
</tr>
<tr>
<td>SIMULATION EXAMPLE EXAMPLE PROCEDURE</td>
<td>36</td>
</tr>
<tr>
<td>RESULTS and DISCUSSION</td>
<td>42</td>
</tr>
<tr>
<td>Summer Conditions</td>
<td>42</td>
</tr>
<tr>
<td>Winter Conditions</td>
<td>55</td>
</tr>
<tr>
<td>Applications</td>
<td>68</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>SUMMARY and CONCLUSIONS</td>
<td>73</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>76</td>
</tr>
<tr>
<td>APPENDICES</td>
<td>79</td>
</tr>
<tr>
<td>A. List of Symbols</td>
<td>80</td>
</tr>
<tr>
<td>B. Mathematical Equations</td>
<td>85</td>
</tr>
<tr>
<td>C. Multiple Regression Analysis of Swine Heat</td>
<td>89</td>
</tr>
<tr>
<td>Simulation Example Inputs</td>
<td>94</td>
</tr>
<tr>
<td>E. Computer Simulation</td>
<td>99</td>
</tr>
</tbody>
</table>
# LIST of FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Environmental temperature effects on productivity</td>
<td>8</td>
</tr>
<tr>
<td>2.</td>
<td>Energy exchange between environment and animal</td>
<td>9</td>
</tr>
<tr>
<td>3.</td>
<td>Relationship of livestock energies</td>
<td>13</td>
</tr>
<tr>
<td>4.</td>
<td>Heat and moisture exchange in livestock structures</td>
<td>18</td>
</tr>
<tr>
<td>5.</td>
<td>Data set reduction of Fourier series prediction function</td>
<td>21</td>
</tr>
<tr>
<td>6.</td>
<td>Flow chart of computer simulation</td>
<td>35</td>
</tr>
<tr>
<td>7.</td>
<td>Simulation example structure</td>
<td>37</td>
</tr>
<tr>
<td>8.</td>
<td>Fourier series prediction of outdoor temperature (summer conditions)</td>
<td>43</td>
</tr>
<tr>
<td>9.</td>
<td>Manure pit bottom temperature (summer conditions)</td>
<td>43</td>
</tr>
<tr>
<td>10.</td>
<td>Predicted sol-air temperature of roof (summer conditions)</td>
<td>45</td>
</tr>
<tr>
<td>11.</td>
<td>Fourier series prediction of outdoor relative humidity (summer conditions)</td>
<td>45</td>
</tr>
<tr>
<td>12.</td>
<td>Swine energy production</td>
<td>47</td>
</tr>
<tr>
<td>13.</td>
<td>Swine weight gain</td>
<td>47</td>
</tr>
<tr>
<td>14.</td>
<td>Ventilation rate for temperature control (summer conditions)</td>
<td>50</td>
</tr>
<tr>
<td>15.</td>
<td>Moisture function with ventilation rate for temperature control (summer conditions)</td>
<td>50</td>
</tr>
<tr>
<td>16.</td>
<td>Ventilation rate for temperature control (summer conditions + 5.6 °C)</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>17</td>
<td>Moisture function with ventilation rate for temperature control (summer conditions + 5.6 °C)</td>
<td>53</td>
</tr>
<tr>
<td>18</td>
<td>Energy function with ventilation rate for temperature control (summer conditions + 5.6 °C)</td>
<td>56</td>
</tr>
<tr>
<td>19</td>
<td>Energy function with MWPS recommended ventilation rate (summer conditions)</td>
<td>57</td>
</tr>
<tr>
<td>20</td>
<td>Energy function with MWPS recommended ventilation rate (summer conditions + 5.6 °C)</td>
<td>57</td>
</tr>
<tr>
<td>21</td>
<td>Fourier series prediction of outdoor temperature (winter conditions)</td>
<td>59</td>
</tr>
<tr>
<td>22</td>
<td>Manure pit bottom temperature (winter conditions)</td>
<td>59</td>
</tr>
<tr>
<td>23</td>
<td>Predicted sol-air temperature of roof (winter conditions)</td>
<td>60</td>
</tr>
<tr>
<td>24</td>
<td>Fourier series prediction of outdoor relative humidity (winter conditions)</td>
<td>60</td>
</tr>
<tr>
<td>25</td>
<td>Ventilation rate for moisture control (insulated winter conditions)</td>
<td>63</td>
</tr>
<tr>
<td>26</td>
<td>Energy function with ventilation rate for moisture control (insulated winter conditions)</td>
<td>63</td>
</tr>
<tr>
<td>27</td>
<td>Ventilation rate for moisture control (uninsulated winter conditions)</td>
<td>64</td>
</tr>
<tr>
<td>28</td>
<td>Energy function with ventilation rate for moisture control (uninsulated winter conditions)</td>
<td>64</td>
</tr>
<tr>
<td>29</td>
<td>Energy function with MWPS recommended ventilation rate (insulated winter conditions)</td>
<td>66</td>
</tr>
<tr>
<td>30</td>
<td>Energy function with MWPS recommended ventilation rate (uninsulated winter conditions)</td>
<td>66</td>
</tr>
<tr>
<td>31</td>
<td>Energy transmission through structure (insulated winter conditions)</td>
<td>67</td>
</tr>
</tbody>
</table>
32. Energy transmission through structure (uninsulated winter conditions) ................. 67
33. Simulation control application schematic ........ 70
C.1. Swine sensible/latent heat production and weight gain ........................................... 92
### LIST of TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Normal livestock rectal temperatures</td>
<td>7</td>
</tr>
<tr>
<td>2.</td>
<td>Production of a 108 kg market hog</td>
<td>14</td>
</tr>
<tr>
<td>D.1.</td>
<td>Building surface construction components</td>
<td>96</td>
</tr>
<tr>
<td>D.2.</td>
<td>Building surface orientation and solar radiation parameters</td>
<td>98</td>
</tr>
</tbody>
</table>
INTRODUCTION and OBJECTIVES

A trend in animal production in the United States, especially for swine and poultry, has been toward large intensified facilities. These facilities have a high initial investment, thus, decreasing the margin of profit per animal (Albright and Scott, 1975). Optimum livestock facilities are, therefore, needed.

Production optimization is greatly influenced by the environment a facility provides for the animal. An animal's environment is affected by all surrounding conditions. The thermal environment; the effects of air temperature, moisture, and velocity balanced with animal heat and moisture production, is part of the total environment. It is one of the most important influences of an animal's surroundings since 25 to 40 percent of an animal's gross feed energy is converted to heat and moisture loss to the environment (MWPS-1, 1983). Successful environmental modification is achieved when a structure enhances the thermal environment to maximize production. Poor livestock thermal environments occur because of poor livestock structures. A structure with the correct thermal environment will provide conditions such that the homeothermic animal will be in a zone of thermal comfort. If the animal's thermal environment falls below the zone of thermal comfort, cold stress takes place and the animal
increases heat production which decreases animal weight gain. If the animal’s thermal environment rises above the zone of thermal comfort, the animal must increase its capabilities to dissipate the excess heat, again, decreasing animal production efficiency. The successful livestock structure will, thus, provide conditions required to maintain the zone of thermal comfort.

The primary parameters of the zone of thermal comfort include environmental temperature and moisture. To achieve proper conditions, the building must be correctly constructed and ventilated. The building construction and ventilation system are interdependent. Harmony must occur between them to provide a zone of thermal comfort. Livestock structures, presently, are constructed under design generalities. Specifications in ventilation type and construction remain virtually the same throughout a climatic area. These specifications resulted from generalizations in design. Design temperatures and animal heat production values are generalized to constant values. Seasonal temperature and moisture highs and lows can cause stress to an animal in a structure designed for a region’s general climate. This coupled with increasing heat production of the animal throughout its growth cycle could, quite often, lead to ventilation system and construction errors producing a poor thermal environment.

Each structure is unique. A simulation of interior
environmental conditions throughout the animal's life span would aid in the proper construction and ventilation of an individual structure by considering the varying effects of animal heat and moisture production in conjunction with climatic variation. These effects change quickly through the animal's life span. Better control is needed to follow these variables to properly match building construction with the ventilation system. A simulation considering the rapidly changing environmental effects would develop structural ventilation curves, predict interior environmental temperature, estimate supplemental heating/cooling, and produce other desired parameters, such as required feed intake, as the animal grows. Additionally, a simulation maybe used as the program statement for the controller of the ventilation system. The two facts that $1.8$ billion dollars in cash receipts for livestock production in South Dakota were received in 1984 and the value of South Dakota's farm buildings reached $1.2$ billion in 1985 emphasize the need for a more sophisticated design practice (USDA, 1985).

Computer simulations have been developed to formulate energy and moisture functions for livestock facilities for the prediction of interior environments. These simulations, however, neglected the effects of animal growth and seasonal climatic changes throughout the
animal's lifecycle. Also, the simulations were conducted on a main-frame computer limiting the model's use. Research was, thus, initiated with the following specific objectives:

1) Develop a simulation to predict interior environmental conditions, in a livestock structure, as animal growth and climatic conditions change throughout a segment of the animal's life cycle.

2) Evaluate the simulation performance and sensitivity for a specific geographic location, climate, construction, and occupant.
LITERATURE REVIEW

**Environmental Factors**

An environment can be described as the aggregate of surrounding things, conditions, or influences (Stein, 1980). In the case of livestock, environment pertains and includes such parameters as building materials, ventilation, temperature, moisture, feed, noise, and other influences. It is widely recognized that, in many cases, animal efficiency is reduced by stress imposed on the animal by environmental factors (Hellickson and Walker, 1983). The environment in which the animal is maintained, the thermal environment, is part of the total environment. But it is the single most important factor affecting productivity (Morrison, 1982). The thermal environment relates the affects of air temperature, moisture, air velocity, and solar radiation on the balance and regulation of animal heat and their total influence on animal production and health (MWPS-1, 1983). For each animal species, there is a thermal environment that permits body functions to take place with a minimum input of energy. The optimal thermal environment is the range of conditions that provides acceptable animal performance (ASHRAE, 1985).

The steady regulation of body temperature in a normal temperature range is an example of homeostasis, the maintenance of a body state within narrow limits. The
animals hypothalamus gland regulates the maintenance of body temperature by controlling the neural and hormonal responses that alter heat production and heat loss from environmental stimuli (MWPS-1, 1983). Thus, the animals maintain a rather constant body temperature through a variety of thermal conditions, with fatality occurring when body temperatures stray only a few degrees from the normal range (Table 1). Therefore, the environment affects the heat production of livestock in their attempt to maintain a normal body temperature. Conversely, heat and moisture losses of the animal affect the temperature and moisture content of the environment surrounding the animal creating a balance between occupant and environment (Hellickson and Walker, 1983).

Table 1. Normal livestock rectal temperatures (MWPS-1, 1983).

<table>
<thead>
<tr>
<th>Animal</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy Cow</td>
<td>Average 38.6</td>
</tr>
<tr>
<td>Beef Cow</td>
<td>38.3</td>
</tr>
<tr>
<td>Pig</td>
<td>39.2</td>
</tr>
<tr>
<td>Sheep</td>
<td>39.1</td>
</tr>
<tr>
<td>Chicken</td>
<td>41.7</td>
</tr>
</tbody>
</table>
Productivity is affected by the ambient air temperature (Figure 1). A small deviation of environmental temperature from optimum produces a drastic reduction in productivity. This, in turn, extends the production period of the animal by increasing the time needed to achieve market weight. The extended production period strains the animal manager's attempt to balance production costs. High humidity levels, at higher temperatures, will also depress animal efficiency. When higher temperature ranges occur, the temperature difference between the environment and animal body is narrow. The animal then has to place more emphasis on evaporation of body excretions for heat dissipation. If the environmental humidity level is high, evaporation is made more difficult and heat stress could develop (Esmay and Dixon, 1986). N.R. Scott, J.A. DeShazer, and W.L. Rollar state the moisture content of the environment will also indirectly affect the performance of the animal by reducing air quality through dust concentrations and pathogens (Hellickson and Walker, 1983).

Occupant and environmental energy exchange is a relationship between metabolic heat production (MHP), sensible heat loss (SHL), evaporative heat loss (EHL), and body temperature as a function of the environment. Many variations in the definition of thermal/environmental zones exist. The N.R. Scott, J.A. DeShazer, and W.L. Rollar depiction was found in Hellickson and Walker (1983)(Figure
Figure 1. Environmental temperature effects on productivity (MWPS-1, 1983).
Figure 2. Energy exchange between environment and animal (Hellickson and Walker, 1983).
2). They defined these zones to be: zone A, zone of hypothermia; zone CD, zone of least thermoregulatory effort; zone CE, zone of minimum metabolism; zone BE, thermoregulatory zone; point B, temperature of maximum MHP and point of incipient hypothermia; point C, critical temperature, below which MHP begins to increase from the minimum as environmental temperature decreases; point D, temperature at which there is a marked increase in EHL with rise in environmental temperature; point E, temperature of incipient hyperthermia; and point G, the point where sensible heat loss no longer exists and animal temperature is equal to environmental temperature. It is important to define the range of the thermal environment for optimum animal performance rather than a single point because of the many changing influences.

**Animal Housing**

Animals in the wilderness survive by moving about and selecting an acceptable environment. They are not only exposed to seasonal extremes of the thermal environment, but are also subjected to killing by predators, starvation in the winter, gorging in the spring, and illness from diseases and parasites. Domesticated livestock used for human consumption and use are, when reared outside animal housing, exposed to similar environmental influences without the freedom of selecting a comfortable thermal environment.
because of area restrictions. These influences have led to increasing numbers of farm animals being housed or raised in intensive production facilities. The last 20 to 30 years have seen dramatic shifts in production methods which have generally benefitted livestock production along with the concerns of animal welfare (Hahn et al., 1982).

Pork production, almost 80 percent, is primarily in 12 midwestern corn belt states. Between 1950 and 1974, the number of hog producers decreased from two million to under 500,000 with a corresponding increase in size of enterprise. Producers selling 1000 or more head annually in 1977 accounted for about 40 percent of the total production compared with seven percent in 1964 (Hahn et al., 1982). This trend of increasing confinement production facilities has also led to a decrease in labor-hours per 45.36 kg hog produced, decreasing from 3.0 in 1945 to 0.3 in 1980 (USDA, 1985). These trends coupled with the need for consistent supplies of animal products has dictated the need for a type of housing to shorten the animal production cycle by reducing animal stress from environmental extremes.

Engineering has improved the technical aspects of livestock production systems similar to the reasons that operations in other production disciplines have improved: increased efficiency, better utilization of resources, improvement of product quality, improvement of environmental
conditions for animals, and reduction of animal drudgery (Hahn et al., 1982). Producers must provide acceptable environments for animals in confined production systems. To accomplish this task, the three main sources of energy input: feed, fuel, and human energy, and their relationships to livestock production, must be examined (Figure 3).

The design of a production facility will affect the behavior of livestock and, in turn, affect the energy intake, heat production, and heat loss (Deshazer and Overhults, 1982). An efficient balance of these is thought to exist in an environmental temperature zone where heat production of the animal is fairly constant. In this zone, little, if any, energy is diverted from production to maintain homeothermy (Deshazer and Overhults, 1982). Thus, livestock are sheltered to improve production efficiency. For example, during cold weather the environmental temperature of a housed animal is higher than that of an animal in an outside lot. The higher environmental temperature of the housed animal conserves heat loss, thus, decreasing the total heat production compared to an animal housed in the outside lot. A decrease in animal heat production diverts the gross feed energy from heat production to energy retained by the animal (Deshazer and Overhults, 1982) (Table 2).

This type of energy management involves the control of interior environmental temperature and moisture, the
Figure 3. Relationship of livestock energies.
Table 2. Production of a 108 kg market hog (MWPS-1, 1983).

<table>
<thead>
<tr>
<th>Environmental Temperature (°C)</th>
<th>Feed (kg)</th>
<th>Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>720</td>
<td>200</td>
</tr>
<tr>
<td>15.7</td>
<td>315</td>
<td>100</td>
</tr>
<tr>
<td>32.5</td>
<td>720</td>
<td>400</td>
</tr>
</tbody>
</table>

thermal environment, along with other variables of the shelter such as insulation, floor type, building material type, and ventilation.

State-Of-The-Art Livestock Environmental Models

The use of mathematics has long been recognized as a very efficient method to access and organize environmental situations and the interaction between livestock and environment. With the development of the computer, mathematical environmental simulations have evolved with tremendous creativity. Several models have been developed describing the interior livestock environment of housing using a variety of approaches.

Normal design procedure of animal housing employs steady-state heat and moisture energy equations. They were considered adequate by Cole (1983) who stated that these equations could be used to predict time-varying building temperature within 10 percent of that which would be predicted from non-steady calculations, which are quite
complex. The steady-state heat and moisture energy equations were, thus, used in many models such as Sparks (1979) for the design analysis and performance simulation for ventilating and heating of livestock structures.

Albright and Scott (1974) presented a mathematical and computer model resulting in a closed-form solution for the steady-periodic temperature of a ventilated building. Parameters considered to affect the interior environmental temperature were: the mass of air in the building, outside air temperature variations, the ventilation rate, solar heating, heat transfer with the floor, heat production within the building, and building construction characteristics. This model takes the steady-state heat and moisture energy equations beyond normal design practices by considering the effects of hourly weather variation. Christianson (1976) expanded on the steady-periodic heat and moisture energy equations by constructing a computer model that economically analyzed energy consumption in a livestock shelter for varying levels of insulation. Albright and Scott (1975) also added to their previously mentioned model by considering multiple, thermally-interacting, air spaces.

All of the previously mentioned simulations seemed to be lacking one or more influences in the balance of heat and moisture. Structures with a manure pit and exposed manure and water areas produce latent heat. Few simulations
account for the fact that most livestock production facilities include some type of exposed aqueous surface to the environment. The majority of previous models took into account daily diurnal weather extremes by constructing the simulation on a hourly basis. Seasonal diurnal weather extremes, however, are much more radical. These climatic fluctuations could be considered by a heat and moisture balance throughout the life cycle of the animal for each day. In doing this, the effects of animal growth, as a function of heat and moisture production, during the animal's entire life cycle could be considered. Along with daily air temperature and moisture, they were considered periodic in nature. In this research, an attempt will be made to examine the previously mentioned considerations and derive a personal computer simulation.
MATHEMATICAL ANALYSIS and COMPUTER SIMULATION

Simulation Description

A computer simulation was developed to account for animal growth and climatic variation in livestock structures. Numerous factors influence the energy exchange between the indoor and outdoor environments. This simulation uses specific climatic data to project outdoor dry-bulb temperature, outdoor relative humidity, and solar energy conditions on a daily basis. An energy and moisture functional is then derived on a daily basis to estimate interior environmental conditions. The procedure involves the balancing of animal heat and moisture production, structural heat and moisture production, and solar heat gains with steady-periodic energy exchange through the walls and roof, through the floor, and through ventilation and infiltration. Considering the structure itself as the control volume, the energy and moisture exchanges can be constructed (Figure 4). For this control volume we may write:

\[
\text{Energy Gained} - \text{Energy Lost} = \Delta \text{Energy} \quad (1)
\]

and

\[
\text{Moisture Gained} - \text{Moisture Lost} = \Delta \text{Moisture} \quad (2)
\]

One of the concerns in the development of the simulation, therefore, is to solve these functionals
Figure 4. Heat and moisture exchange in livestock structures.

\[ Q_{\text{anim}} \] = livestock heat production
\[ Q_{\text{struc}} \] = supplemental and structural heat production
\[ Q_{\text{floor}} \] = heat exchange through floor
\[ Q_{\text{sol}} \] = solar energy exchange
\[ Q_{\text{vent}} \] = ventilation/infiltration heat exchange
\[ Q_{\text{cond}} \] = surface conductive/convective heat exchange

\[ M_{\text{anim}} \] = livestock moisture production
\[ M_{\text{struc}} \] = supplemental and structural moisture production
\[ M_{\text{floor}} \] = moisture exchange through floor
\[ M_{\text{vent}} \] = ventilation/infiltration moisture exchange
to produce desired environmental conditions.

This model can be used to simulate the daily interior environment of almost any livestock structure that is well ventilated and lightly constructed. This limitation must be imposed because the thermal storage effects are not considered. It was assumed that a structure that is well ventilated and has small mass would not contain a significant amount of energy or moisture from the previous day. From equations (1) and (2) we can, therefore, develop:

\[
\text{Energy Gained} = \text{Energy Lost} \tag{3}
\]

and

\[
\text{Moisture Gained} = \text{Moisture Lost} \tag{4}
\]

Another limitation of this simulation is the construction of the building will remain the same through the time period being examined. The facility was, thus, considered steady-state in nature. No condensation on interior surfaces was assumed.

**Outdoor Climatic Data**

The simulation begins by considering a model for the outdoor environmental parameters - ambient air temperature, relative humidity, and solar radiation. Data sets for these weather parameters are readily available. For a finite time period, the data sets are continuous.

Continuous functions defined over an interval of
finite length can be approximated by a Fourier series (Beckwith and Buck, 1982). The real Fourier series for any single-valued function $F(x)$ that is continuous can be represented by a series in the form (Albright, 1981):

$$F(x) = A_0 + \sum_{j=1}^{\infty} A_j \cos(jx) + \sum_{j=1}^{\infty} B_j \sin(jx); \ 0 \leq x \leq 2\pi$$  \hspace{1cm} (5)

were $j$ is the number of harmonics (Symbol descriptions are listed in Appendix A).

Albright and Scott (1974) indicated that the benefit of using additional harmonics is lessened after the fifth harmonic, although with each additional harmonic there is an improved fit. The Albright and Scott model (1974) was truncated after five harmonics with a reasonable fit. Truncation for this simulation will, therefore, occur after five harmonics. Because the Fourier series is the sum of circular functions, the series must return to its starting value after completing a cycle. A time period less than or greater than a year of weather data will not return to the same data value. Because of this effect, an increased data set is necessary to allow the Fourier series functional to dampen before the climatic period that includes the animal growth cycle. In the example simulation, the data set was increased by ten percent at the periodic functional's beginning and ending to define the animal's growth cycle (Figure 5).
Figure 5. Data set reduction of Fourier series prediction function.
Sol-Air Temperature

The technique that was used to consider heat gain due to solar radiation through the exterior walls and roof involves the concept of sol-air temperature. The sol-air temperature is the temperature of the outdoor air that, in the absence of all radiation exchanges, gives the same rate of heat transfer to the exterior surface as actually occurs by solar radiation, convection, and conduction (McQuiston and Parker, 1982). Assuming the rate of heat transfer in terms of the sol-air temperature, $t_e$ ($°C$), ASHRAE (1985) has defined:

$$t_e = t_o + \alpha_a H_t / h_o - \varepsilon \Delta R / h_o$$

(6)

where:

- $t_o$ = outdoor air temperature, °C
- $\alpha_a$ = absorptance of the surface for solar radiation
- $H_t$ = total daily incident solar radiation upon the surface, W/m²
- $h_o$ = coefficient of heat transfer, W/(m² - °C)
- $\varepsilon$ = emittance of surface
- $\Delta R$ = difference between the long wavelength radiation incident on the surface from the sky and radiation emitted from a blackbody at outdoor air temperature, W/m

The term $\varepsilon \Delta R / h_o$ varies from about zero °C for vertical surfaces to -4 °C for horizontal surfaces. The ratio $\alpha_a / h_o$ varies from 0.026 (m² - °C)/W for a light-colored surface to
0.053 \( \text{m}^2 \cdot \circ C/W \) for a dark-colored surface. The total incident solar radiation upon the surface, \( H_t \), was computed from the Fourier series approximation of the direct and diffuse solar radiation incident on a horizontal surface. Duffie and Beckman (1980) define a ratio, \( R_r \), of the daily total radiation on a tilted surface to that on a horizontal surface. The procedure for calculating \( R_r \) is accomplished by adding the contributions of the direct solar radiation, diffuse solar radiation, and reflected solar radiation from the ground. \( R_r \) can be expressed by the relationship:

\[
R_r = (1-H_d/H)R_b + (H_d/H)(1+\cos \beta/2) + \rho_s(1-\cos \beta/2) \quad (7)
\]

\( \rho_s \) is the ground surface reflectance ranging from zero for dark surfaces to one for light surfaces and \( \beta \) is the surface slope, in degrees, ranging from zero to 180. \( H_d/H \) is the ratio of daily diffuse radiation on a horizontal surface to daily direct and diffuse radiation on a horizontal surface. \( R_b \) is the ratio of the average daily direct radiation on the tilted surface to that on a horizontal surface. The methodology in calculation of \( H_d/H \) and \( R_b \) is found in Appendix B.

**Animal Heat and Moisture Production**

By balancing heat production and heat loss to the environment, homeothermic animals maintain nearly constant body temperatures. The homeothermic animal produces both
sensible and latent heat. For simulation purposes, the sum of latent and sensible heat is total heat. A total energy and moisture balance is being performed, therefore, both latent and sensible heat must be described. Calorimetry data sets of livestock sensible and latent heat are incomplete over the animal's growth cycle. Design graphs, such as D270.4 in the Agricultural Engineers Standards (1984), however, are readily available and complete. For this simulation, regression equations of the design graphs were used (Appendix C). Animal sensible and latent heat design graphs are functions of environmental temperature and animal size. A multiple regression analysis, therefore, was performed with the design graphs. Also, animal size in terms of weight and age must be modeled. This was accomplished using the same technique as the animal sensible and latent heat model - a multiple regression analysis of animal age versus animal weight curve.

**Structural Heat and Moisture Production**

Another form of heat production within a building can arise from electrically generated heat such as from lights and motors. This type of heat gain is sensible and is usually independent of environmental conditions. MWPS-1 (1983) recommends that mechanical heat gain be estimated from:
1 watt sensible heat per watt incandescent lighting

1.2 watts sensible heat per watt fluorescent lighting

1.6 watts sensible heat per watt fractional hp motor 
(motor heat gain does not apply to exhaust fans because it is assumed the heat is immediately exhausted)

Supplemental heating/cooling is also accounted for in this portion of the analysis. Sensible supplemental heating/cooling is usually, however, calculated from the energy balance. Latent heat or moisture might also be added internally to the structure by animal cooling techniques such as misting or drip cooling. Condensation may also occur when surface temperatures fall below interior environmental dew point temperature. Condensation was not incorporated into this model.

**Steady-Periodic Heat Exchange Through Wall and Roof Surfaces**

A good estimate of energy transfer through wall and roof surfaces is essential for proper simulation. No moisture transfer will be assumed to occur through these surfaces, only sensible heat exchange will take place. The energy exchanged through the walls, ceiling, roof, windows, and doors is termed transmission heat exchange and is computed from:

\[ Q_t = UA_s (t_i - t_e) \]  

where:
\[ Q_t = \text{transmission heat exchange, W} \]
\[ U = \text{overall heat transfer coefficient, W/}(m^2 \cdot ^\circ C) \]
\[ A_s = \text{area, m}^2 \]
\[ t_i = \text{interior environmental temperature, } ^\circ C \]

A separate calculation is made for each different surface in the structure. The overall heat transfer coefficient is calculated from the theory of thermal resistance which is analogous to electrical resistance.

The heat flow through structural components is essentially one-dimensional for each surface and is steady-state heat flow with time varying, steady-periodic. The structure of walls, windows, doors, and roof are a rather complex assembly of materials. Because of the non-homogeneity of the structure, precise rates of heat transfer are difficult. The concept of thermal resistance, however, has been proven to be a very reliable method in the computation of heat exchange estimates (McQuiston and Parker, 1982). McQuiston and Parker (1982) define the unit thermal resistance as the "R-factor". This parameter is very commonly found in thermal/HVAC handbooks and literature. If a surface is constructed of two or more layers of dissimilar material, series thermal resistance, the overall R-factor \( R' \) for that surface is defined:

\[
R' = R_1 + R_2 + \ldots + R_n \tag{9}
\]
Simply, the sum of the R-factors for each dissimilar material found in that surface. The overall heat transfer coefficient found in equation (8) is then defined from the overall R-factor to be:

\[ U = \frac{1}{R'} \]

Thermal resistances may also occur in parallel such as in a framed wall situation with dissimilar materials in parallel. As in parallel electrical resistances, the overall R-factor is defined as:

\[ \frac{1}{RA'} = \frac{1}{R_1A_1} + \frac{1}{R_2A_2} + \ldots + \frac{1}{R_nA_n} \]

Again, the overall R-factor is substituted into equation (10) for use in equation (8).

When computing the overall R-factors for a surface, one must be careful to include the thermal resistances of air spaces and condensation. One must be careful to include these thermal resistances will result in the neglect of convective effects of that surface.

**Ventilation/Infiltration Heat and Moisture Exchange**

Ventilation/infiltration adds both sensible and latent heat into the livestock structure and also energy and moisture at the same time. The net energy and moisture loss and/or gain. Because
energy and a moisture functional were created, the ventilation flow rate can be an unknown to develop ventilation curves or predetermined to maintain a desired energy or moisture level. A model must, therefore, be developed that considers both the sensible and latent heat gain/loss by the ventilation system.

MWPS-1 (1983) describes the sensible heat loss in the ventilating air as the amount of energy needed to raise or lower the temperature of incoming air to the exhaust air temperature:

$$Q_{vs} = V \rho_v c_0 (T_i - T_o)$$  \hskip 0.5in (12)

where:

\[ Q_{vs} \] = sensible heat loss/gain of ventilating air, W  
\[ V \] = volume flow rate, m³/s  
\[ \rho_v \] = air density, kg/m³  
\[ c_0 \] = specific heat capacity of moist air, kJ/(kg - °C) at outdoor air temperature

Ventilation air that flows through the livestock structure evaporates moisture from floors, pits, and other aqueous surfaces along with animal moisture production from their upper respiratory tracts. Moisture losses in a structure occur almost solely from the ventilating air. The amount of latent heat removed by the ventilating air is given by (McQuiston and Parker, 1982):

$$Q_{vl} = V \rho_v (w_i - w_o) l_f$$  \hskip 0.5in (13)
where:

\[ Q_{v1} = \text{latent heat removed by ventilating air, } W \]
\[ w_i = \text{indoor humidity ratio, kgw/kgda} \]
\[ w_o = \text{outdoor humidity ratio, kgw/kgda} \]
\[ i_{rs} = \text{latent heat of vaporization of air at indoor conditions, kJ/kgw} \]

**Heat and Moisture Exchange with Floor**

In livestock structures, the floor is a complex arrangement of energy and moisture exchanges and involves considerable uncertainty. A floor slab or manure pit or combination of both usually form the construction of the floor in a livestock building. The energy and moisture exchange of the floor is thus reduced to that of a crawl or half space. The structure floor and interior environment exchange of energy and moisture depends on the ventilation, defecated waste, foundation perimeter, and manure pit. The following steady-periodic equation can be used to estimate the energy and moisture exchange of the floor:

\[ Q_f = Q_{pr} + Q_{p,c} + Q_w + Q_{pt} \]  \hspace{1cm} (14)

where:

\[ Q_f = \text{energy exchange of the floor and interior environment, } W \]
\[ Q_{pr} = \text{perimeter energy exchange, } W \]
\[ Q_{p,c} = \text{conduction pit energy exchange, } W \]
\[ Q_w = \text{defecated waste energy exchange, } W \]
\( Q_{pt} = \text{convection pit energy exchange, W} \)

Experiments with slab floors have indicated that the heat loss from a concrete slab floor is mostly through the structures perimeter rather than through the floor and into the ground (ASHRAE, 1985). Heat loss was, therefore, found to be more nearly proportional to the length of the perimeter rather than the area of the floor. ASHRAE (1985) has estimated the energy exchange by the following equation for both unheated and heated slab floors:

\[
Q_{pt} = FP(T_i - T_o)
\]

(15)

where:

- \( F \) = overall heat transfer coefficient of perimeter, \( W/(m - ^\circ C) \)
- \( P \) = perimeter or exposed floor edge, m

As with the thermal resistance values for materials, perimeter overall heat transfer coefficients are available in thermal/HVAC handbooks and other literature.

The conduction energy exchange with the manure pit, \( Q_{pit} \), was determined by using equation (8). The area, \( A_s \), is the surface area of the pit itself. The overall heat transfer coefficient of the manure pit will be determined using series thermal resistance theory with the manure and air space being the primary dissimilar constituents. An assumption that the pit bottom temperature will be that of the soil at pit bottom depth is made. Therefore, the
exposed waste surface. This drying rate is constant and can be calculated from the convective heat transfer equation (Esmay and Dixon, 1986):

\[ Q_{pt} = hA_{sw}(t_i - t_w) \]  

where:

\[ h = \text{coefficient of convective heat transfer, W/(m}^2\text{-°C)} \]
\[ A_{sw} = \text{area of exposed waste surface, m}^2 \]
\[ t_w = \text{temperature of exposed waste surface (usually interior environmental wet bulb temperature), °C} \]

**Simulation Solution**

The terms of equation (3) and equation (4) have now been defined. Equation (3) in terms of Figure 4 becomes:

\[ Q_s + Q_{pt} = Q_i + Q_f + Q_{vl} + Q_{vs} \]  

(18)

Extracting the latent heat terms from equation (18) and dividing each term by the appropriate latent heat of vaporization, we develop the moisture balance, equation (4), in terms of the moisture flows (Figure 4).

\[ M_s + M_{pt} = M_{vl} + M_f \]  

(19)

The utility of the simulation allows for the development of ventilation curves and resulting heating/cooling requirements for the maintenance of the specified interior environmental conditions. Ventilation curves are developed from both the energy and moisture
balances. Moisture control is accomplished through the solution of the moisture balance for ventilation flow rate. Temperature control is achieved through the solution of the energy balance for ventilation flow rate.

Algebraic manipulation led to a closed form solution of the real energy and moisture functionals. A closed form solution does not produce the complexities in computer coding length of run-time that an implicit solution would. Once interior environmental conditions are specified and the structure and location are described, both the energy and moisture balance are functions of ventilation flow rate alone. As stated earlier, the solution of one of the functionals for ventilation flow rate for moisture or temperature control allows the flow rate to be substituted into the other functional to provide moisture or heating/cooling requirements to maintain the specified interior environmental conditions. The simulation had a maximum ventilation rate of 57 L/s per animal, the recommended ventilation rate for 100 kg swine under hot weather conditions (MWPS-1, 1983). The maximum was established to analyze summer conditions when outdoor temperature nears the specified interior temperature or rises above it.

Computer Simulation Structure

The computer simulation was used to describe the
daily interior environmental conditions of a livestock structure for the life cycle of an animal type. To accomplish this, the equations previously described must be solved. This was achieved by coding equations (3) thru (21) into the computer simulation structure (Figure 6).

The simulation was coded in GW-BASIC 3.2. The language provided sufficient memory allocation with reasonable calculation time for the examples used. However, longer animal growth cycles combined with a more elaborate livestock structure construction might lead to insufficient memory. In this case, a different language, such as Professional BASIC or QuickBASIC, with greater memory allocation, might be used. The simulation was run on a dual-disk drive personal computer with 256 kilobytes of Random Access Memory (RAM). The simulation, in GW-BASIC computer coding, can be used on any compatible computer.
Figure 6. Flow chart of computer simulation.
SIMULATION EXAMPLE PROCEDURE

The purpose of the simulation was to predict interior environmental conditions as animal growth and climatic conditions change. Development of the simulation is followed by computer implementation for the evaluation of model performance and sensitivity. This will be accomplished by examining the response of a livestock facility of two different constructions and two different climatic seasons. From these specifications, ventilation curves and supplemental heating/cooling requirements were developed based upon imposed limitations as the animal grows.

A swine, environmentally controlled, growing-finishing facility was simulated. The structure plan was obtained from Midwest Plan Service (1983), a 8.53 m by 24.38 m stud-frame wall building (Figure 7). The structure is a monoslope, modified open front building housing 240 animals and is naturally ventilated year around. Manure is stored below a fully slotted floor in a 3.05 m wide pit extending the length of the building. The facility site is located near Brookings, South Dakota at 44.308° latitude north and 96.792° west longitude. The building is located with the length of the facility oriented east-west and roof sloping upward to the south. Facility description data were processed and stored by the
Figure 7. Simulation example structure (MWPS-22603, 1983).
simulation for manipulation.

The data and simulation were used in English units and manipulated to Standard International units for the manuscript. All data used in the simulation can be found in Appendix D. As previously stated, the simulation evaluation will take place near Brookings, South Dakota during two different production cycle periods. The production cycle was defined to begin in the piglets ninth week and end in the animal's 23 week of age. The production cycle is 96 days long. The length of the data set and simulation period will extend to 120 days to accommodate the Fourier series data set adjustment. The two different production cycle periods are the months of May thru August for summer conditions and November thru February for winter conditions. The simulation site was assumed not to have any obstructions to hinder facility construction or ventilation system performance. The facility orientation was the same for both production cycle periods. Weather data for the production cycle periods were obtained from the weather station at South Dakota State University, Brookings, South Dakota (Lytle, 1987). The climatic parameters used were daily average dry-bulb temperature, relative humidity, and direct and diffuse radiation on a horizontal surface. The instrumentation used to collect this data were thermometers, observing dry-bulb and wet-bulb temperatures, and a pyranometer, mounted on a horizontal surface to observe
direct and diffuse radiation. The daily climatic data were averages of the years 1984, 1985, and 1986. The soil parameters that were used in the equation developed by Carslaw and Jaeger (1959) were taken from ASHRAE (1987). Solar radiation constants and variables needed for the conversion of horizontal to tilted surface direct and diffuse solar radiation were found in Duffie and Beckman (1980).

To simulate the structure's interior environment, specifications must be imposed. A moisture specification of 75 percent interior relative humidity was made along with an energy specification of 25.6 °C interior environmental temperature. Manure thermal properties and production were taken from MWPS-1 (1983), Hobson and Taiganides (1983), and Dixon, Wells, and Esmay (1978). These properties were taken at 10 percent total solids. The multiple regression analysis for animal heat and moisture production and weight gain was preformed on graphs found in Agricultural Engineers Standards (1984), D270.4, for swine. Transformation from graphical to functional form was excellent with a multiple regression coefficient of determination of no less than 0.984. As seen in the analysis in Appendix C, one could conclude the swine heat and moisture production and weight gain curves were reproduced into equations with no less than 98.4 percent accuracy.
The building construction consisted of eight wall types, two door types, no window types, and a monoslope roof. A 15.3 cm cement wall construction formed the base of the four building sides. A frame wall with studs 61 cm on center, approximately 7.3 percent framing, shaped the continuation of the four building sides. Ventilation doors were fully opened for summer conditions and tightly closed for winter conditions. The ventilation doors were of frame-type construction on the south and north side of the structure. The ventilation doors had 23 percent framing. The structure's entrance doors, 4.5 cm thick with a urethane core, are found on the building sides that do not have the ventilation doors (east and west sides). The facility has a monoslope roof with beams located 61 cm on center and has a 12 percent upward slope to the south.

Summer conditions were analyzed when using (1) the Fourier series daily temperature prediction values and (2) 5.6 °C added to these values. The higher value accounted for the extreme daily diurnal temperature maximums and established simulation verification and sensitivity. Altering facility construction by varying insulation levels and ventilation doors for winter conditions also established simulation verification and sensitivity. Two insulation levels were simulated: (1) R-21 in roof, R-13 in walls, and R-5 in ventilation doors and (2) R-13 in roof and R-0 in walls and ventilation doors. Material combinations of
construction types can be found in Appendix D.
RESULTS and DISCUSSION

Summer Conditions

A steady-periodic energy and moisture analysis was used to examine the previously described building. The interior environmental conditions specified during the summer conditions were 75 percent relative humidity and a temperature of 25.6 °C. The steady-state parameters of this analysis can be found in Appendix D. The periodic parameters are described in Figure 8 through Figure 13 - the animal production period occurs between the vertical dashed lines on the horizontal axis.

The Fourier series was fitted to real data - averaged weather values of 1984, 1985, and 1986 for Brookings, South Dakota (Figure 8). The data set began in May and ended in August. The average temperature data reflects a normal May, June, and July for Brookings, South Dakota and a below average August. The Fourier series with five harmonics provided a good visual fit to the real temperature data and reflects a seasonal fluctuation with a range from 13.5 °C to 22 °C. The problem of fitting a Fourier series to real data which does not return exactly to its starting point was previously mentioned. The effect is evident here. One must be careful not to analyze outside the dashed-line because the Fourier series is derived
Figure 8. Fourier series prediction of outdoor temperature (summer conditions).

Figure 9. Manure pit bottom temperature (summer conditions).
to begin and end at the same data value. The Fourier representation of temperature data begins and ends at the same value. This is an indication of a proper model.

Manure pit bottom temperature was assumed to be ground temperature at that depth level (Figure 9). In this example, simulation for the manure pit bottom is at the 2.44 meter level. The Carslaw and Jaeger (1959) representation provided a sinusoidal increase in temperature from 4 °C at the beginning of the production cycle to 11 °C at the end of the production period for summer conditions. The Carslaw and Jaeger (1959) representation of ground temperature at the 2.44 meter level seem to have a valley in April and a peak in September for Brookings, South Dakota. The function is in agreement with soil temperature design data (ASHRAE, 1987).

Sol-air temperatures for eight wall types, two door types, and the roof were calculated for summer conditions. If one examines the sol-air temperature of the roof, it is evident the sol-air temperature variation follows that of the Fourier series prediction of outdoor temperature (Figure 10). Sol-air temperature is a function of outdoor temperature and direct and diffuse radiation on a horizontal surface (Appendix B). The sol-air temperature function fluctuates between 22 °C and 32 °C. The offset between the Fourier series prediction of outside temperature and sol-air temperature ranges from 7 °C to 10 °C.
Figure 10. Predicted sol-air temperature of roof (summer conditions).

Figure 11. Fourier series prediction of outdoor relative humidity (summer conditions).
Relative humidity data, averaged 1984, 1985, and 1986 values, were fitted to a curve by Fourier analysis identical to the outdoor temperature data (Figure 11). The three year average outdoor relative humidity data are quite scattered. A linear regression might have provided a sufficient fit to the data. A linear regression analysis, however, would not have provided the seasonal fluctuation that the Fourier series analysis produces. The Fourier series outdoor relative humidity prediction ranged from 64 percent to 74 percent for summer conditions. This simulation used the outdoor relative humidity prediction functional along with the outdoor temperature prediction functional and applied Brooker, Bakker-Arkema, and Hall’s (1982) representation of the psychrometric chart to produce the daily outdoor humidity ratio.

Animal sensible and latent heat production were a multiple regression functional of interior environmental temperature and animal weight gain (Figure 12). The interior environmental temperature was specified to be 25.6 °C and swine weight gain is represented in Figure 13. The specified interior environmental temperature remained the same throughout the production cycle and for both summer and winter conditions for comparison. Since the multiple regression analysis is a function of interior environmental temperature, the simulation could accommodate varying indoor temperature. The swine weight gain curve increases
Indoor Conditions: 25.6 °C 75% RH

Figure 12. Swine energy production.

Figure 13. Swine weight gain.
curvilinearly from 22 kg to 100 kg throughout the production cycle. Applying these specifications to the multiple regression analysis, a swine latent, sensible, and total heat functional was developed. Latent heat production increases linearly from 52 watts to 85 watts over the production cycle. Whereas sensible heat production follows the swine weight gain functional and increases curvilinearly from 40 watts, crosses the latent heat functional at 70 kg of growth, and continues to 95 watts. At a constant interior environmental temperature, animal sensible heat production increases at a faster rate than animal latent heat production through the swine's production cycle. Coupling these functionals together produces a total heat equation that increases curvilinearly from 92 watts to 180 watts.

The periodic functionals were combined with steady-state parameters and the energy balance equation was solved for temperature control to maintain the specified interior environmental conditions. When the moisture functional is solved for ventilation rate - moisture control - and the energy functional is solved for ventilation rate - temperature control - the ventilation rate for temperature control is larger than that for moisture control and theoretically governs it for summer conditions (MWPS-1, 1983). A ventilation rate for temperature control was, therefore, used with the previously described maximum
ventilation rate. Two situations were examined for summer conditions. The first scenario used the Fourier series average temperature functional as outdoor temperature. In the second scenario, 5.6 °C was added to each day of the temperature functional. The increased outdoor temperature was used to examine simulation sensitivity and diurnal fluctuations.

The ventilation rate required to produce the specified interior environmental conditions follows the outdoor temperature functional with a coupling influence from the swine total heat functional (Figure 14). Since outdoor temperature never rose past the specified interior temperature, the ventilation rate never approached a specified maximum ventilation rate. The ventilation rate for summer conditions varied from 900 L/s at the beginning of the production period to 6000 L/s when the highest average daily outdoor temperature occurred. The specified maximum ventilation rate of 13,680 L/s for the building was the recommended ventilation rate for finishing swine in hot weather conditions (MWPS-1, 1983). The Midwest Plan Service (1983) recommends two ventilation rates, if mild weather conditions are assumed. For the specified structure and occupant conditions, the recommended ventilation rate is 2718 L/s until the swine reach a weight of 68 kg and 3965 L/s thereafter. When the ventilation rate functional is
Indoor Conditions: 25.6 °C 75% RH

Figure 14. Ventilation rate for temperature control (summer conditions).

Indoor Conditions: 25.6 °C 75% RH
(+) Moisture Removal (-) Moisture Addition

Figure 15. Moisture function with ventilation rate for temperature control (summer conditions).
averaged to a swine weight of 68 kg, the resulting ventilation rate is 2307 L/s. The difference between the MWPS recommended ventilation rate and the averaged ventilation rate is 411 L/s, 15 percent. After the hog has reached a weight of 68 kg, the averaged ventilation rate is 4626 L/s. A difference of 661 L/s, 17 percent, exists between the recommended and averaged ventilation for swine after attaining a weight of 68 kg. It is apparent that outdoor temperature has a larger influence on the structure’s interior environment at the end of the production cycle when the animal has its largest requirement to dissipate heat (Figure 12 and 14).

During summer conditions, the ventilation rate for temperature control is above that of moisture control. All the moisture, therefore, that is produced is removed from the building and the interior moisture level is that of outdoor conditions if moisture is not added or subtracted. For summer conditions this is not a problem until outdoor relative humidity becomes extremely low or extremely high. A high moisture level will stress the animal by hampering its ability to dissipate heat and creating disease problems. Conversely, a low interior moisture level will tend to create a dust problem and produce a poor working environment for the animal manager. When the ventilation rate for temperature control is used in the moisture balance for summer conditions, the amount of moisture addition to
Indoor Conditions: 25.6 °C 75% RH

Figure 16. Ventilation rate for temperature control (summer conditions + 5.6 °C).

Indoor Conditions: 25.6 °C 75% RH
(+ Moisture Removal (−) Moisture Addition

Figure 17. Moisture function with ventilation rate for temperature control (summer conditions + 5.6 °C).
recommended ventilation rate is 8500 L/s for swine to 68 kg and 13680 L/s, the specified maximum rate, thereafter. Comparing the average ventilation rate up to a swine weight of 68 kg - 5267 L/s - with the recommended ventilation rate, a difference of 3224 L/s, 31.5 percent, exists. After the hog has reached a weight of 68 kg, the average ventilation rate is 12,362 L/s. The difference between the recommended ventilation rate and the average ventilation rate is 1318 L/s, 10 percent. Comparing the summer condition scenarios, one can conclude that a structure of small mass is very sensitive to temperature fluctuations.

When the ventilation rate for summer conditions with the addition of 5.6 °C was used in the moisture balance to maintain 25.6 °C and 75 percent relative humidity, the resulting balance yields a peak when the ventilation maximum rate is first reached (Figure 17). This would be the point where low interior moisture problems might occur with low outdoor relative humidity. As time proceeds, this problem relaxes because the swine are increasing their latent heat production while the ventilation system's ability to dissipate moisture remains the same.

Once the ventilation maximum rate has been reached, the ventilation system is not maintaining the specified indoor temperature condition. If the ventilation function for temperature control is reused in the energy balance, the amount of supplemental energy throughout the production
cycle is obtained (Figure 18). The peak amount of cooling needed occurs at the peak temperature. In a large number of confinement facilities the ventilation rate remains the same throughout the animal production cycle for the season. The recommended ventilation rate for finishing swine in mild weather, 17 L/s per hog (MWPS-1, 1983), was used in the energy function for summer conditions (Figure 19) and summer conditions + 5.6 °C (Figure 20). The range in energy required to maintain the specified interior conditions throughout the animal's life cycle remained the same, 240,000 watts, for both scenarios. The increase of 5.6 °C in temperature, however, offset the energy functions by 60,000 watts. It is evident from the previous scenarios that diurnal temperature fluctuations greatly affect the interior environment of the structure. The seasonal temperature fluctuations have the greatest effect on the interior environment of the structure at the end of the production cycle when animal energy production is a maximum (Figure 12, 14, and 16).

**Winter Conditions**

The simulation was also applied to winter conditions where the interior environmental specifications remained identical to the summer conditions of 25.6 °C and 75 percent relative humidity. The steady state conditions
Indoor Conditions: \(25.6 \, ^\circ\text{C}, 75\% \, \text{RH}\)

\(\text{(+) Energy Removal (--) Energy Addition}\)

Figure 18. Energy function with ventilation rate for temperature control (summer conditions + 5.6 \(^\circ\text{C}\)).
Indoor Conditions: 25.6 °C 75% RH
(+ Energy Removal (-) Energy Addition

Vent. Rate - 3965 L/s

Figure 19. Energy function with MWPS recommended ventilation rate (summer conditions).

Indoor Conditions: 25.6 °C 75% RH
(+ Energy Removal (-) Energy Addition

Vent. Rate - 3965 L/s

Figure 20. Energy function with MWPS recommended ventilation rate (summer conditions + 5.6 °C).
of the winter analysis can be found in Appendix D. The periodic parameters involved can be found in Figure 21 through Figure 24. Swine energy production (Figure 12) and swine weight gain (Figure 13) remained the same for winter conditions as it was for summer conditions because of the same interior environmental specifications.

The data-averaged temperatures, humidities, and radiation values from 1984, 1985, and 1986 for Brookings, South Dakota - were fitted by Fourier series for outdoor winter conditions (Figure 21). The data set began in November and ended in February. The temperature data reflect a normal November, December, and February for Brookings, South Dakota and an above normal January. The seasonal temperature fluctuation ranged from -4 °C to -12 °C. The Fourier series began and ended at the same point, -0.5 °C.

The manure pit bottom temperature was assumed to be ground temperature at 2.44 meters as was the case for summer conditions. The Carslaw and Jaeger (1959) representation provided a sinusoidal decrease in temperature data from 12.5 °C at the beginning of the production cycle to 5.5 °C at the end of the production cycle (Figure 22).

The sol-air temperatures for all construction surfaces were calculated. The roof sol-air temperature follows the Fourier series prediction of outdoor temperature for the production cycle (Figure 23). The offset between
Figure 21. Fourier series prediction of outdoor temperature (winter conditions).

Figure 22. Manure pit bottom temperature (winter conditions).
Figure 23. Predicted sol-air temperature of roof (winter conditions).

Figure 24. Fourier series prediction of outdoor relative humidity (winter conditions).
the sol-air temperature and outdoor temperature ranged from 1 °C to -9 °C. Actual solar radiation data were used in the development of the sol-air temperatures. Upon examining the roof sol-air functional, sharp deviations occur on day 48, day 68, and days 76 through 83. These deviations occurred because of overlapping overcast days in the solar radiation data for the chosen years of 1984, 1985, and 1986 for winter conditions.

Relative humidity data for winter conditions were also fit by Fourier series (Figure 24). Again, the relative humidity data set was quite scattered. The seasonal fluctuation of relative humidity ranged from 76.5 percent at the beginning of the production cycle to 85 percent at the end of the production cycle. Because the Fourier series is a circular function, the relative humidity for winter conditions began and ended at the same value.

For winter conditions, a ventilation rate for moisture control is recommended because it is larger than the ventilation rate for temperature control (MWPS-1, 1983). The moisture balance became the governing equation and was solved for a ventilation rate on a daily basis throughout the production period. The two situations examined for winter conditions involved: (1) an insulated structure, R-22 roof, R-13 walls, and R-5 ventilation doors and (2) an uninsulated structure, R-13 roof and R-0 walls and ventilation doors.
The ventilation rate required to produce the indoor specifications for winter conditions follows the outdoor relative humidity prediction functional with a coupling effect of animal heat production (Figure 25). The ventilation rate range was from 1100 L/s to 1300 L/s. This is a much smaller range than for summer conditions because of the range difference in summer outdoor temperatures versus winter outdoor relative humidities throughout the production cycle. The Midwest Plan Service (1983) recommendation for winter ventilation is 1132 L/s throughout the production period. The average ventilation rate is 1180 L/s. A difference of 48 L/s, 4.2 percent, existed. Similar to summer conditions, outdoor relative humidity when coupled with animal growth has a more sensitive effect on ventilation rate at the end of the animal's growth cycle (Figure 12 and 25).

When ventilation rate for moisture control in winter conditions is used in the energy function, the amount of energy needed to maintain the specified interior conditions is developed (Figure 26). In an insulated structure, the supplemental heating requirements ranged from 26,500 watts to 33,000 watts. The function has the general shape of the outdoor temperature equation.

When the majority of the insulation is removed, there is no effect on the ventilation rate for winter
Indoor Conditions: 25.6 °C 75% RH

Ave. Vent.
Rate - 1180 L/s

MWPS Vent.
Rate - 1132 L/s

Figure 25. Ventilation rate for moisture control (insulated winter conditions).

Indoor Conditions: 25.6 °C 75% RH
(+) Energy Removal (-) Energy Addition

Figure 26. Energy function with ventilation rate for moisture control (insulated winter conditions).
Indoor Conditions: 25.6 °C 75% RH

Figure 27. Ventilation rate for moisture control (uninsulated winter conditions).

Indoor Conditions: 25.6 °C 75% RH
(+) Energy Removal (-) Energy Addition

Figure 28. Energy function with ventilation rate for moisture control (uninsulated winter conditions).
conditions (Figure 27). The ventilation rates for both the insulated and uninsulated building were calculated for moisture control using the moisture balance. Varying insulation levels has no effect on this equation. The supplemental heating requirements, however, are affected because they are a function of insulation level (Figure 28). When the ventilation function for winter conditions is used in the energy balance for an uninsulated structure, supplemental heating requirements range from 30,500 watts to 40,000 watts. The removal of insulation requires an average of 7000 additional watts of heating.

The recommended ventilation rate for growing swine in winter conditions is 4.74 L/s per hog (MWPS-1, 1983). This ventilation rate was used in the energy functional for insulated winter conditions (Figure 29) and uninsulated winter conditions (Figure 30) throughout the production cycle. Both energy functions had the general shape of the outdoor temperature functional coupled with effects of animal growth. The energy function for the insulated winter condition ranged from 16,000 watts heating to 36,000 watts heating while the energy function for uninsulated winter conditions ranged from 23,000 watts to 43,000 watts heating. The offset in supplemental heating between the insulated and uninsulated structure for a constant ventilation rate was 7000 watts. Examining the heat transmission through construction components alone, there is again an offset of
Indoor Conditions: 25.6 °C 75% RH
(+) Energy Removal (-) Energy Addition

Indoor Conditions: 25.6 °C 75% RH
(+) Energy Removal (-) Energy Addition

Figure 29. Energy function with MWPS recommended ventilation rate (insulated winter conditions).

Figure 30. Energy function with MWPS recommended ventilation rate (uninsulated winter conditions).
Indoor Conditions: 25.6 °C 75% RH
(+) Energy Gain (-) Energy Loss

Figure 31. Energy transmission through structure (insulated winter conditions).

Indoor Conditions: 25.6 °C 75% RH
(+) Energy Gain (-) Energy Loss

Figure 32. Energy transmission through structure (uninsulated winter conditions).
7000 watts between the insulated (Figure 31) and uninsulated (Figure 32) winter conditions. The sharp deviations in the functions occur in the same place and are of the same shape as the deviations in the roof sol-air functional (Figure 23). Thus, the deviations are related to overcast days in the radiation data.

A constant ventilation rate, for both insulated (Figure 29) and uninsulated (Figure 30) winter conditions, produces a larger range in supplemental heating requirements than varying the ventilation rate throughout the animal production cycle (Figure 26 and 28). The range in supplemental heating requirements is reduced by a factor of two, from 20,000 watts to 10,000 watts, when the ventilation rate is varied throughout the animal production cycle rather than held constant. Also, a constant ventilation rate will not maintain the specified interior environmental moisture level.

**Applications**

The newly developed simulation considers varying livestock heat production and climatic conditions as the animal grows throughout the animal production cycle rather than being held constant. Simulation utility allows for both control and analysis applications. Analysis applications are governed by the moisture and total energy balance. These functionals allow for the solution of two
unknowns. For simulation applications discussed in this manuscript, ventilation rate and supplemental moisture or energy requirements were examined on a daily basis throughout the production cycle of the animal. Any of the specified parameters could be switched with the unknowns for optimization. One limitation of the simulation was the structure's construction was considered steady-state throughout the production cycle. For example, if a growing-finishing swine facility was being considered for simulation in the fall or spring, its construction would change through that time period - ventilation doors would be opened or closed. If just one simulation is performed, the structures ability to dissipate heat must be compensated for by the ventilation system. Doors could not be opened. Therefore, more than one simulation could be performed during an animal's life cycle to account for construction changes in these types of climatic periods. Animal stress produced by interior environmental conditions could also be examined by comparing the supplemental energy requirements to animal energy production along with the eventual determination of feed rations.

The simulation is applicable to control situations (Figure 33). Ventilation flow rate and supplemental energy could be controlled by this simulation. A microprocessor could sense all periodic inputs, except animal latent and
Figure 33. Simulation control application schematic.
sensible heat production. Steady-state parameters, including animal sensible and latent heat production, could be directly inputted into the controller. Set points for the controller would be the desired interior environmental conditions. A switch would have to be implemented into the simulation to exchange between temperature control and moisture control depending on the governing conditions. A ventilation maximum rate would also be enforced when outdoor environmental conditions approach interior conditions and a need for supplemental energy/moisture would exist.

An hourly energy and moisture balance could be implemented by the changing of simulation time constants from a daily basis to a hourly basis. Hourly energy and moisture balances have been developed. These simulations have not, however, accounted for seasonal climatic and animal energy variation. Past simulations have held these parameters constant throughout the production cycle. The newly developed simulation could employ seasonal parametric variation in a hourly energy and moisture balance by varying seasonal climatic and animal energy parameters on a daily basis.

Animal latent and sensible heat dissipation are the major contributors of energy to a livestock structure. A simulation accounting for changing animal energy effects performs only to the level of the animal energy model. Research of animal environments has progressed to the stage
where parameters that have been assumed for many years should be verified with present analytical techniques. Future research with this simulation should combine and implement the previously discussed analysis and control applications to authenticate previously assumed parameters such as ventilation rates through the animal's production cycle or feed rations from animal calorimetry data.
SUMMARY and CONCLUSIONS

A simulation was developed to predict interior environmental conditions, in a livestock structure, as animal growth and climatic conditions change throughout the animal's life cycle. The simulation accounted for animal growth and seasonal climatic changes by conducting a steady-periodic total energy and moisture analysis on a daily basis for the production period of the animal. The simulation considers changing livestock heat production by employing a multiple regression analysis of design diagrams and also, considers varying climatic conditions using actual weather data. Building construction and interior environmental options were specified, and ventilation curves along with supplemental energy or moisture requirements were developed for each day of the animal's growth period.

This newly developed simulation has a wide range of applications for environmental analysis and control. Analysis applications are governed by the moisture and total energy functionals in conjunction with specified construction and environmental parameters. Interchangability of specified construction and environmental parameters with simulation unknowns develops a range of animal environmental conditions for optimization throughout the production period. The range of animal environmental conditions can be used in the analysis of animal stress. Control applications
involve the sensing of periodic parameters along with assigning the steady-state construction and environmental specifications for the ventilation system and requirements of supplemental energy and moisture.

Evaluation of simulation performance was for a swine growing-finishing MOF facility for Brookings, South Dakota. The simulation closely predicted ventilation rates and supplemental energy or moisture requirements for the structure through varying climatic and animal heat production conditions. Averaged ventilation rates were within 4.2 to 31.5 percent of Midwest Plans Service (1983) recommendations for swine ventilation systems. Additional simulation justification was achieved through the following concluded evaluations of animal environments:

1. Summer ventilation rates follow outdoor temperature with a coupling effect of animal heat production throughout the animal's growth period.

2. The outdoor temperature has a greater influence on a structure's interior environment at the end of the production cycle when the animal has its greatest requirement to dissipate heat.

3. Moisture and dust problems can occur when maximum ventilation rates develop.

4. Diurnal temperature fluctuations affect the interior environment of the structure.

5. Winter ventilation rates follow outdoor relative humidity with a coupling effect of animal heat production through the animal's growth period.
6. In winter conditions, varying the ventilation rate throughout the production cycle reduces the range in supplemental heating requirements by a factor of two.
REFERENCES


Agricultural Engineers Standards. 1984. Design of ventilation systems for poultry and livestock shelters (D270.4). ASAE, St. Joseph, MI 49085.


APPENDICES
APPENDIX A: List of Symbols
Symbols

A = see equation (5)
A_s = surface area, m^2
B = see equation (5)
c = specific heat capacity, kJ/(kg - °C)
c_s = soil specific heat capacity, kJ/(kg - °C)
d = soil depth, m
F = perimeter overall heat transfer coefficient, W/(m - °C)
h = convective heat transfer coefficient, W/(m^2 - °C)
H = daily direct and diffuse radiation on a horizontal surface, W/m^2
H_d = daily diffuse radiation on a horizontal surface, W/m^2
H_t = total daily incident solar radiation upon a tilted surface, W/m^2
i_v = latent heat of vaporization, kJ/kgw
k_s = thermal conductivity of soil, W/(m - °C)
k_t = ratio of daily direct and diffuse radiation on a horizontal surface to average extraterrestrial radiation
m = mass defacated waste, kg/s
M = environmental moisture transfer, kg/s
P = perimeter or exposed floor edge, m
P_a = atmospheric pressure, pa
P_k = phase constant of minimum surface temperature, days
P_v = vapor pressure, pa
Q = heat exchange, W
\[ R = \text{thermal resistance}, \ (\text{m}^2 \cdot \text{oC})/\text{W} \]

\[ \Delta R = \text{difference between the long wavelength radiation incident on the surface from the sky and radiation emitted from a blackbody at outdoor air temperature, W/m} \]

\[ R_b = \text{ratio of daily direct radiation on a tilted surface to that on a horizontal surface} \]

\[ R_r = \text{ratio of daily total radiation on a tilted surface to that on a horizontal surface} \]

\[ \text{RH} = \text{relative humidity, percent} \]

\[ S_s = \text{annual surface swing, oC} \]

\[ t = \text{air temperature, oC} \]

\[ T_{\text{er}} = \text{mean earth temperature, oC} \]

\[ U = \text{overall heat transfer coefficient, W/(m}^2 \cdot \text{oC}) \]

\[ V = \text{volume flow rate, m}^3/\text{s} \ (1 \text{ m}^3/\text{s} = 1000 \text{ L/s}) \]

\[ w = \text{humidity ratio, kgw/kgda} \]

\[ y = \text{time, days} \]

**Subscripts**

\[ a = \text{animal body conditions} \]

\[ b = \text{direct solar radiation conditions} \]

\[ d = \text{diffuse solar radiation conditions} \]

\[ e = \text{sol-air conditions} \]

\[ g = \text{ground surface conditions} \]

\[ gr = \text{soil conditions} \]

\[ f = \text{floor conditions} \]

\[ i = \text{interior conditions} \]

\[ j = \text{index number of harmonics} \]
l = latent energy conditions
o = outdoor conditions
pr = perimeter conditions
pt = convective pit conditions
ptc = conductive pit conditions
r = total solar radiation conditions
s = sensible energy conditions
sr = sunrise conditions on a tilted surface
ss = sunset conditions on a tilted surface
st = structural conditions
t = transmission heat exchange conditions
v = ventilating air conditions
w = waste conditions

Greek Symbols

β = surface slope, degrees
ργ = ground reflectance
ρv = air density of ventilating air, kg/m³
αs = absorptance of the surface for solar radiation
ε = emittance of surface
ϕ = location latitude, degrees
δ = declination, degrees
γ = surface azimuth angle, degrees
ωs = sunset hour angle, degrees
ωss = surface sunset hour angle, degrees
\( \omega_{sr} \) = surface sunrise hour angle, degrees
\( \alpha_{sr} \) = soil thermal diffusivity, \( k_{sr}/\alpha_{sr} \) or \( \bar{c}_{sr} \)
\( \rho_{sr} \) = soil density, \( \text{kg/m}^3 \)
APPENDIX B: Mathematical Equations
Ratio of Daily Diffuse Radiation to Daily Direct and Diffuse Radiation on a Horizontal Surface (Duffie and Beckman, 1980)

\[
\frac{H_d}{H} = 0.775 + 0.00653(\omega_s - 90) - (0.505 + 0.00455(\omega_s - 90))\cos(115K_t - 103)
\]

where:

- \(\frac{H_d}{H}\) = ratio of daily diffuse radiation to daily direct and diffuse radiation on a horizontal surface
- \(\omega_s\) = sunset hour angle, the angular displacement of the sun at sunset west of the local meridian due to the rotation of the earth, degrees
- \(K_t\) = ratio of daily direct and diffuse solar radiation on a horizontal surface to average extraterrestrial daily radiation over the lifecycle of the animal

Ratio of the Average Daily Direct Radiation on a Tilted Surface to that on a Horizontal Surface (Duffie and Beckman, 1980)

\[
R_b = \frac{(\cos\beta \sin\delta \sin\phi)(\omega_{s\cdot} - \omega_{s\cdot})(\pi/180) - (\sin\delta \cos\phi \sin\gamma)(\omega_{s\cdot} - \omega_{s\cdot})(\pi/180)}{2(\cos\phi \cos\delta \sin\omega_s + (\pi/180) \omega_s \sin\phi \sin\delta)}
\]

where:

- \(\beta\) = surface slope, the angle between the plane surface in question and the horizontal \(0^\circ < \beta < 180^\circ\)
- \(\phi\) = location latitude, the angular location north or south of the equator, north positive, \(-90^\circ < \phi < 90^\circ\)
- \(\delta\) = declination, the angular position of the sun at solar noon with respect to the plane of the equator, north positive, \(-23.45^\circ < \delta < 23.45^\circ\)
- \(\gamma\) = surface azimuth angle, the deviation of the
projection on a horizontal plane of the normal to the surface from the local meridian, with zero due south, east negative, west positive -180° < γ < 180°

if γ > 0

\[ \omega_{ss} = \min \left( \omega_s, \arccos \left( \frac{AB + \sqrt{A^2 - B^2 + 1}}{(A^2 + 1)} \right) \right) \]

\[ \omega_{sr} = \min \left( \omega_s, \arccos \left( \frac{AB - \sqrt{A^2 - B^2 + 1}}{(A^2 + 1)} \right) \right) \]

if γ < 0

\[ \omega_{ss} = \min \left( \omega_s, \arccos \left( \frac{AB - \sqrt{A^2 - B^2 + 1}}{(A^2 + 1)} \right) \right) \]

\[ \omega_{sr} = \min \left( \omega_s, \arccos \left( \frac{AB - \sqrt{A^2 - B^2 + 1}}{(A^2 + 1)} \right) \right) \]

A = \frac{\cos \phi}{\sin \gamma \tan \beta} + \frac{\sin \phi}{\tan \gamma}

B = \tan \delta \left[ \frac{\cos \phi}{\tan \gamma} + \frac{\sin \phi}{\sin \gamma \tan \beta} \right]

if γ = 0

\[ R_b = \frac{\cos(\phi - \beta) \cos \delta \sin \omega_s + (\pi/180) \omega_s \sin(\phi - \delta) \sin \delta}{\cos \phi \cos \delta \sin \omega_s + (\pi/180) \omega_s \sin \phi \sin \delta} \]

\[ \omega_s = \min \left[ \arccos(-\tan \phi \tan \delta), \arccos(-\tan(\phi + \beta) \tan \delta) \right] \]

Earth Temperature (Carslaw and Jaeger, 1959)

\[ T(d, y) = T_{sr} - S_s \exp \left( -d \frac{\pi}{365 \alpha_{gr}} \right) \cos \left( \frac{2\pi A}{365} \right) \]
\[
A = \left( y - P_{fr} - \frac{d}{2} \left( \frac{365}{\pi a r} \right)^{1/2} \right)
\]

where:

- \( T_{fr} \) = mean earth temperature, °C
- \( S_s \) = annual surface swing, °C
- \( \alpha_{fr} \) = soil thermal diffusivity, \( k_{fr}/\rho_{fr}c_{fr} \), m²/day
- \( k_{fr} \) = thermal conductivity, W/(m °C)
- \( \rho_{fr} \) = soil density, kg/m³
- \( c_{fr} \) = soil specific heat, kJ/(kg °C)
- \( P_{fr} \) = phase constant day of minimum surface temp, days
- \( d \) = soil depth, m
- \( y \) = time, days

Conversion from Relative Humidity to Humidity Ratio
(Brooker, et al., 1982)

\[
w = \frac{0.6219 \ RH \ P_{vs}}{P_{s} - \ RH \ P_{vs}}
\]

- \( w \) = humidity ratio, kgw/kg
- \( RH \) = relative humidity, percent
- \( P_{s} \) = atmospheric pressure, pa
- \( P_{vs} \) = saturated vapor pressure, pa
APPENDIX C: Multiple Regression Analysis of Swine Heat Production and Weight Gain Information
Multiple Regression Analysis of Swine Weight Gain Information (Mendenhall and Sincich, 1984)

Dependent variable: Swine Weight (W), lb
Independent variable: Swine Age (age), days

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<th>Source</th>
<th>DF</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
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<td>8.9910</td>
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<tr>
<td>Correct Total</td>
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<td>93561.7912</td>
<td></td>
</tr>
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Model $F = 5194.09$  
Pr $> F = 0.0001$

R-Square  
C.V.  
Root MSE

0.99827  
2.7202  
2.99850

Swine Weight Prediction Equation

$W = -1.9943 + 0.49337 \text{age} + 0.00544 \text{age}^2$

Multiple Regression Analysis of Swine Latent Heat Production (Mendenhall and Sincich, 1984)

Dependent Variable: Latent Heat Production (LHP), BTU/(hr - animal)
Independent Variable: Temperature (T), °F
Independent Variable: Weight (W), lb

<table>
<thead>
<tr>
<th>Source</th>
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<th>Mean Square</th>
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Model $F = 1619.09$  
PR $> F = 0.0001$

R-Square  
C.V.  
Root MSE

0.98973  
3.3609  
9.55402

Swine Latent Heat Production Equation

$LHP = 280.21652 - 10.47373 T + 0.12025 T^2 + 1.30685 W$
$- 0.00162 W^2 - 0.00352 T W$
Multiple Regression Analysis of Swine Sensible Heat Production (Mendenhall and Sincich, 1984)

Dependent Variable: Sensible Heat Production (SHP), BTU/(hr - animal)
Independent Variable: Temperature (T), °F
Independent Variable: Weight (W), lb

<table>
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<tr>
<th>Source</th>
<th>DF</th>
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<th>Mean Square</th>
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<td>Corrected Total</td>
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<td>5184777.6556</td>
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</tr>
</tbody>
</table>

R-Square C.V. Root MSE
0.99502 4.2668 17.53121

Swine Sensible Heat Prediction Equation

\[
\text{SHP} = 572.88786 - 8.37193 T + 0.021113 T^2 + 2.62255 W + 0.00050 W^2 - 0.02289 T W
\]
Figure C.1. Swine sensible/latent heat production and weight gain (ASAE Standards, 1984).
APPENDIX D: Simulation Example Inputs
General

Building length - 80 ft
Building width - 28 ft
Perimeter of building - 216 ft
Building capacity - 240 pigs
Data set length - 120 days
Age of swine at data set beginning - 51 days
Location latitude - 44.308°
Specific heat of air - 0.24 BTU/(lb - °F)
Density of air - 0.074 lb/ft³
Latent heat of vaporization - 1054 BTU/lb
Manure pit width - 10 ft
Manure pit depth - 8 ft
Average depth of manure - 4 ft
Specific heat of manure - 0.934 BTU/(lb - °F)
Manure production - 0.0027 lb/(hr - animal)
Manure pit surface area - 800 ft²
Manure heat transfer coefficient - 3.046 BTU/(hr - ft² - °F)
Swine body temperature - 102.5 °F
Incandescent lighting - 1000 watts
Motor horsepower - 1/2
Soil mean earth temperature - 47 °F
Soil annual surface swing - 26 °F
Soil thermal conductivity - 0.5 BTU/(hr - ft - °F)
Soil density - 100 lb/ft³
Soil specific heat - 0.25 BTU/(lb - °F)

Phase constant day of minimum surface temperature - 35 days

**Summer Conditions**

Beginning of data set - May 1
Reflectance of ground - 0.2
Sunset hour angle of a horizontal surface - 114.78°
Extraterrestrial radiation - 138.89 BTU/(hr - ft²)
Manure pit surface temperature - 65 °F
Latent heat of vaporization at pit surface - 1060 BTU/hr

**Winter Conditions**

Beginning of data set - November 1
Reflectance of ground - 0.6
Sunset hour angle of a horizontal surface - 65.08°
Extraterrestrial radiation - 47.5 BTU/(hr - ft²)
Manure pit surface temperature - 45 °F
Latent heat of vaporization at pit surface - 1068 BTU/hr
### Table D.1. Building surface construction components.

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<th>Wall Type</th>
<th>Wall Construction</th>
<th>Percent Framing</th>
<th>Area (ft²)</th>
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<tr>
<td>South Base Wall</td>
<td>1. 6&quot; insulated concrete wall</td>
<td>0</td>
<td>160</td>
</tr>
<tr>
<td>South Vent. Door</td>
<td>1. plastic wall lining</td>
<td>24.3</td>
<td>640</td>
</tr>
<tr>
<td></td>
<td>2. 1.5&quot; insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. plastic wall lining</td>
<td></td>
<td></td>
</tr>
<tr>
<td>East Base Wall</td>
<td>1. 6&quot; insulated concrete wall</td>
<td>0</td>
<td>46</td>
</tr>
<tr>
<td>East Frame Wall</td>
<td>1. hollow-backed siding</td>
<td>7.38</td>
<td>129.75</td>
</tr>
<tr>
<td></td>
<td>2. .375&quot; plywood</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3. 3.5&quot; insulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4. plastic wall lining</td>
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<td></td>
</tr>
<tr>
<td>North Base Wall</td>
<td>1. 6&quot; insulated concrete wall</td>
<td>0</td>
<td>160</td>
</tr>
<tr>
<td>North Vent. Door</td>
<td>1. plastic wall lining</td>
<td>24.3</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>2. 1.5&quot; insulation</td>
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<tr>
<td></td>
<td>3. plastic wall lining</td>
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<td>West Base Wall</td>
<td>1. 6&quot; insulated concrete wall</td>
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<td>46</td>
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<td>West Frame Wall</td>
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<td>129.75</td>
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<td></td>
<td>2. .375&quot; plywood</td>
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<td></td>
<td>3. 3.5&quot; insulation</td>
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<td>4. plastic wall lining</td>
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Table D.1 continued.

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<tr>
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</table>

* Insulation was replaced by an airspace or concrete for noninsulated winter conditions
Table D.2. Building surface orientation and solar radiation parameters.

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<tr>
<th>Wall Type</th>
<th>$\beta$ (deg.)</th>
<th>$\gamma$ (deg.)</th>
<th>Summer Cond. $\omega_{ss}$ (deg.)</th>
<th>Winter Cond. $\omega_{sr}$ (deg.)</th>
<th>Summer Cond. $\omega_{ss}$ (deg.)</th>
<th>Winter Cond. $\omega_{sr}$ (deg.)</th>
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<td>South Vent. Door</td>
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<td>63.9</td>
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<td>0</td>
<td>65.08</td>
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<td>North Vent. Door</td>
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<td>65.08</td>
</tr>
<tr>
<td>West Frame Wall</td>
<td>90</td>
<td>-114.78</td>
<td>114.78</td>
<td>-65.08</td>
<td>65.08</td>
<td>65.08</td>
</tr>
<tr>
<td>Roof</td>
<td>0</td>
<td>-12.09</td>
<td>63.9</td>
<td>0</td>
<td>65.08</td>
<td>0</td>
</tr>
<tr>
<td>East Door</td>
<td>-90</td>
<td>114.78</td>
<td>-114.78</td>
<td>65.08</td>
<td>-65.08</td>
<td>-65.08</td>
</tr>
<tr>
<td>West Door</td>
<td>90</td>
<td>-114.78</td>
<td>114.78</td>
<td>-65.08</td>
<td>65.08</td>
<td>65.08</td>
</tr>
</tbody>
</table>
APPENDIX E: Computer Simulation
This program was written by Mark Diesch
Agricultural Engineering Department
South Dakota Dakota State University

MAIN PROGRAM

Initialization of variables, input general simulation data, and call program subroutines

OPTION BASE 1
DEFDBL A-H,N-Z
DEFINT I-M

DIM VENTM(120), VENTE(120), MA(120), EA(120)
DIM ALPH(11), ERHO(11), SAT(120,11), CTWAW(11), W(120), SAA(11), CTWW(11), CTDD(11), SLOP(11), AW(11), SSHA(11), SRHA(11), DMT(120), T(120), A(3), F(120)
DIM C4(120), C6(120), C8(120), C10(120), C12(120), C14(120), C16(120), C18(120), C20(120), C22(120), A1(3), A2(3), A4(3), A5(3), B1(3), B2(3), B3(3), B4(3), B5(3)
PI=3.1415927#
CLS
PRINT "This program is an attempt to predict various parameters"
PRINT "of the interior environment of livestock structures."
PRINT "Environmental conditions. The program is constructed assuming"
PRINT "steady-periodic heat and moisture flow. Lets begin!!"
PRINT "**NOTE** Surface conditions are included when entering R-values"
PRINT
PRINT
PRINT
PRINT "Enter (1) if you would like to input data on the keyboard and create and store a file."
PRINT "Enter (2) if you would like to input the data on the keyboard alone."
INPUT "Enter (3) if you would like to access data from a file";JJJ:CLS
IF JJJ=3 THEN GOTO 1340
INPUT "What type of animal is being housed in this facility";A$:CLS
INPUT "Enter the average extraterrestrial daily radiation (BTU/HR-FT(2)) over the lifecycle of the animal";EDR:CLS
INPUT "Enter the average sunset hour angle (Degrees), for a horizontal surface, over the lifecycle of the animal";ASSHA:CLS
INPUT "How many days from the beginning of the year is
the first day of the animal's cycle"; TIME: CLS
350 INPUT"Enter the latitude of the livestock structure geographic location"; LAT: CLS
360 INPUT"Enter the ground reflectance parameter for the structure site (1) for bright surfaces to (0) for dark surfaces"; ROG: CLS
370 ASSHA = ASSHA * PI / 180: LAT = LAT * PI / 180
380 INPUT"How long, in days, is the cycle of the animal"; J : CLS
390 INPUT"How many animals are in the building"; NUM : CLS
400 INPUT"What is the specific heat (BTU/LB-F), density (LBS/FT(3)), and latent heat of vaporization (BTU/LB) for air at it's average temperature during the life cycle of the animal"; SPHA, DENA, LHVA : CLS
410 INPUT"Enter the age of the animal (Days) at the beginning of the cycle"; BAGE : CLS
420 INPUT"How many wall types, excluding the roof, floor, windows, and doors, form the construction of this building"; WT : CLS
430 INPUT"How many window types form the construction of this structure"; WWT : CLS
440 INPUT"How many door types form the construction of this structure"; DT : CLS
450 L = WT + WWT + DT + 1
460 K = 1
470 GOSUB 2840
480 GOSUB 3310
490 GOSUB 4680
500 GOSUB 4010
510 GOSUB 4350
520 GOSUB 4810
530 GOSUB 4920
540 GOSUB 5050
550 GOSUB 5130
560 GOSUB 630
570 GOSUB 920
580 FOR I = 1 TO J
590 GOSUB 5230
600 NEXT I
610 GOSUB 5500
620 GOTO 5670
630 '***********************************************************************************************
640 '* SUBROUTINE WEATHER DATA '*
650 '***********************************************************************************************
660 '*' Outdoor weather data is gathered and sent for '*
670 '* Fourier analysis. Interior environmental specific-*
680 '* ations are made '*
690 '***********************************************************************************************
700 FOR I = 1 TO J
710 PRINT USING"For day ## of the life cycle of the animal, what is the average"; I
1030 GOSUB 2170
1040 DDR=((A(3)/2)+(A1(3)*COS(T(I))+A2(3)*COS(2*T(I))
  +A3(3)*COS(3
  *T(I))+A4(3)*COS(4*T(I))+A5(3)*COS(5*T(I)))
  +(B1(3)*SIN(T(I))
  +B2(3)*SIN(2*T(I))+B3(3)*SIN(3*T(I))+B4(3)*SIN(4*T(I))
  +B5(3)*SIN(5*T(I)))))
1050 FOR LL=1 TO L
1060 GOsub 2310
1070 SAT(I,LL)=DMT(I)+(ALPH(LL)RTS)-ERHO(LL)
1080 NEXT LL
1090 NEXT I
1100 TCTA=CTRARC+CLPERM+((SA*.8155743)/DM)
1110 FOR LL=1 TO L
1120 TCTA=TCTA+CTWAW(LL)+CTWW(LL)+CTDD(LL)
1130 NEXT LL
1140 IF JJJ=2 GOTO 1540
1150 OPEN "O", #1,"B:SIDATA"
1160 PRINT #1, J, CLPERM, CTRARC, DWR, NUM, SPHA, SPHM,
  LHVW, HT, SA, DMT, HR, TCTA, ABT, EMT, LHVA, SHC,
  BAGE, TIME, DENA, DP, PPERM, SHGT, L, WT, WWT, DT, DM,
  A$
1170 PRINT #1, ETM, ASS, THCOND, SDEN, SPHS, PCST, AWI, AGE,
  AGE2, HPRODL1, HPLTEM, HPLTEM2, HPLWT, HPLWT2, HPLTW,
  HPRODSI, HPSTEM, HPSTEM2, HPSWT, HPSWT2, HPSTW
1180 FOR I=1 TO J
1190 PRINT #1, DMT(I), W(I)
1200 FOR LL=1 TO L
1210 PRINT #1, SAT(I,LL)
1220 NEXT LL
1230 NEXT I
1240 FOR LL=1 TO WT
1250 PRINT #1, CTWAW(LL)
1260 NEXT LL
1270 FOR LL=WT TO (WT+WWT)
1280 PRINT #1, CTWW(LL)
1290 NEXT LL
1300 FOR LL=(WT+WWT) TO (WT+WWT+DT)
1310 PRINT #1, CTDD(LL)
1320 NEXT LL
1330 CLOSE #1
1340 OPEN "I", #1,"B:SIDATA"
1350 INPUT #1, J, CLPERM, CTRARC, DWR, NUM, SPHA, SPHM,
  LHVW, HT, SA, DMT, HR, TCTA, ABT, EMT, LHVA, SHC,
  BAGE, TIME, DENA, DP, PPERM, SHGT, L, WT, WWT, DT, DM,
  A$
1360 INPUT #1, ETM, ASS, THCOND, SDEN, SPHS, PCST, AWI, AGE,
  AGE2, HPRODL1, HPLTEM, HPLTEM2, HPLWT, HPLWT2, HPLTW,
  HPRODSI, HPSTEM, HPSTEM2, HPSWT, HPSWT2, HPSTW
1370 FOR I=1 TO J
1380 INPUT #1, DMT(I), W(I)
1390 FOR LL=1 TO L
1400 INPUT #1, SAT(I,LL)
1410 NEXT LL
1420 NEXT I
1430 FOR LL=1 TO WT
1440 INPUT #1, CTWA(W)(LL)
1450 NEXT LL
1460 FOR LL=WT TO (WT+WWT)
1470 INPUT #1, CTWW(LL)
1480 NEXT LL
1490 FOR LL=(WT+WWT) TO (WT+WWT+DT)
1500 INPUT #1, CTDD(LL)
1510 NEXT LL
1520 CLOSE #1
1530 IF JJ=3 GOTO 580
1540 RETURN
1550 '************************************************************************
1560 'SUBROUTINE FOURIER SERIES
1570 '************************************************************************
1580 'Fourier analysis of outdoor periodic parameters
1590 '************************************************************************
1600 FOR I=1 TO J
1610 T(I)=(I*(360/J)*3.141593)/180
1620 NEXT I
1630 FOR I=1 TO J
1640 C3=SIN(T(I))
1650 C4(I)=F(I)*C3
1660 C5=COS(T(I))
1670 C6(I)=F(I)*C5
1680 A=2*T(I)
1690 C7=SIN(A)
1700 C8(I)=F(I)*C7
1710 C9=COS(A)
1720 C10(I)=F(I)*C9
1730 B=3*T(I)
1740 C11=SIN(B)
1750 C12(I)=F(I)*C11
1760 C13=COS(B)
1770 C14(I)=F(I)*C13
1780 D=4*T(I)
1790 C15=SIN(D)
1800 C16(I)=F(I)*C15
1810 C17=COS(D)
1820 C18(I)=F(I)*C17
1830 E=5*T(I)
1840 C19=SIN(E)
1850 C20(I)=F(I)*C19
1860 C21=COS(E)
1870 C22(I)=F(I)*C21
1880 NEXT I
1890 T2=0:T4=0:T6=0:T8=0:T10=0:T12=0:T14=0:T16=0:
T18=0:T20=0:T22=0
1900 FOR I=1 TO J
1910 T2=T2+F(I)
1920 T4=T4+C4(I)
1930 T6=T6+C6(I)
1940 T8=T8+C8(I)
1950 T10=T10+C10(I)
1960 T12=T12+C12(I)
1970 T14=T14+C14(I)
1980 T16=T16+C16(I)
1990 T18=T18+C18(I)
2000 T20=T20+C20(I)
2010 T22=T22+C22(I)
2020 NEXT I
2030 G=(J*.5)
2040 A(K)=T2/G
2050 B1(K)=T4/G
2060 A1(K)=T6/G
2070 B2(K)=T8/G
2080 A2(K)=T10/G
2090 B3(K)=T12/G
2100 A3(K)=T14/G
2110 B4(K)=T16/G
2120 A4(K)=T18/G
2130 B5(K)=T20/G
2140 A5(K)=T22/G
2150 K=K+1
2160 RETURN
2170 '******************************************************************************
2180 ' SUBROUTINE RELATIVE HUMIDITY TO HUMIDITY RATIO *
2190 '******************************************************************************
2200 ' Conversion of relative humidity data from Fourier *
2210 ' prediction equation to humidity ratio data (W) *
2220 '******************************************************************************
2230 TR=DMT(I)+459.69
2240 IF TR >=491.99 GOTO 2270
2250 PVS=EXP(23.3924-(11286.6489#/TR)-(.46057*LOG(TR)))
2260 GOTO 2280
2270 PVS=EXP((((-27405.5258#)+(54.1896*TR)+(-.045137#*TR^2)+(.000021532#*TR^3)+(-.000000046202#*TR^4))/((2.4161*TR)-(.001215*TR^2)))*3206.1822#
2280 PV=(DMHR/100)*PVS
2290 W(I)=(.6219*PV)/(14.696-PV)
2300 RETURN
2310 '******************************************************************************
2320 ' SUBROUTINE HORIZONTAL TO TILTED SURFACE RADIATION *
2330 '******************************************************************************
2340 ' Converts direct and diffuse radiation on a *
2350 ' horizontal surface (Pyranometer data) to that on a *
2360 ' tilted surface (RTS) *
2370 '*******************************************************************************
2380 KT=DDR/EDR
2390 HDH=.775+.00653*(SSHA-90)-(.505+.00455*(SSHA-90))*COS((PI*115*KT-103)/180)
2400 SLOP=SLOP(LL)*PI/180
2410 SAA=SAA(LL)*PI/180
2420 SSHA=SSHA(LL)*PI/180
2430 SRHA=SRHA(LL)*PI/180
2440 DEC=(PI*23.45*SIN((PI*2*(284+TIME-1+I))/365))/180
2450 IF SAA=0 THEN GOTO 2500
2460 A=COS(SLOP)*SIN(DEC)*SIN(LAT)*(SSHA-SRHA)-SIN(DEC)*COS(LAT)*SIN(SLOP)*COS(SAA)*(SSHA-SRHA)+COS(DEC)*COS(LAT)*COS(SLOP)*(SIN(SSHA)-SIN(SRHA))
2470 B=COS(DEC)*COS(SAA)*SIN(LAT)*SIN(SLOP)*(SIN(SSHA)-SIN(SRHA))
2480 C=2*(COS(LAT)*COS(DEC)*SIN(ASSHA)+ASSHA*SIN(DEC)*SIN(LAT))
2490 RB=(A+B)/C
2500 RB=(COS(LAT-SLOP)*COS(DEC)*SIN(SSHA)+SSHA*SIN(LAT-SLOP)*SIN(DEC))/(COS(LAT)*COS(DEC)*SIN(ASSHA)+ASSHA*SIN(LAT)*SIN(DEC))
2510 R=(1-HDH)*RB+.5*HDH*(1+COS(SLOP))+.5*ROG*(1-COS(SLOP))
2520 RTS=R*DDR
2530 RETURN
2540 '*******************************************************************************
2550 ' SUBROUTINE R-VALUES
2560 '*******************************************************************************
2570 ' Resistance values of common materials
2580 ' for calculation of an overall heat transfer
2590 ' coefficient
2600 '*******************************************************************************
2610 PRINT"*****Material**********R-Value*************Material**********R-Value"
2620 PRINT"Batt insulation Building materials"
2630 PRINT" Glass,Mineral wool 3.00-3.80"
2640 PRINT"Concrete,solid 0.08"
2650 PRINT"Fill-Type insulation Concrete,block,3-hole,8in. 1.11"
2660 PRINT"Cellulose aggregate 2.00"
2670 PRINT" Glass,Mineral lightweight,insulated 5.03"
2680 PRINT" Vermiculite 2.20 Brick,common 0.20"
2690 PRINT" Shavings,Sawdust 2.22 Metal siding 0.00"
2700 PRINT" Hay,Straw,20 backed 0.61 Hollow Insulated"
2710 PRINT"Rigid insulation backed,3/8in. 1.82"
PR INT " Exp. polystyrene, Softwoods, fir, pine 1.25*"
PR INT " extruded, plain 5.00*"
Hardwoods, maple, oak 0.91*"
PR INT " molded beads, 1 pcf 5.00* Plywood 1.25*"
PR INT " molded beads, over 1 pcf 4.20* Particleboard 1.06*"
PR INT "Expanded rubber 4.55*"
Hardboard, tempered 1.00*"
PR INT "Expanded polyurethane, aged 6.25* Ins. sheathing, 25/32in. 2.06**"
PR INT "Glass fiber 4.00*"
Gypsum, plasterboard, 1/2in. 0.45**"
PR INT "Wood, Cane fiberboard 2.50* Wood siding 1/2in.X8in. 0.81**"
PR INT "Polyisocyanurate 7.04* Ashpalt shingles 0.44**"
PR INT "Foam, Polyurethane 6.00* Wood shingles 0.94**"
PR INT "Foam, Polyurethane 6.00* Wood shingles 0.94**"
PR INT "* Per inch of material ** For listed thickness"
RETURN
'SUBLRUTE WALL COEFFICIENT *
'Subroutine Calculation of overall heat transfer coefficient of wall surfaces (CTWAW). Description of wall surface orientation and solar radiation properties
* (ALPH, SAA, SLOP, SSHA, SRHA)
IF WT=0 THEN RETURN
FOR LL=1 TO WT
PRINT USING"How many components is wall #";LL
INPUT"constructed of";M;CLS
FOR MM=1 TO M
IF MM=1 THEN RTOTA=.85
IF MM=1 THEN RTOTB=.85
KK=0
GOSUB 2540
IF KK=1 GOTO 3080
PRINT USING"Between the framing, for wall #, component #, noting asterisks,";LL,MM
INPUT"select the appropriate R-Value";COMPB
INPUT"If the R-Value listed is per inch of material, in decimal form, input the component thickness, otherwise enter (1)";THICKB;CLS
RTOTB=RTOTB+COMPB*THICKB
KK=1
GOSUB 2540
3080 PRINT USING"At the framing, for wall #, component #, noting asterisks,";LL,MM
3090 INPUT"select the appropriate R-value (If this is not a frame wall enter (0))";COMPA
3100 INPUT"If the R-value listed is per inch of material, in decimal form, input the component thickness, otherwise enter .1 (If this is not a frame wall enter (0))";THICKA:CLS
3110 RTOTA=RTOTA+COMPA*THICKA
3120 NEXT MM
3130 INPUT"What is the percentage of framing for this wall type (If no framing exists enter (0))";PERC:CLS
3140 CTW=((1/RTOTA)*((PERC/100))+((1/RTOTB)*((100-PERC)/100))
3150 PRINT USING"For wall #, what is the total area (FT(2))";LL
3160 INPUT AW(LL):CLS
3170 CTWAW(LL)=CTW*AW(LL)
3180 PRINT USING"For wall type ##, enter the average outside surface color parameter.";LL
3190 INPUT"Under normal circumstances the range is from 0.15 for light surfaces to 0.30 for dark surfaces";ALPH(LL):CLS
3200 PRINT USING"For wall type ##, enter the surface azimuth (Degrees)";LL
3210 INPUT"South (0) East (-) West(+)";SAA(LL):CLS
3220 PRINT USING"For wall type ##, enter the";LL
3230 INPUT"the surface slope (Degrees)";SLOP(LL):CLS
3240 ERHO(LL)=((90-SLOP(LL))/90)*(-7)
3250 PRINT USING"For wall type ##, enter the";LL
3260 INPUT"sunset hour angle";SSHA(LL):CLS
3270 PRINT USING"For wall type ##, enter the";LL
3280 INPUT"sunrise hour angle";SRHA(LL):CLS
3290 NEXT LL
3300 RETURN
3310 '******************************************************************************
3320 '* SUBROUTINE ROOF COEFFICIENT *
3330 '******************************************************************************
3340 '*Calculation of the overall heat transfer coefficient*
3350 '* of the roof surface (CTRARC). Describes roof *
3360 '* surface orientation and solar radiation properties *
3370 '******************************************************************************
3380 INPUT"If you have a pitched roof-attic-ceiling combination enter (0). If just a pitched roof exists enter (1). If just a ceiling (Flat roof) exists enter (2)";KKK:CLS
3390 IF KKK=2 GOTO 3620
3400 INPUT"How many components is the roof constructed of";M:CLS
3410 FOR MM=1 TO M
3420 IF MM=1 THEN RTOTA=1.27
3430 IF MM=1 THEN RTOTB= .88
3440 KK=0
3450 GOSUB 2540
3460 IF KK=1 GOTO 3530
3470 PRINT USING"Between the framing, for roof component #, noting asterisks,";MM
3480 INPUT"select the appropriate R-value";COMPB
3490 INPUT"If the R-value listed is per inch of material, in decimal form, input the component thickness, otherwise enter (1)";THICKB:CLS
3500 RTOTB=RTOTB+COMPB*THICKB
3510 KK=1
3520 GOSUB 2540
3530 PRINT USING"At the framing, for roof component #, noting asterisks,";MM
3540 INPUT"select the appropriate R-value (If no framing exists enter (0))";COMPA
3550 INPUT"If the R-value listed is per inch of material, in decimal form, input the component thickness, otherwise enter (1) (If no framing exists enter (0))";THICKA:CLS
3560 RTOTA=RTOTA+COMPA*THICKA
3570 NEXT MM
3580 KK=0
3590 INPUT"What is the percentage of framing in the roof (If no framing exists enter (0))";PERC:CLS
3600 CROOF=((1/RTOTA)*(PERC/100))+((1/RTOTB)*((100-PERC)/100))
3610 IF KKK=1 GOTO 3880
3620 INPUT"How many components is the ceiling constructed of";M:CLS
3630 FOR MM=1 TO M
3640 IF MM=1 THEN RTOTA=1.22
3650 IF MM=1 THEN RTOTB=1.71
3660 KK=0
3670 GOSUB 2540
3680 IF KK=1 GOTO 3750
3690 PRINT USING"Between the framing, for ceiling component #, noting asterisks,";MM
3700 INPUT"select the appropriate R-value";COMPB
3710 INPUT"If the R-value listed is per inch of material, in decimal form, input the component thickness, otherwise enter (1)";THICKB:CLS
3720 RTOTB=RTOTB+COMPB*THICKB
3730 KK=1
3740 GOSUB 2540
3750 PRINT USING"At the framing, for ceiling component #, noting asterisks,";MM
3760 INPUT"select the appropriate R-value (If no framing exists enter (0))";COMPA
3770 INPUT"If the R-value listed is per inch of material,
in decimal form, input the component thickness, otherwise enter (1) (If no framing exists enter (0))";THICKA:CLS
3780 RTOTA=RTOTA+COMPA*THICKA
3790 NEXT MM
3800 INPUT"What is the percentage of framing in the ceiling (If no framing exists enter (0))";PERC:CLS
3810 CCEIL=((1/RTOTA)*(PERC/100))+(1/RTOTB)*((100-PERC)/100))
3820 IF KKK=2 GOTO 3910
3830 INPUT"What is the area of the roof (ft(2))";AR:CLS
3840 INPUT"What is the area of the ceiling (ft(2))";AC:CLS
3850 CTRARC=(1/((1/(CROOF*(AR/AC)))+(1/CCEIL)))*AR
3860 AW(L)=AR
3870 GOTO 3930
3880 INPUT"What is the area of the roof (ft(2))";AW(L):CLS
3890 CTRARC=CROOF*AW(L)
3900 GOTO 3930
3910 INPUT"What is the area of the ceiling (ft(2))";AW(L):CLS
3920 CTRARC=CCEIL*AW(L)
3930 PRINT"For the roof, enter the average outside surface color parameter"
3940 INPUT"Under normal circumstances the range is from 0.15 for light surfaces to 0.30 for dark surfaces";ALPH(L):CLS
3950 INPUT"For the roof, enter the surface azimuth (Degrees) South (0) East (-) West (+)";SAA(L):CLS
3960 INPUT"For the roof, enter the surface slope (Degrees)";SLOP(L):CLS
3970 ERHO(L)=((90-SLOP(L))/90)*(-7)
3980 INPUT"For the roof, enter the sunset hour angle";SSHA(L):CLS
3990 INPUT"For the roof, enter the sunrise hour angle";SRHA(L):CLS
4000 RETURN
4010 '**********************************************************************************************************
4020 '**********************************************************************************************************
4030 '**********************************************************************************************************
4040 'Calculation of the overall heat transfer coefficient* of window surfaces (CTWW). Describes window * surface orientation and solar radiation properties *
4065 '**********************************************************************************************************
4070 IF WWT= 0 THEN RETURN
4080 FOR LL=1 TO WWT
4090 PRINT:PRINT:PRINT:PRINT
4100 PRINT"****************************************************************************Window Type***************R-Value****************************************************************************":"PRINT
4110 PRINT" Single glazed 0.91"
4120 PRINT" With storm windows 2.00"
4130 PRINT" Insulating glass,1/4 in.space
PRINT"Double pane 1.69" pane
PRINT"Triple pane
2.56":PRINT
PRINT"************************************************************
****************************
PRINT:PRINT:PRINT
PRINT USING"For window type #, enter the corresponding";LL
INPUT"R-value";RTOT:CLS
INPUT"What is the area (FT(2)) of this window type";AW(LL+WT):CLS
CTW(LL+WT)=((1/RTOT)*AW(LL+WT))
PRINT USING"For window type ##, enter the average outside surface color parameter";LL
INPUT"Under normal circumstances the range is from 0.15 for light surfaces to 0.30 for dark surfaces";ALPH(LL+WT):CLS
PRINT USING"For window type ##, enter the surface azimuth (Degrees)";LL
INPUT"South (0) East (-) West (+)";SAA(LL+WT):CLS
PRINT USING"For window type ##, enter the";LL
INPUT"the surface slope (Degrees)";SLOP(LL+WT):CLS
ERHO(LL+WT)=((90-SLOP(LL+WT))/90)*(-7)
PRINT USING"For window type ##, enter";LL
INPUT"the sunset hour angle";SSHA(LL+WT):CLS
PRINT USING"For window type ##, enter";LL
INPUT"the sunrise hour angle";SRHA(LL+WT):CLS
NEXT LL
RETURN
'* SUBROUTINE DOOR COEFFICIENT *
'* Calculation of the overall heat transfer coefficient *
'* of door surfaces (CTDD). Description of door *
'* surface orientation and solar radiation properties *
'* *******************************************************************************
IF DT=0 THEN RETURN
FOR LL=1 TO DT
PRINT:PRINT:PRINT:PRINT
PRINT"************************************************************Door Type************************************R-Value************************************":PRINT
PRINT"Wood, solid core, 1 3/4 in. 3.03"
PRINT"Metal, urethane core, 1 3/4 in. 2.50"
PRINT"Metal, polystyrene core, 1 3/4 in. 2.13":PRINT
PRINT"***************************************************************
********************************************************************
PRINT:PRINT:PRINT
PRINT USING"For door type #, enter the
corresponding";LL
4520 INPUT"R-value";RTOT:CLS
4530 INPUT"What is the area (FT(2)) of this door type";AW(LL+WT+WWT):CLS
4540 CTDD(LL+WT+WWT)=((1/RTOT)*AW(LL+WT+WWT))
4550 PRINT USING"For door type ##, enter the average outside surface color parameter";LL
4560 INPUT"Under normal circumstances the range is from 0.15 for light surfaces to 0.30 for dark surfaces";ALPH(LL+WT+WWT):CLS
4570 PRINT USING"For door type ##, enter the surface azimuth (Degrees)";LL
4580 INPUT"South (0) East (-) West(+)";SAA(LL+WT+WWT):CLS
4590 PRINT USING"For door type ##, enter the";LL
4600 INPUT"surface slope (Degrees)";SLOP(LL+WT+WWT):CLS
4610 ERHO(LL+WT+WWT)=((90-SLOP(LL+WT+WWT))/90)*(-7)
4620 PRINT USING"For door type ##, enter";LL
4630 INPUT"the sunset hour angle";SSHA(LL+WT+WWT):CLS
4640 PRINT USING"For door type ##, enter";LL
4650 INPUT"the sunrise hour angle";SRHA(LL+WT+WWT):CLS
4660 NEXT LL
4670 RETURN
4680 '******************************************************************************************************
4690 '* SUBROUTINE FLOOR COEFFICIENT *
4700 '******************************************************************************************************
4710 '* Describes the overall heat transfer coefficient of *
4720 ' * the perimeter (CLPERM) *
4730 '******************************************************************************************************
4740 INPUT"What is the perimeter of the building (FT)";LPERM:CLS
4750 INPUT"If the perimeter is insulated enter (1) if the perimeter is uninsulated enter (0)";M:CLS
4760 IF M=1 THEN CLPERM=LPERM*(1/2.22)
4770 IF M=0 THEN CLPERM=LPERM*(1/1.23)
4780 INPUT"Enter the average depth of waste in the pit";DM:CLS
4790 INPUT"Enter the depth (Ft) of the pit";DP:CLS
4800 RETURN
4810 '******************************************************************************************************
4820 '* SUBROUTINE SENSIBLE HEAT GAIN *
4830 '******************************************************************************************************
4840 '* Calculation of heat gain from structure (SHC, SHGT) *
4850 '******************************************************************************************************
4860 INPUT"Enter the amount of supplimental heating, or cooling, (BTU/HR) supplied to the structure. (+) For heating, (-) For cooling.";SHC:CLS
4870 INPUT"Enter the total wattage of all incandescent lighting in operation";SHGI:CLS
4880 INPUT"Enter the total wattage of all fluorescent lighting in operation";SHGF:CLS
4890 INPUT"Enter the horsepower of all motors in operation
(Do not include the exhaust fans)"; SHGM:CLS
4900 SHGT=3.4*SHGI+4.1*SHGF+4000*SHGM
4910 RETURN
4920 '*****************************************************************************
4930 ' SUBROUTINE PIT MOISTURE PRODUCTION *
4940 '*****************************************************************************
4950 ' Describes manure pit and aqueous surface conditions*
4960 '*****************************************************************************
4970 INPUT"Enter the mass rate of defecated waste (LB/HR-LB) from the animal"; DWR:CLS
4980 INPUT"Enter the average animal body temperature (F) of the animal"; ABT:CLS
4990 INPUT"Enter the specific heat (BTU/LB-F) of the manure"; SPHM:CLS
5000 INPUT"Enter the surface area of the exposed manure surface"; SA:CLS
5010 INPUT"Enter the average temperature (F) of the exposed manure surface (Usually the wet-bulb temperature)"; EMT:CLS
5020 INPUT"Enter the average latent heat of evaporation (BTU/LB) at the surface of the manure (Usually found at the wet-bulb temperature)"; LHVW:CLS
5030 INPUT"Enter the convective heat transfer coefficient (BTU/HR-FT(2)-F) of the exposed waste surface"; HT:CLS
5040 RETURN
5050 '*****************************************************************************
5060 ' SUBROUTINE SOIL TEMPERATURE DATA *
5070 '*****************************************************************************
5080 ' Describes soil parameters *
5090 '*****************************************************************************
5100 INPUT"Enter the mean earth temperature (F), annual surface swing (F), and the thermal conductivity (BTU/HR-FT-F) of the soil"; ETM, ASS, THCOND:CLS
5110 INPUT"Enter the soil density (LB/FT(3)), soil specific heat (BTU/LB-F), phase constant day of minimum surface temperature (Days)"; SDEN, SPHS, PCST:CLS
5120 RETURN
5130 '*****************************************************************************
5140 ' SUBROUTINE ANIMAL SENSIBLE AND LATENT HEAT PROD. *
5150 '*****************************************************************************
5160 ' Describes animal sensible and latent heat *
5170 ' production parameters *
5180 '*****************************************************************************
5190 INPUT"Enter the coefficients of the animal weight prediction equation - intercept, age term, age squared term"; AWI, AGE, AGE2:CLS
5200 INPUT"Enter the coefficients of the animal latent heat production prediction equation - intercept, temperature, temperature squared, weight, weight squared, and temperature*weight interaction terms"; HPRODLI, HPLTEM, HPLTEM2, HPLWT, HPLWT2, HPLTW:CLS
INPUT "Enter the coefficients of the animal sensible heat production prediction equation - intercept, temperature, temperature squared, weight, weight squared, and temperature*weight interaction terms"; HPRODSI, HPSTEM, HPSTEM2, HPSWT, HPSWT2, HPSTW: CLS

RETURN

'******************************************************************************

* SUBROUTINE BALANCE POINT PARAMETER CALCULATIONS *

'******************************************************************************

* Parameters for moisture control (Ventilation rate * VENTM) and temperature control (Ventilation rate * VENTE) and resulting energy requirements (EA, * energy balance, MA, moisture balance *

******************************************************************************

CTWAWT=0

FOR LL=1 TO L

IF LL<=WT THEN CTWAWT=CTWAWT+SAT(I,LL)*CTWAW(LL)

IF (LL>WT) AND (LL<=WT+WWT) THEN

CTWAWT=CTWAWT+SAT(I,LL)*CTWW(LL)

IF (LL>WT+WWT) AND (LL<=WT+WWT+DT) THEN

CTWAWT=CTWAWT+SAT(I,LL)*CTDD(LL)

IF LL=L THEN CTWAWT=CTWAWT+SAT(I,LL)*CTRARC

NEXT LL

DMGT=ETM-ASS*EXP(-DP*(PI/365*((THCOND*24)/(SDEN*SPHS))))+.5)*COS(((2*PI)/365)*(((TIME-1+I)-PCST- (DP/2)*((PI*((THCOND*24)/(SDEN*SPHS))))-.5))

CTWAWT=CTWAWT+CLPERM*DMDT(I)+((SA*DMGT*.815574)/DM)

WGT=AWI+AGE*BAGE+AGE2*BAGE^2

BAGE=BAGE+1

ALHP=HPRODLI+HPLTEM*DMDT+HPLTEM2*DMDT^2+HPLWT*WGT +HPLWT^2+WGT^2+HPLTW*DMDT*WGT

ASHP=HPRODSI+HPSTEM*DMDT+HPSTEM2*DMDT^2+HPSWT*WGT +HPSWT^2+WGT^2+HPSTW*DMDT*WGT

VENTM(I)=(((ALHP*NUM)/LHVA)+(((DWR*WGT*NUM*SPHM*(ABT-DIMT))+(HT*SA*(DIMT-EMT)))/LHVW)/(60*DENA*(HR-W(I))))

VENTE(I)=(-(TCTA*DMDT)+CTWAWT+((NUM*ASHP) +SHC+SHGT+((NUM*ALHP)+((DWR*WGT*NUM*SPHM*(ABT-DIMT))+(HT*SA*(DIMT-EMT)))/((SPHA*DENA*60*(DIMT-DMT(I))))+(DENA*60*(HR-W(I)))))*LHVA)

IF (VENTE(I) > 28800) OR (VENTE(I) < 0) THEN VENTE(I)=28800

MA(I)=-VENTE(I)*60*DENA*(HR-W(I))+((ALHP*NUM)/LHVA)+((DWR*WGT*NUM*SPHM*(ABT-DIMT))/LHVW+(HT*SA*(DIMT-EMT)))/LHVW

EA(I)=-(VENTE(I)*60*SPHA*DENA*(DIMT-DMT(I)))-VENTE(I)*60*LHVA*DENA*(HR-W(I))+CTWAWT-TCTA*DMDT+SHC+SHGT+DWR*WGT*NUM*SPHM*(ABT-DIMT)+HT*SA*(DIMT-EMT)+(ASHP+ALHP)*NUM

RETURN
SUBROUTINE OUTPUT

Creation of output files

OPEN "O",#1,"B:VENTESI"
OPEN "O",#2,"B:ENERGSI"
OPEN "O",#3,"B:MOISTSI"
FOR I=1 TO J
PRINT #1, VENTE(I)
PRINT #2, EA(I)
PRINT #3, MA(I)
NEXT I
CLOSE #1
CLOSE #2
CLOSE #3
RETURN
END