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To the Graduate Council:

I am submitting herewith a thesis written by Lewis Ewing Larsen entitled "An Investigation of Temperature Patterns for Conventional, Windowless, and Solar Broiler Houses." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

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Accepted for the Council:

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AN INVESTIGATION OF TEMPERATURE PATTERNS FOR CONVENTIONAL, WINDOWLESS, AND SOLAR BROILER HOUSES

A Thesis

Presented to

the Graduate Council of

The University of Tennessee

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

Lewis Ewing Larsen

June 1964

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CHAPTER I

THE PROBLEM

The commercial production of broilers has become a multi-billion dollar industry since its start in 1935. Prior to this time, with the exception of farms adjacent to metropolitan areas, poultry production was primarily for consumption by the farm family. Due to the absence of adequate refrigeration facilities, poultry provided the farm family with a source of fresh meat during warm weather and it, therefore, was a highly seasonal operation. Farms near metropolitan areas generally produced some poultry for marketing (8)*.

By the early 1940's broiler production in some areas had developed into an enterprise of significant importance. General recommendations for the brooding of chicks, as well as basic suggestions for management, housing, and feeding, were being made by colleges of agriculture and the United States Department of Agriculture. The basic recommendations in regard to housing included procedures to prevent overheating and provide ample ventilation, but no specific values were given except for minimum temperatures for brooding of young chicks. Growers were advised to observe the behavior of the chicks and use this as the best guide for heat and ventilation requirements (15).

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*Numbers in parenthesis refer to references in the Bibliography.

The outbreak of World War II had a stimulating effect on poultry production since the demand for food increased. Broilers could be produced faster, at lower cost, and with less labor than other meat animals. Even with wartime price restrictions, broiler production was in most cases a highly profitable enterprise. Under these conditions, expansion in existing broiler areas was very rapid, and new producing areas in the South developed.

Post war production continued, but there was increasing competition with other meat sources (26). While profit margins narrowed, the unit cost of production decreased and production increased further. In some areas, land had been taken out of crop production by controls, or it was no longer profitable to compete with higher producing crop areas. A replacement for cash crops in some of these areas was broiler production. This was a logical transition since available land and labor could be utilized (27).

In the meantime, broiler production declined in some of the older producing areas, but southern areas continued to increase (28,34). In 1950, Georgia became the nation's largest broiler producing state and has maintained that position (29). In 1963, the top ten broiler states produced 87 per cent of the nation's broilers, and the top five accounted for 62 per cent. The rank, production in thousands and per cent of the national production of the top five states, in 1963 was:

Georgia	359,760	18%
Arkansas	257,461	13%

Alabama	227,461	12%
North Carolina	215,314	11%
Mississippi	155,835	8%

In recent years the national broiler production has more than doubled to approximately two billion birds annually (6). The per capita consumption has increased approximately one and one-half times to an estimated twenty-five pounds per year (7). It has been estimated that a minimum of a quarter of a million dollars of working capital is needed to sustain the production facilities for a million broilers (10). Thus, it is apparent that the total broiler industry has developed from a part-time enterprise to a multibillion dollar industry.

With rapid expansion of the broiler industry, declining market prices, and increased competition, efficiency of production became a more important factor. To effectively meet competition and remain in production, the hatcherymen, growers, feedmen, and processors entered into an integrated operation which relieved part of the financial problems. However, some of the problems of reduced efficiency that had developed in early periods remained unsolved, while new and more complex ones developed in the most modern facilities. Due to the rapid expansion, research lagged behind the needs of the industry. Recommendations for large-scale production were desired, but this information was generally unavailable and inadequate. Means of preventing and controlling diseases were needed. Feeds in adequate supply and means of handling them to produce the

most efficient growth rates were desired. Methods of handling live broilers for shipment to processors without injury were needed. Processing, transporting, and marketing produced new problems. There was a demand for broiler chicks that presented a good dressed appearance, were disease resistant, and were fast growing. Some of the needs involved problems that were inter-related and others that could not be isolated (19,24).

Recommendations and information on the most suitable environment and the most efficient housing, two of the most neglected items, were in great demand. Housing arrangements for efficient operation and healthy environmental conditions presented complex problems. These were problems of construction costs, diseases, mortality rates, space requirements, feeding methods, watering, litter, ammonia production from litter, ventilation, moisture, and temperature conditions. Environmental conditions were known to be related to the efficiency of production, but the extent of this relation was not well defined (8).

Interior environment was affected by management factors, types of housing, and the outside weather conditions. In expanding production, growers had increased the size of the existing structures and reduced the floor space per bird. These changes in housing and management resulted in increased disease problems, mortality rate, and a general lowering of growth efficiency. It was recognized that these problems were inter-related with temperature, ventilation, and other factors of environment (20). In an

attempt to reduce heating cost, improve temperature conditions, and increase efficiency, means of utilizing solar energy were developed (21). Also, caves and abandoned mines, with relative constant temperatures were used, and in some cases were found to be quite satisfactory (31). Thus, broiler housing in many areas began to diverge from the once traditional housing into different types with various modifications.

The first of these types was the conventional house which developed from improved traditional housing. It was in most cases a partially open structure which provided natural ventilation and generally had little or no insulation. A second type was the solar house which was developed to reduce heating cost by utilizing a solar heat collector. It usually required insulation and forced ventilation for satisfactory performance. A third type was a windowless house which was well-insulated, forced ventilated, and artificially lighted to stimulate underground conditions.

Thus, a variety of housing began to develop. This was in an effort to increase efficiency which was related to production conditions. To obtain more specific information, research projects along this line were developed. Some growers became interested in solar houses, whereas, others were more concerned with windowless or conventional housing. It was apparent that there was need for more research pertaining to all types of housing in all geographical areas.

Object of the investigation. It was the object of this

investigation to determine and compare the inside and outside temperature patterns for conventional, windowless, and solar broiler housing in the same location simultaneously. It was also the object of this investigation to provide information on temperature relationships that could be used by the engineer in designing broiler housing and the grower in house management.

Statement of the problem. The problem was designed to compare the hourly ambient dry-bulb temperatures during the fall, winter, and spring growing seasons for two consecutive years. This required continuous recordings of the ambient dry-bulb temperatures of the air. These were obtained at two locations inside each of the three types of broiler houses and at one location outside each house during the growing periods.

Importance of the study. The need for reducing production costs in the broiler industry demanded higher production efficiency. This in turn created a need for more research on factors which affected production. Information on temperature conditions were especially needed. With a better understanding of the temperature relationships, the grower could have greater control over the temperatures inside the house. Likewise, the engineer would have better information on which to base designs for producing the desired temperature conditions. At the time of this investigation, there were no known average hourly temperature patterns for windowless, solar, and conventional houses at the same location. This

study provided such data for design and management purposes. It was hoped that the information reported herein might be of significant value to the broiler industry, particularly the research worker, the engineer, and the grower.

Review of previous work reported on this project. This study of three types of broiler houses was a cooperative project between the Agricultural Engineering and Poultry Departments of the University of Tennessee. The project began in the fall of 1958 and continued through the spring of 1960. Data pertaining to temperature conditions, humidity conditions, and bird growth were obtained for each house during this period.

Due to the fact that this project was of a continuing nature, several reports were made on certain phases of the work. The first report was a thesis which presented a description of the housing, method of obtaining data, and reported the findings on temperature and humidity for the first four seasons (13). The thesis contained plots of the maximum and minimum wet-bulb and dry-bulb temperatures for the four seasonal production periods. The hourly wet-bulb and dry-bulb temperatures for the midweeks of broiler production were also presented. A paper that was a condensation of the thesis findings with additional treatments of humidity was prepared (3). Another paper concerning seven seasonal trials was prepared. This paper gave a summary of the temperature, humidity, and broiler production in graphical and tabular form (4). A progress report that summarized the findings of the seven trials was also published

on this project (5).

Review of related investigations. Initial studies on physical and environmental requirements were not conducted specifically for broilers, but for poultry in general. Starting in 1924, Barott and Pringle worked with the incubating egg and continued their studies to obtain basic data on heat production and gaseous exchange for chickens of all ages (1). Growth rate studies were conducted by Kleiber and Dougherty in 1934 on chickens from 6 to 15 days of age under temperatures ranging from 69.8 ^{o}F to 104.0 ^{o}F (16). Growth rates were compared and found to be maximum at the lower temperature. Later experiments in 1938 by Winchester and Kleiber found that food consumption was inversely related to environmental temperature (41). Other research by Barott and Pringle determined that 12 Rhode Island hens under fasting conditions had a minimum heat output between 75 ^{o}F and 80 ^{o}F (2). Promersberger and Bryant found in a study of forced and natural ventilation that natural ventilation, though usually adequate in the summer periods, provided a winter environmental temperature only a few degrees warmer than the outside and would vary with the outside temperature (25).

A report on the environmental requirements for designing poultry shelters for laying hens was prepared by Stewart and Hinkle. They stated that in most respects the information was applicable to broilers with the exception of the size of the bird. The report contained typical design figures with respect to heat

production, moisture, ventilation, space requirements, and temperatures (33). An experiment with the use of a heat pump system for the control of environmental conditions in a laying house was conducted in South Dakota (14). Performance of this type of unit and cost analysis for owning and operating it were presented. The heat pump unit performed satisfactorily, and the minimum power consumption occurred at an average outside temperature of approximately 30 ^{o}F.

Ota and McNally found that condemnation of broilers at slaughter houses, particularly in southern areas, showed a relationship to time of year. They concluded that this was a result of housing difficulties of an environmental nature (20). Experiments were conducted by Prince and Wheeler to determine the effect of different constant temperatures and ventilation rates on feed consumption, weight gain, and feed efficiency of broiler chicks four to eight weeks of age. At different constant temperature levels between 45 ^{o}F and 75 ^{o}F, they found that an increase in temperature level resulted in a highly significant linear decrease in feed consumption. Feed consumption was also reduced significantly as a result of decreasing the constant ventilation from 2 to 3/4 cubic feet per minute per bird. However, weight gain was not significantly affected by the temperature or ventilation treatments (23).

Rokeby and Smith conducted a study of temperature and humidity conditions, and efficiency of broiler production for four types of housing. These types consisted of an air-conditioned

solar, fan-ventilated solar, naturally-ventilated uninsulated conventional with asphalt roof covering, and an improved naturally ventilated uninsulated conventional with aluminum covering. The daily inside and outside maximum, minimum, mean, and average range of dry-bulb temperatures were reported for each type of housing during three summer, two fall, and two winter growing seasons. More uniform temperatures were obtained in the solar type houses, and these produced significantly heavier birds in both summer periods. The conventional type houses had widely fluctuating temperatures, but produced significantly heavier birds in three out of the four fall and winter periods. No apparent differences in relative humidity or mortality were reported between houses (30).

The Farmstead Engineering Conference Issue of Agricultural Engineering, September, 1960, contained articles by several authors pertaining to poultry housing (22). The purpose of the conference was to collect and disseminate the most current information on confinement housing. These articles contained functional and basic requirements for poultry and broiler housing, but specific recommendations for temperature and humidity levels for good production of broilers at various ages were not given (11,12,17,32).

Work by Mueller found that pullets, subjected to an environment of cycling temperature of 55 ^{o}F to 90 ^{o}F and back to 55 ^{o}F every 24 hours, produced more eggs than pullets kept at constant temperatures of 55 ^{o}F and 90 ^{o}F, respectively (18). Other investigators found that broilers performed better under variable temperature conditions than when temperatures were held constant (9).

CHAPTER II

DESCRIPTION OF EXPERIMENTAL HOUSES AND PROCEDURE OF OBTAINING DATA

The houses used in this project were existing structures which were remodeled for research purposes. They were located on the Cherokee Farm of The University of Tennessee Agricultural Experiment Station, Knoxville. This was a cooperative project of the Agricultural Engineering and Poultry Departments.

Description of the houses. The houses were aligned on the crest of a ridge, and the fronts faced south 38 degrees east (Figure 1). A study of the sun patterns for this orientation was conducted and reported in an earlier thesis (13). It was found that this orientation caused the maximum solar heat gain to occur earlier in the day than for a house facing true south, and the time of occurrence was related to the degree of orientation toward the east. The existing orientation was considered satisfactory for comparative studies. However, results may differ somewhat from those for houses facing true south. There were several trees in the area of the experimental houses, and it was recognized that they could have had some effect on temperature conditions inside the houses. After a study of shade patterns on the houses, a previous investigator concluded that effects would be minor (13).

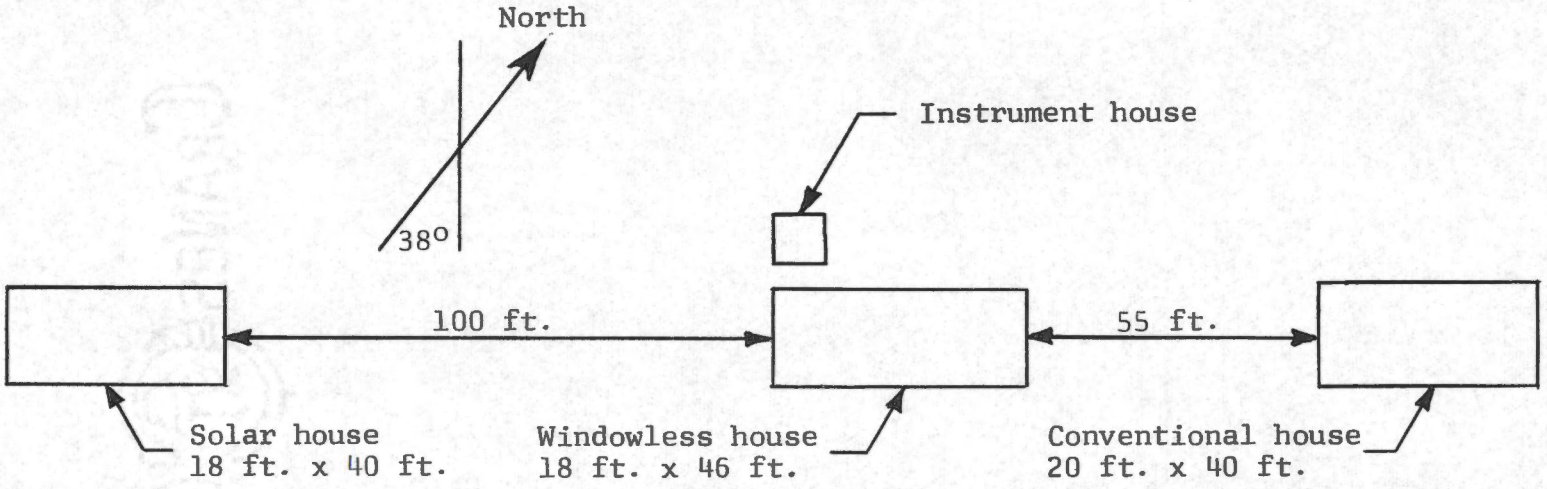


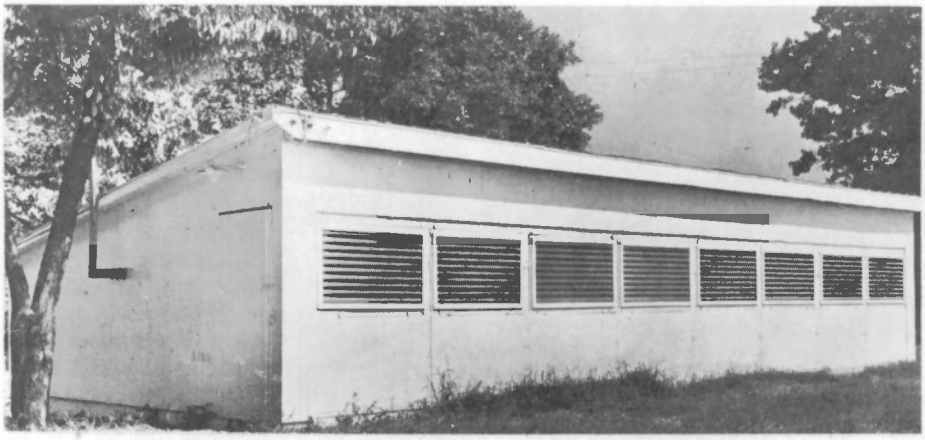
Figure 1. Orientation and layout of the experimental broiler houses.

The over-all dimensions of the conventional, windowless, and solar houses were 20 by 40 feet, 18 by 46 feet, and 18 by 40 feet, respectively (Figure 1). The differences in the dimensions of these existing structures could have caused some variations in the inside environment. All three houses measured eight and one-half feet high at the front plate and had a shed type roof with a one-twelfth pitch. The roof covering was galvanized metal applied over one inch solid sheathing supported by typical frame construction. The insulation for the solar and windowless houses, and the solar panels for the solar house were furnished by an industrial firm. Also, the installation of the insulation and solar panels, as well as the construction of the solar roof projection were according to the recommendations of this firm. The conventional house had no insulation, but both the windowless and solar houses had three and one-half inch blankets in the side walls and ceiling. The sidewall insulation was backed on both sides by heavy brown paper, and the ceiling insulation was backed on both sides by aluminum foil. The exterior covering for all three houses was three-fourths inch tongued and grooved wood sheathing painted white. The conventional house had bare stud interior walls while the windowless and solar houses had an interior wall covering of three-sixteenths cement-asbestos board. The floors of all three houses consisted of a four-inch concrete slab covered with three to four inches of woodchip or peat moss litter.

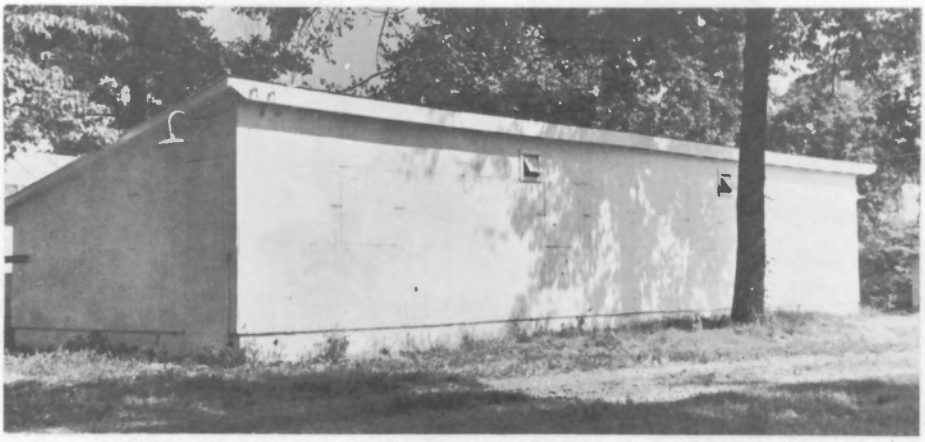
The conventional house had removable windows constructed of corrugated translucent rigid plastic panels with a window to floor

area ratio of 1 to 8.8 (Figure 2a). There were eight windows in front measuring 26 inches high and 48 inches long. The rear of the house had four windows measuring 26 inches high and 30 inches long. The windowless house had no windows as the name implies (Figure 2b). The solar house had no windows in the rear, but it had eleven solar panels installed in the front that measured 36 inches wide and 58 inches high with a window to floor area ratio of 1 to 4.5 (Figure 2c). During the first year of this investigation, the windows of the solar house were unobstructed which allowed the sun to shine directly onto the floor area. During the second year, the windows were covered inside by a black body solar heat collector designed to admit the solar heat energy by conduction and convection excluding all daylight from the interior of the house. This was done to eliminate the factor of natural light from the solar house, but retain the factor of solar heat gain. Thus, a more direct comparison of broiler growth could be made between the birds of the solar and windowless houses. A cross section of the solar house which is similar in construction to the other two houses is given in Figure 3.

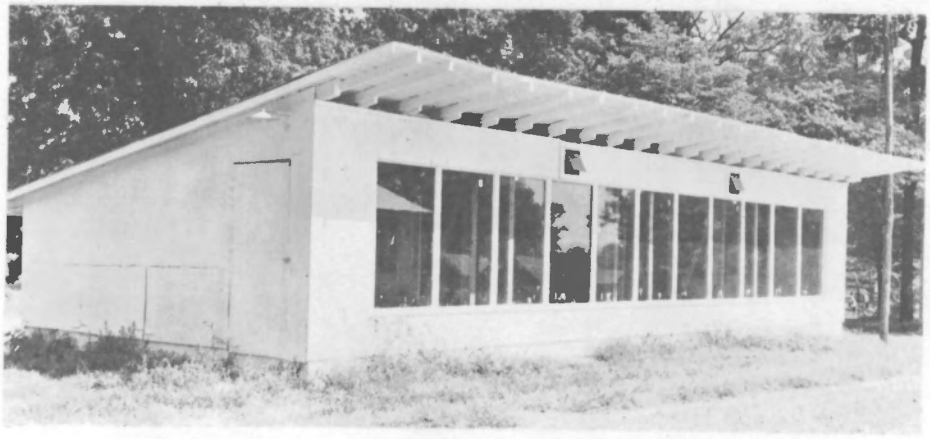
The conventional house had only natural ventilation while the windowless and solar houses required forced ventilation. The forced systems consisted of two intake fans having a nominal capacity of 700 cubic feet per minute each and one exhaust louver (Figure 3). One fan was thermostatically controlled to start when the temperature inside the house reached 75 ^{o}F and the other when



a. Front view of the conventional house.



b. Front view of the windowless house.



c. Front view of the solar house.

Figure 2. Front views of the experimental houses.

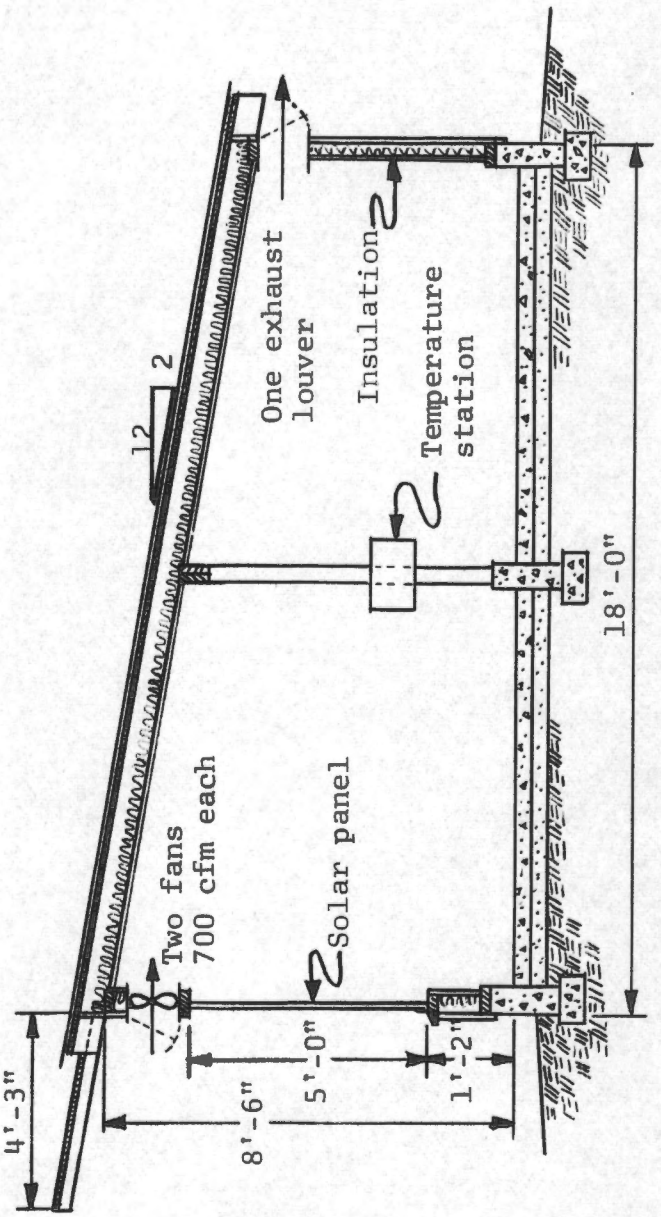


Figure 3. Cross section of the solar house.

it reached 80 ^{o}F. The exhaust louver was opened automatically when the fans started. Also, to insure the minimum requirements of ventilation and the removal of fumes or odors, a time clock was used to automatically operate the ventilation system for two minutes duration every eight minutes.

The lighting system used in all three houses consisted of a time clock controlling eight 40-watt incandescent light bulbs set to provide 14 hours of light from 6:00 a.m. to 8:00 p.m. The systems in the conventional and solar houses were also set to turn off the lights from 9:00 a.m. to 4:00 p.m., for there was adequate natural light during these hours. During the second year of this investigation, the lighting of the solar house was the same as the windowless.

The interior of each house was divided into four equal pens to hold 100 chicks each. The heat for the chicks in each pen was provided by a 600-watt hover type electric brooder which was thermostatically controlled. The thermostats were set at 95 ^{o}F for the first week and reduced 5 ^{o}F each week until a setting of 70 ^{o}F was reached. The brooders were then operated at this setting for the remainder of the growth period. During extremely cold weather it was occasionally necessary to use an oil heater at night in the conventional house to prevent unusual stress on the birds.

The management of the houses was provided by the Poultry Department. This included placement of the chicks, setting brooder thermostats, cleaning the houses, supplying fresh litter, obtaining

test weights, and other essential matters pertaining to their phase of the project. The responsibility of the Agricultural Engineering Department was to obtain and analyze the temperature data under the existing conditions for each house.

Procedure of obtaining data. The object of this investigation as previously stated was to determine and compare the inside and outside temperature patterns for these three types of broiler housing at the same location. It was desired to obtain continuous recordings of the inside and outside ambient dry-bulb temperatures for the fall, winter, and spring growing seasons. These recordings were obtained for two consecutive years. The fifth week was thought to be representative of the eight or nine week growing periods, and the data of this week was used as the basis of this study.

The thermocouple was found to be the most reliable temperature sensing element for this project. In conjuncion with the thermocouples, recording potentiometers were used to obtain recordings of the temperatures on strip charts. The recording potentiometers were placed in an instrument house at a central location. Thermocouple leads extended from the potentiometers to the thermocouples at their respective locations inside and outside each house.

A study of humidity conditions was being conducted during part of the over-all investigation. It was practical to collect both the wet-and dry-bulb temperatures by the use of thermocouples

at the same time. To obtain the wet-bulb readings continuous air movement was necessary. Both of the thermocouples were placed in the specially constructed intake tube of a squirrel cage type fan. The fan and tube assembly were designed to produce the proper air velocity for obtaining correct wet-bulb readings (Figure 4). The dry-bulb thermocouple was placed ahead of the wet-bulb to prevent erroneous readings due to the evaporation from the wet-bulb wick. This fan unit was installed in a box which was fitted with furnace type air filters on two sides. For additional protection, the filters were covered with 72 mesh cotton cloth. The filters were necessary to reduce dust collection on the wet-bulb thermocouple to tolerable limits (13).

Two of these boxes which measured 14 by 21 by 10½ inches were fastened to the supports of the interior wire partitions. They were located approximately 10 feet from the end wall, halfway between the front and rear walls, and three feet above the floor (Figure 5). Cabinets of weather proof construction containing the same type of equipment as the inside boxes were installed outside on the north side of each house (Figure 6a, page 22). The outside boxes did not require the cotton cloth filter or as much filter area to prevent dust accumulation (Figure 6b, page 22). Outside air was drawn into the enclosed box through the filters on two sides under a large overhanging lid.

A twelve point recording potentiometer was used to obtain the temperature data for the conventional and solar houses. The

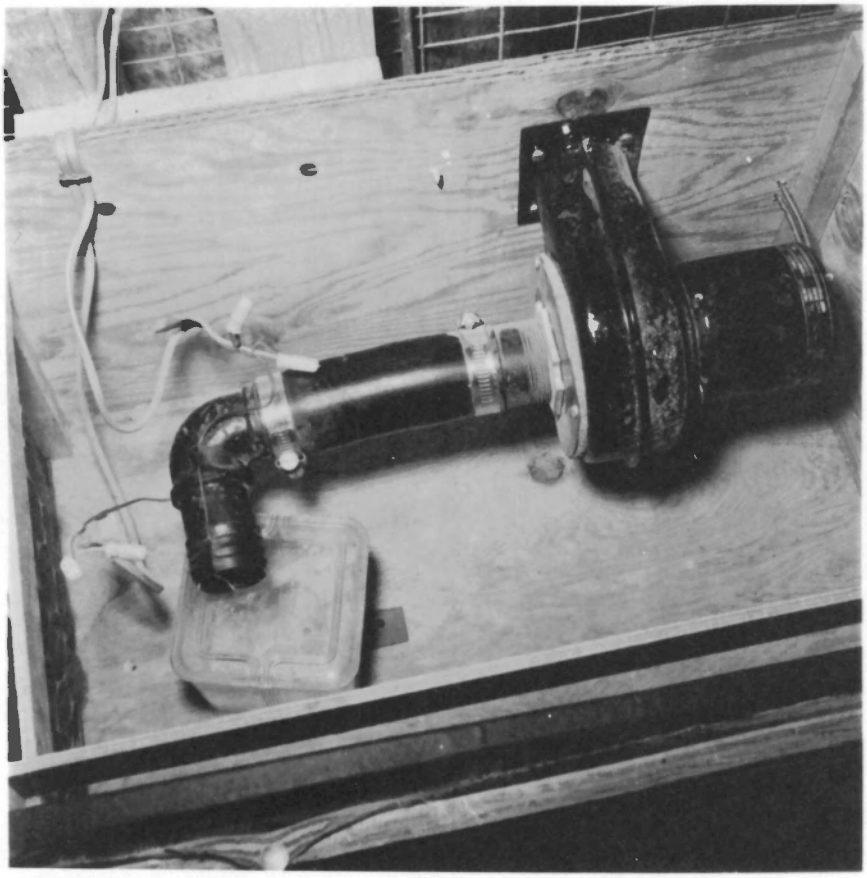


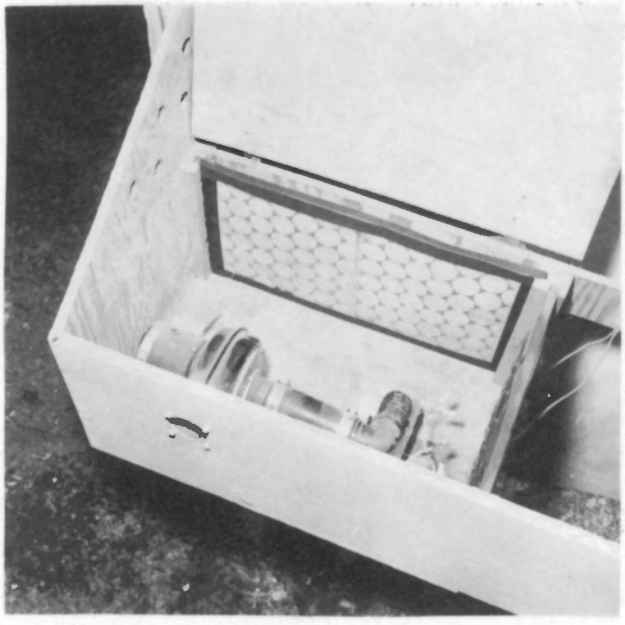
Figure 4. Interior view of a temperature station.



Figure 5. Exterior view of a temperature station.



a. External view of an outside temperature station.



b. Internal view of an outside temperature station.

Figure 6. Views of an outside temperature station.

thermocouples for this recorder were constructed of 24 gauge copper and constantan wires having a thermoplastic insulation. The leads from the thermocouples to the recorder were made of 16 gauge copper and constantan wires with thermoplastic insulation. A six-point recorder was used for the windowless house. The thermocouples and leads were both made of cotton covered 16 gauge enameled iron and constantan wires. These leads were not weather-proof and required a conduit between the windowless house and the instrument house.

The thermocouples and recorders were calibrated using a laboratory standard mercury thermometer. Calibration was checked periodically to insure correct readings. The ambient dry-bulb and wet-bulb temperatures from two locations inside and one location outside for each house were recorded continuously on a 12-minute cycle by the potentiometers on strip chart paper. Each thermocouple was identified by a number printed on the chart. These charts provided the continuous temperature readings needed for this investigation.

CHAPTER III

PRESENTATION OF THE FINDINGS

The data was collected during the fall, winter, and spring growing seasons that began in the fall of 1958 and ended in the spring of 1960. The fifth week of data was selected to be representative of each growing season. The fall periods for the first and second years began on October 8, 1958 and 1959, respectively. The winter season period for the first year began on December 31, 1958 and the second year on January 7, 1960. The spring season period for the first year began on April 6, 1959 and the second year on March 21, 1960. The dates of the winter and spring periods of the second year did not coincide with those of the first year due to management factors and changes in other phases of the joint project.

Explanation of the terms used. In an effort to avoid confusion, the terminology used in this investigation required defining due to the similarity between the terms used. As much as possible, the terms were those commonly used to report similar climatological data. They were:

Dry-bulb temperature. The temperature indicated by any type of thermometer or thermocouple not affected by the water vapor of the air or by radiation.

Mean temperature. The mean of the maximum and minimum dry-bulb temperatures recorded for a day.

Normal temperature. The average of all of the mean temperatures recorded on any given date for a particular location.

Departure from normal. The difference found by subtracting the normal temperature from the mean temperature on any given date.

Per cent available sunshine. The percentage of the total available sunshine that was actually received on any given date.

The next group of terms were used in the analysis of the test data for this investigation. These terms were developed for this analysis and were not standard terminology. They were:

Station temperature. The ambient dry-bulb temperatures recorded on the roll charts of the potentiometers from each temperature station.

Hourly temperature. The hourly average of the recorded ambient temperatures for the respective temperature station.

Average daily temperature pattern. The respective ambient temperature patterns of the inside or outside temperature stations of each house. These were obtained by plotting the average of the hourly temperatures by hour of occurrence for the seasonal period under investigation.

Typical daily temperature pattern of the season. The temperature patterns for a respective location which were obtained by

combining the average daily temperature patterns of the same season.

Average temperature of the pattern. The average of the temperatures used in plotting the individual temperature patterns.

Maximum temperature of the pattern. The maximum temperature used in plotting the individual temperature patterns.

Minimum temperature of the pattern. The minimum temperature used in plotting the individual temperature patterns.

Temperature range of the pattern. The difference between the maximum and minimum pattern temperatures used in plotting the individual temperature patterns.

The plots of the hourly temperatures for all seven days of the periods under investigation did not provide temperature patterns that indicated the average conditions for the week. The average daily temperature patterns provided plots that were more representative of the periods under investigation. The outside temperature, per cent available sunshine, and the wind conditions varied each day according to the information recorded by the local Weather Bureau. The local Weather Bureau, located at the McGhee-Tyson Airport, Knoxville, Tennessee, was approximately 7 miles southwest of the project location. Periodically, the temperatures obtained for this investigation were compared to the Weather Bureau temperatures. The differences were seldom greater than one or two degrees.

The Weather Bureau information was used as a general reference for the outside weather conditions that existed during this investigation. By analyzing the data from the local Weather Bureau, it was found that an average of the mean temperatures for the test periods of each respective season showed a slight departure from normal, and this average departure was less than the individual departure of either of the two test periods. Plots that were more typical of normal outside temperature conditions were obtained by combining the two average daily temperature patterns for each seasonal period to provide a typical daily temperature pattern of the season. Tables summarizing the average and typical daily temperature patterns were organized using the average, maximum, minimum, and range of the pattern temperatures.

Organization of the presentation. The findings were organized for presentation by seasons of the year. The average daily temperature patterns for the two consecutive years of each season were arranged by year of occurrence. The Weather Bureau information for each seasonal period was analyzed to establish the general outside weather conditions. The average daily temperature patterns of the outside and inside conditions of each house were examined for individual characteristics, and the average, maximum, minimum, and range of the pattern temperatures were presented in tabular form. The typical daily temperature patterns of the seasons were prepared for presentation in a similar manner and analyzed to determine how closely the patterns for the houses were correlated

to the outside typical daily temperature pattern of the season. The temperature data for the average daily patterns and the typical daily patterns of the seasons are in the Appendix.

Fall season findings. The general outside weather conditions for the first fall period indicated that the mean temperature averaged 1.4 ^{o}F below normal, and the wind velocity averaged 4.9 miles per hour. The average hourly wind velocities were a minimum between 2:00 and 6:00 a.m. They reached a maximum at about 1:00 p.m. and diminished gradually until approximately 5:00 p.m. This period contained four days that had 100 per cent of the available sunshine and averaged 79.9 per cent for the week (35).

The average daily temperature patterns for the first fall period are shown in Figure 7. The outside pattern indicated the rapid warming of the outside air during a period having a high percentage of the available sunshine. The conventional house pattern was very similar to the outside pattern, but it indicated a more rapid temperature increase during the morning. The pattern for the windowless house was relatively constant and resembled the outside pattern the least. The similarity of the solar house pattern to the outside pattern was between that of the conventional and windowless. A summary of the average daily temperature patterns of the first fall period is given in Table I. The windowless house had the highest average and highest minimum temperatures of the patterns, and the solar house had the highest maximum temperature of the patterns. The outside pattern had the greatest temperature range.

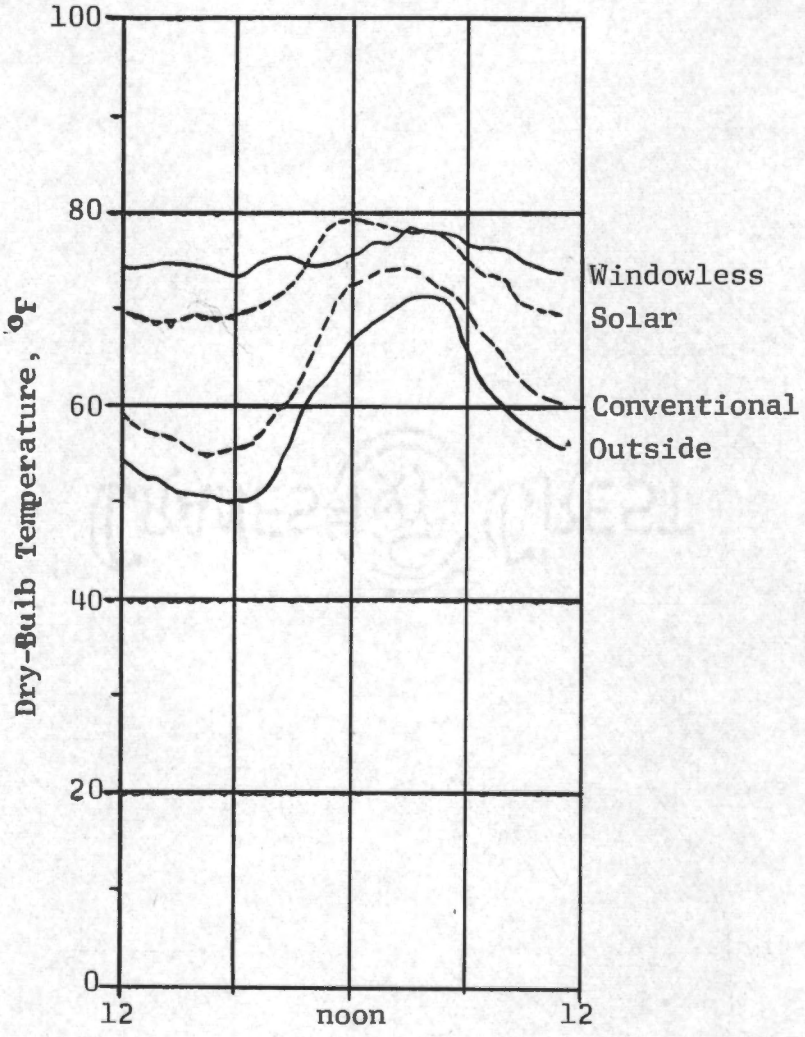


Figure 7. Average daily temperature patterns for the first fall period, October 8-14, 1958.

TABLE I

SUMMARY OF THE AVERAGE DAILY TEMPERATURE PATTERNS
FIRST FALL PERIOD, OCTOBER 8-14, 1958

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	59.5	71.4	50.6	20.8
Conventional	64.1	74.1	55.4	18.7
Windowless	75.6	78.3	73.9	4.4
Solar	73.5	79.7	69.1	10.6

The general outside weather conditions for the second fall period were different from those of the first. During the second fall period the mean temperature average 3.9 ^{o}F above normal, and there was only one day that had 100 per cent of the available sunshine. During this period the houses average receiving 31.6 per cent of the available sunshine compared to 79.9 per cent for the first fall period. The wind velocity average 4.8 miles per hour, and the average hourly velocities reached a maximum at approximately 10:00 a.m. and diminished through the afternoon. The first four days of the week were very warm, but the temperatures dropped to below normal on the last day. The month of October was the wettest since that of 1949 and had the least amount of sunshine for any October since 1919. The departure from normal temperature and the per cent of available sunshine for the second fall period were almost opposite to those of the first (36).

The average daily temperature patterns for the second fall period are shown in Figure 8. The outside temperature did not fluctuate over as great a range as it did in the first fall period. According to the test data, there was a tendency for each day to gradually become cooler which was indicated by the temperatures being lower at the end of the outside average daily pattern than at the beginning. The conventional house pattern was almost parallel to that of the outside and averaged only 4.6 ^{o}F warmer. There was very little difference in the windowless and solar house patterns during this period, and their patterns did not fluctuate as much as

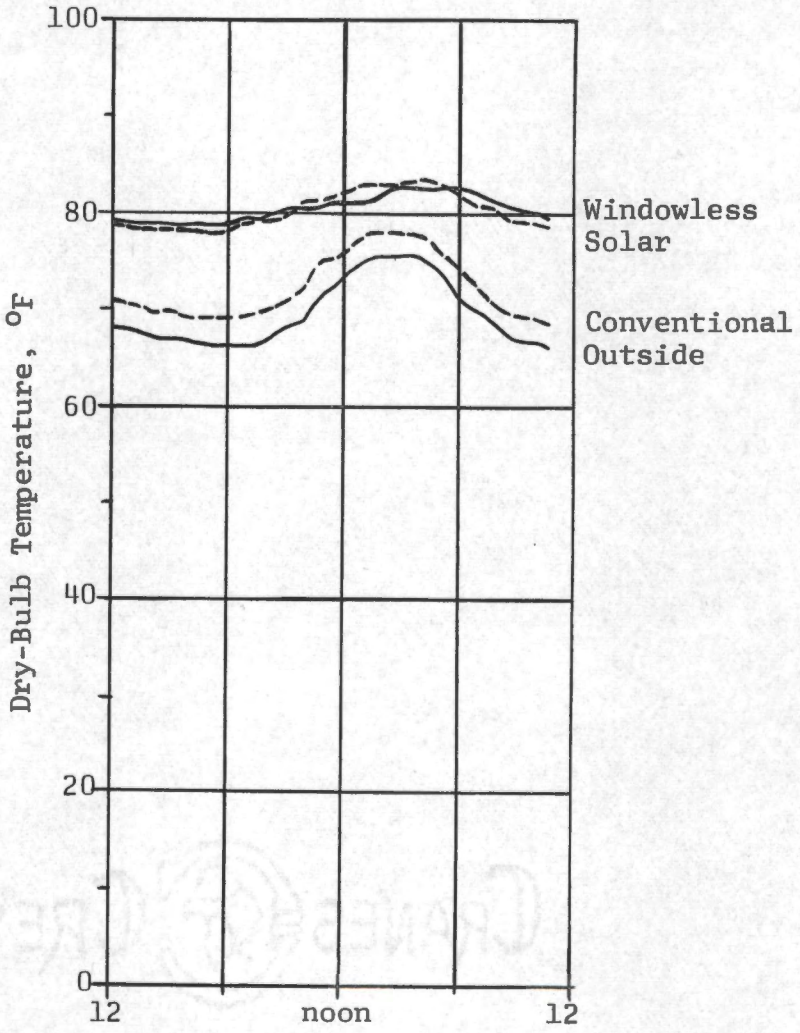


Figure 8. Average daily temperature patterns for the second fall period, October 8-14, 1959.

the outside pattern or the conventional house pattern. A summary of the average daily temperature patterns for the second fall period is given in Table II, page 34. The windowless house had the highest average and the highest minimum temperatures of the patterns as it did during the first fall period. The solar house again had the highest maximum temperature of the patterns, but the conventional house pattern had the greatest temperature range.

The outside weather conditions for the typical daily temperature patterns during the fall season were obtained by averaging the conditions of temperature, per cent available sunshine, and wind velocity. The average mean temperature was 62.7 ^{o}F which was a 1.25 ^{o}F departure above the average normal temperature for these two periods. There was an average of 55.8 per cent available sunshine and 4.75 miles per hour of wind velocity. The resulting outside weather conditions during the typical daily temperature patterns of the fall season were more representative of normal conditions than either of the two individual fall periods.

The typical daily temperature patterns of the fall season and a summary of the temperatures for these patterns are given in Figure 9 and in Table III, page 36. The patterns of the outside and conventional house temperatures were very similar in form, with the conventional pattern averaging 3.6 ^{o}F warmer than the outside. The windowless house pattern was the least similar to the outside pattern. The solar house pattern displayed characteristics that were similar to the outside pattern but not to the extent obtained

TABLE II

SUMMARY OF THE AVERAGE DAILY TEMPERATURE PATTERNS
SECOND FALL PERIOD, OCTOBER 8-14, 1959

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	69.6	75.6	66.1	9.5
Conventional	72.3	78.1	68.3	9.8
Windowless	80.5	82.3	78.9	3.5
Solar	80.2	83.3	78.0	5.3

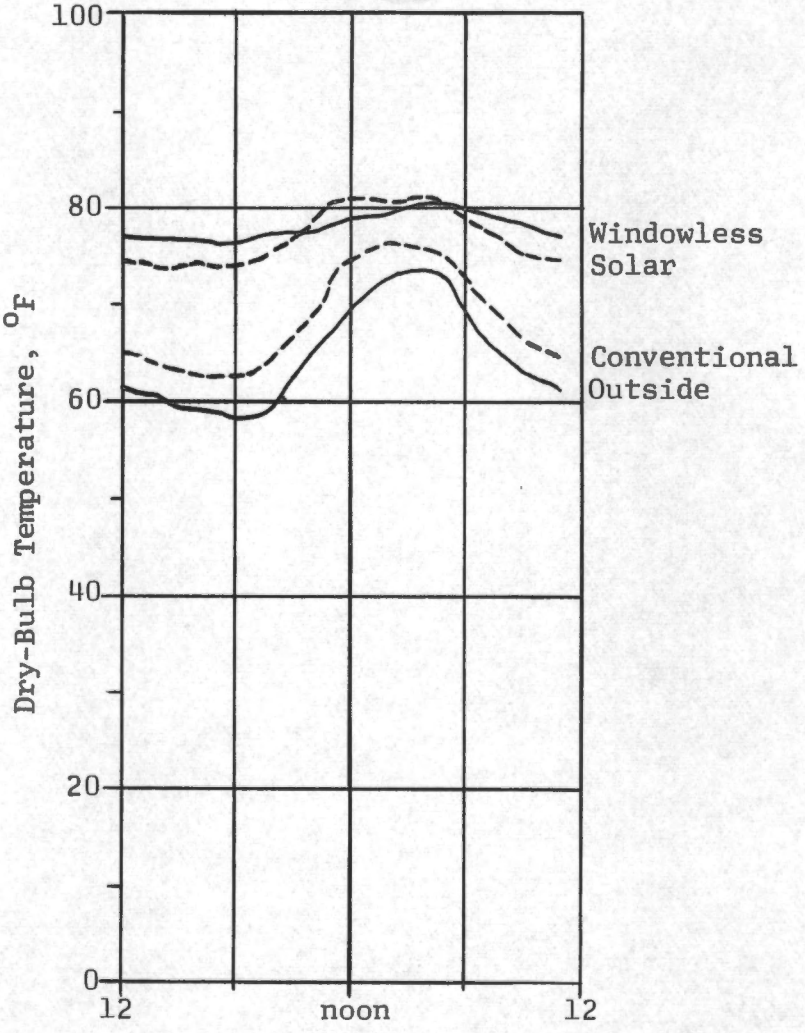


Figure 9. Typical daily temperature patterns of the fall season.

TABLE III

SUMMARY OF THE TYPICAL DAILY TEMPERATURE PATTERNS OF THE FALL SEASON

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	64.6	73.5	58.4	15.1
Conventional	68.2	76.1	62.4	13.7
Windowless	78.1	80.3	76.4	3.9
Solar	76.9	80.9	73.8	7.1

by the conventional house pattern. As in the average daily temperature patterns, the windowless house had the highest average and highest minimum temperatures of the patterns. The outside had the greatest temperature range of the patterns.

As a final treatment of the typical daily temperature patterns of the fall season, calculations were made of the coefficients of correlation (r) between the outside pattern temperatures and those for the houses. The results were:

Between outside and conventional	$r = 0.9857$
Between outside and windowless	$r = 0.9411$
Between outside and solar	$r = 0.9415$

The coefficients of correlation provided a measure of the association between the inside temperatures and those of the outside with unity being the strongest association. The departure from unity by the coefficients indicated the effect of the different types of housing on this association. The degree of association was strongest for the conventional house temperature and about the same for the windowless and solar. The strong association between the conventional house temperatures and those of the outside was a result of the natural ventilation and the lack of insulation, both which allowed the inside temperatures to follow those of the outside. The levels of association for the windowless and solar houses were not as strong due to the controlled ventilation and the insulation, both of which tended to prevent the inside temperatures from fluctuating as much as the temperatures of the outside. All three of the coefficients

were significant above the 1 per cent level. This level indicated that for a given outside temperature a corresponding house temperature could be predicted that should be within the scatter range of the coefficient. This prediction should hold true 99 per cent of the time under similar conditions of housing, climate, and location.

Winter season findings. The general outside weather conditions for the first winter period indicated that the mean temperature average 5.9 ^{o}F below normal, and the wind velocity averaged 7.3 miles per hour. The average hourly wind velocities were a minimum between 10:00 a.m. and 8:00 p.m. while the maximum velocities occurred during the night. This period contained two days that had 100 per cent of the available sunshine and another with 96 per cent. The average for the week was 48.6 per cent. The beginning of the period had above normal seasonal temperatures, but the latter part was well below normal (37).

The average daily temperature patterns for the first winter period are shown in Figure 10. The outside temperature averaged 0.6 ^{o}F above freezing during the period. The conventional house pattern averaged 19.2 ^{o}F above the outside pattern but was very similar in pattern form. The windowless house pattern had a very constant temperature and had very little similarity to the outside pattern. The solar house pattern ranked next to that of the conventional house in similarity to the outside pattern. A summary of the average daily temperature patterns for the first winter period is given in Table IV. The pattern of the windowless house had the

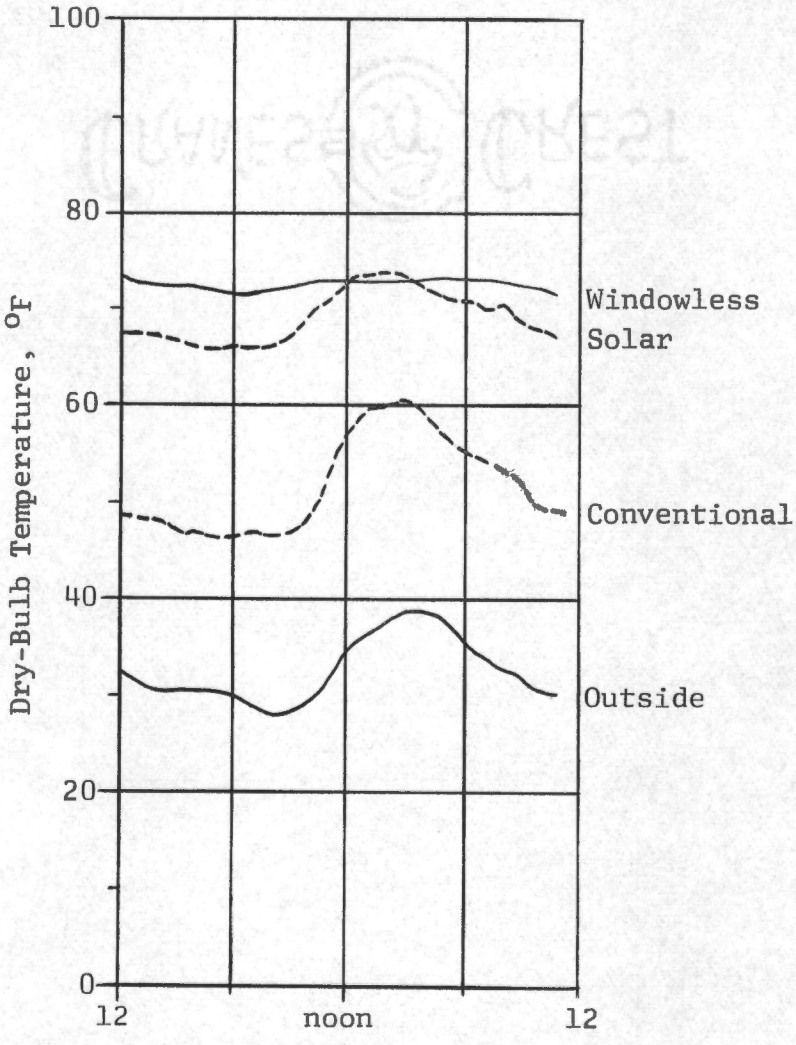


Figure 10. Average daily temperature patterns for the first winter period, December 31, 1958-January 6, 1959.

TABLE IV

SUMMARY OF THE AVERAGE DAILY TEMPERATURE PATTERNS, FIRST WINTER PERIOD, DECEMBER 31, 1958-JANUARY 6, 1959

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	32.6	38.7	28.0	10.7
Conventional	51.8	60.6	46.3	14.3
Windowless	72.7	73.6	71.7	1.9
Solar	69.2	73.9	65.9	8.0

highest average and highest minimum temperatures of the patterns, and the solar house had the highest maximum temperature of the patterns. The conventional house had the greatest temperature range.

The general outside weather conditions for the second winter period differed from those of the first. During the second winter period the mean temperature average 7.7 ^{o}F above normal, and there were zero days having 100 per cent of the available sunshine. This period averaged 45.7 per cent of the available sunshine compared to 48.6 per cent for the first winter period. The wind velocity averaged 7.2 miles per hour, and the average hourly velocities were a maximum between 10:00 a.m. and 5:00 p.m. The temperatures at the beginning of this period were below normal, but they were 21 ^{o}F above normal by the last day (38).

The average daily temperature patterns for the second winter period are shown in Figure 11, page 42. The conventional house pattern was almost parallel to that of the outside but averaged 21.7 ^{o}F warmer. The windowless house pattern was neither as constant nor as warm during this period as it was in the first winter period. The solar house pattern did not fluctuate quite as much as the windowless. A summary of the average daily temperature patterns for the second winter period is given in Table V, page 43. The solar house had the highest average, highest maximum, and highest

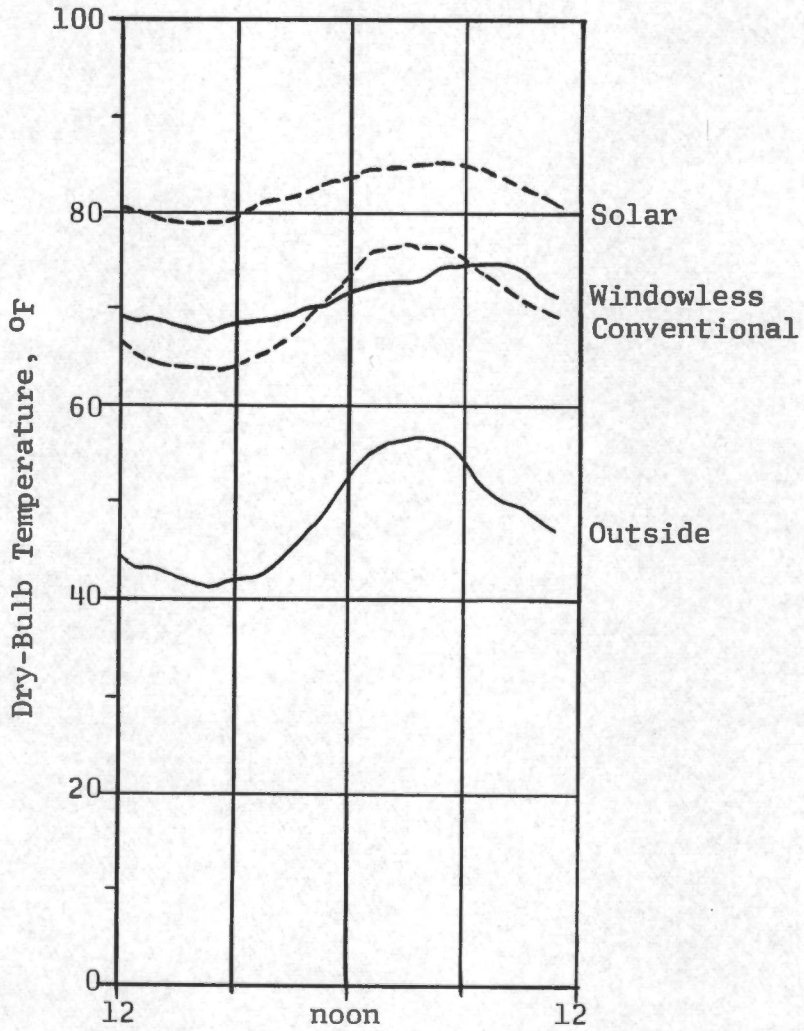


Figure 11. Average daily temperature patterns for the second winter period, January 7-13, 1960.

TABLE V

SUMMARY OF THE AVERAGE DAILY TEMPERATURE PATTERNS
SECOND WINTER PERIOD, JANUARY 7-13, 1960

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	48.4	56.7	41.6	15.1
Conventional	70.1	76.9	63.9	13.0
Windowless	71.2	74.6	67.9	6.7
Solar	82.3	85.4	79.3	6.1

minimum temperatures of the patterns while the outside pattern had the greatest temperature range.

The outside weather conditions during the typical daily temperature patterns of the winter season were obtained by averaging the conditions present during the two consecutive winter periods. As mentioned previously these two periods did not begin on the same day of the year and the Weather Bureau data showed the mean temperature of the first period to be 1 ^{o}F lower than that of the second. The average of the mean temperatures was 40.5 ^{o}F which provided a 0.9 ^{o}F departure above the average normal temperature. There was an average of 47.2 per cent available sunshine and 7.25 miles per hour of wind velocity. The resulting outside weather conditions during the typical daily temperature patterns of the winter season were more representative of normal conditions than either of the two individual winter periods.

The typical daily temperature patterns of the winter season and a summary of the temperatures for these patterns are given in Figure 12 and Table VI, page 46. The outside pattern was similar to that of the fall typical daily temperature pattern, but it averaged 24.1 ^{o}F warmer. The windowless house pattern was the most constant and least similar to the outside pattern. The solar house pattern was warmer than the patterns of the other two houses, and the average temperature of the pattern was only 1.2 ^{o}F cooler than it was in the typical daily temperature pattern of the fall. The solar house had the highest average, highest maximum, and highest

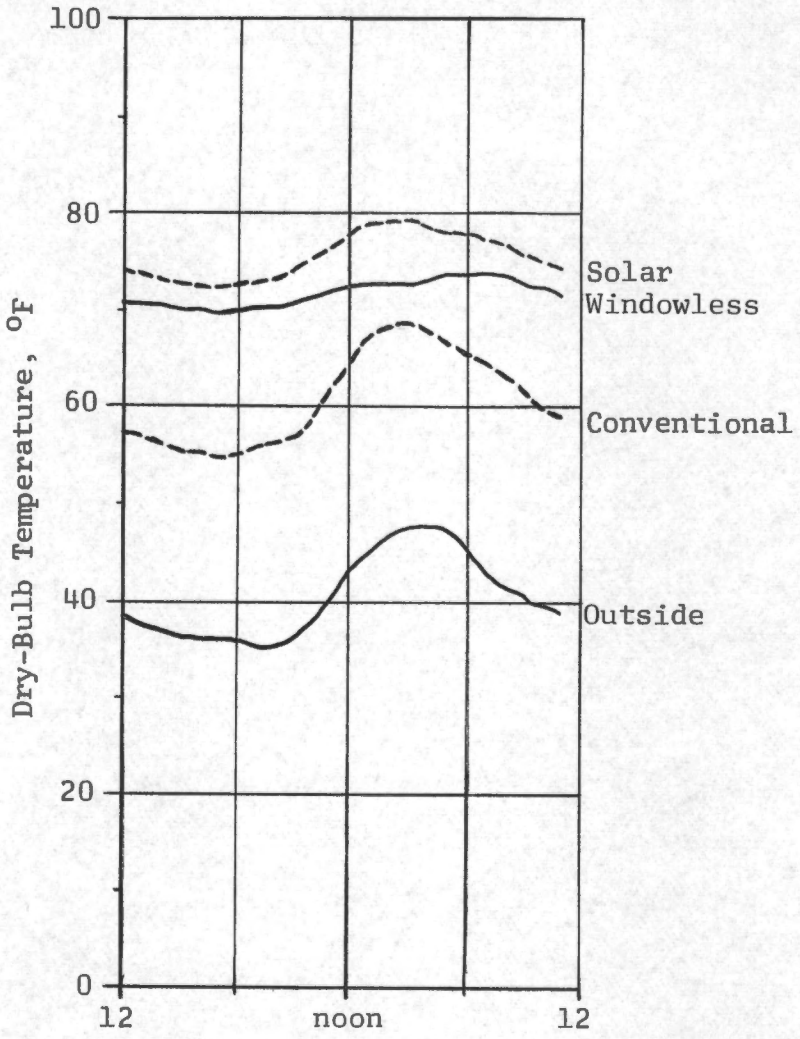


Figure 12. Typical daily temperature patterns of the winter season.

TABLE VI

SUMMARY OF THE TYPICAL DAILY TEMPERATURE PATTERNS OF THE WINTER SEASON

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	40.5	47.7	35.5	12.2
Conventional	60.9	68.7	55.1	13.6
Windowless	71.9	73.9	69.9	4.0
Solar	75.7	79.2	72.7	6.5

minimum temperatures of the patterns while the conventional house pattern had the greatest temperature range.

The coefficients of correlation between the outside temperatures and those of the houses supported the observations made from the patterns. The results of the calculation were:

Between outside and conventional $r = 0.9837$

Between outside and windowless $r = 0.8757$

Between outside and solar $r = 0.9621$

The degree of association between the outside and inside temperatures of the houses was strongest for the conventional house and almost as strong for the solar house. The windowless house had the lowest association of the three houses, but all three of the coefficients were significant above the 1 per cent level. The effects of the different types of housing were again indicated by the departure from unity. The conventional house temperatures again had the strongest association to these of the outside due to the natural ventilation and the lack of insulation. The controlled ventilation system and the insulation of the windowless house caused the temperatures to be warmer and more constant than those of the outside. The solar house with the same type of ventilation system and insulation was warmer than the windowless house, and it had temperature fluctuations similar to those of the outside due to the solar heat collector. The collector was designed to be most beneficial at this time of year.

Spring season findings. The general outside weather

conditions for the first spring period indicated that the mean temperature averaged 9.6 ^{o}F above normal, and the wind velocity averaged 9.5 miles per hour while the average hourly velocities were a maximum between 1:00 and 6:00 p.m. This period contained zero days of 100 per cent available sunshine, and the average for the period was 34.6 per cent. The temperature for the first five days was above normal, but it dropped to 10 ^{o}F below normal on the last day. There were approximately two inches of rainfall during the latter part of the period (39).

The average daily temperature patterns for the first spring period are shown in Figure 13. The outside pattern was similar to those of the other test periods, and the pattern of the conventional house was again almost parallel to the outside pattern. The conventional house pattern was only a few degrees warmer than the outside pattern between 5:00 and 7:00 p.m. The windowless house pattern was the most constant as it had been in the other periods. The solar house pattern was almost parallel to that of the windowless and averaged 3.7 ^{o}F warmer. The temperature range of the windowless and solar house patterns was very similar. A summary of the average daily temperature patterns for the first spring period is given in Table VII, page 50. The solar house pattern had the highest average, highest maximum, and highest minimum temperatures of the patterns, and the outside pattern had the greatest temperature range.

The general outside weather conditions for the second spring period showed that the mean temperature averaged 9.7 ^{o}F below normal.

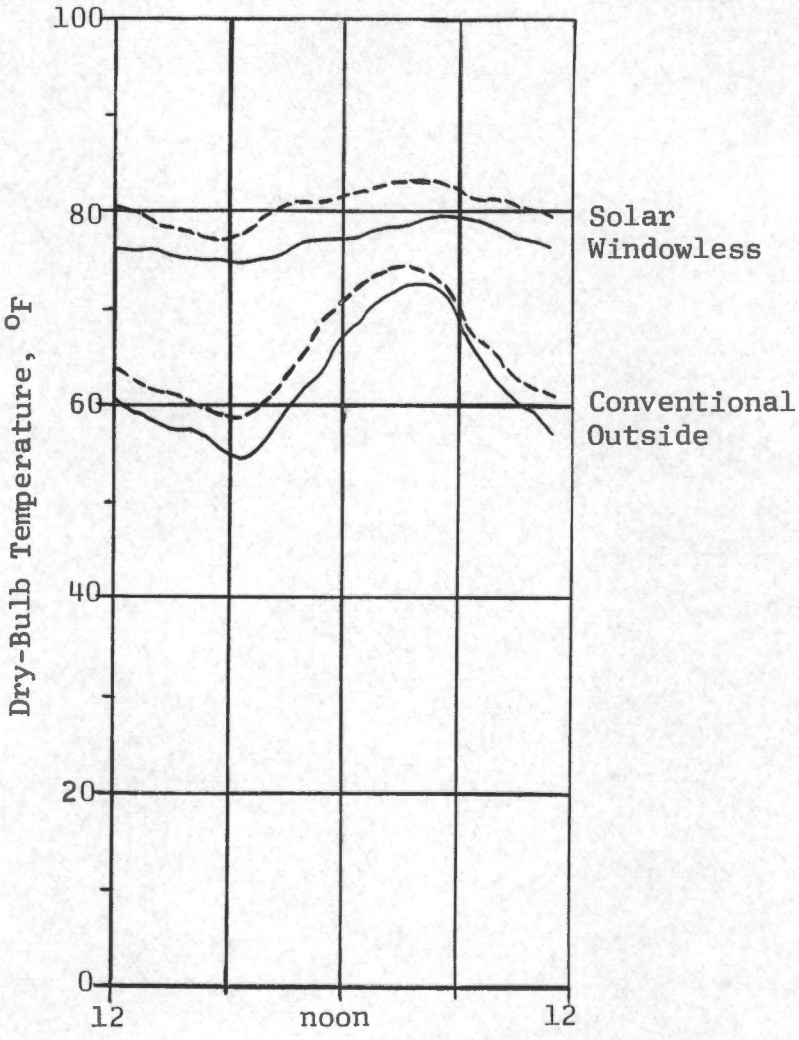


Figure 13. Average daily temperature patterns for the first spring period, April 6-12, 1959.

TABLE VII

SUMMARY OF THE AVERAGE DAILY TEMPERATURE PATTERNS
FIRST SPRING PERIOD, APRIL 6-12, 1959

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	62.4	72.3	54.6	17.7
Conventional	65.5	74.1	58.9	15.2
Windowless	76.9	79.7	74.6	5.1
Solar	80.6	83.3	77.3	6.0

The month of March, 1960 was the coldest on record. The wind velocity averaged 9.3 miles per hour, and the maximum average velocities occurred at approximately the same time of day as they did during the first spring period. There was only one day with 100 per cent of the available sunshine, but the average for the period was 74.6 per cent (40).

The average daily temperature patterns for the second spring period are shown in Figure 14, page 52. The outside pattern had the greatest range of all periods investigated and the average pattern temperature was 16.2 ^{o}F below that of the first spring period. The conventional house pattern was very similar to that of the outside, but the temperature range of the patterns was greater for the conventional house by 1.3 ^{o}F. The windowless house pattern had the least fluctuation of temperature. The solar house pattern displayed some similarity to the outside pattern, but not as much as the pattern of the conventional house. A summary of the average daily temperature patterns for the second spring period is given in Table VIII. The solar house had the highest average, highest maximum, and highest minimum temperatures of the patterns, and the conventional house pattern had the greatest temperature range.

The outside weather conditions during the typical daily temperature patterns of the spring season were obtained by averaging the conditions present during the two consecutive spring periods. The second spring period began 16 days earlier than the first spring

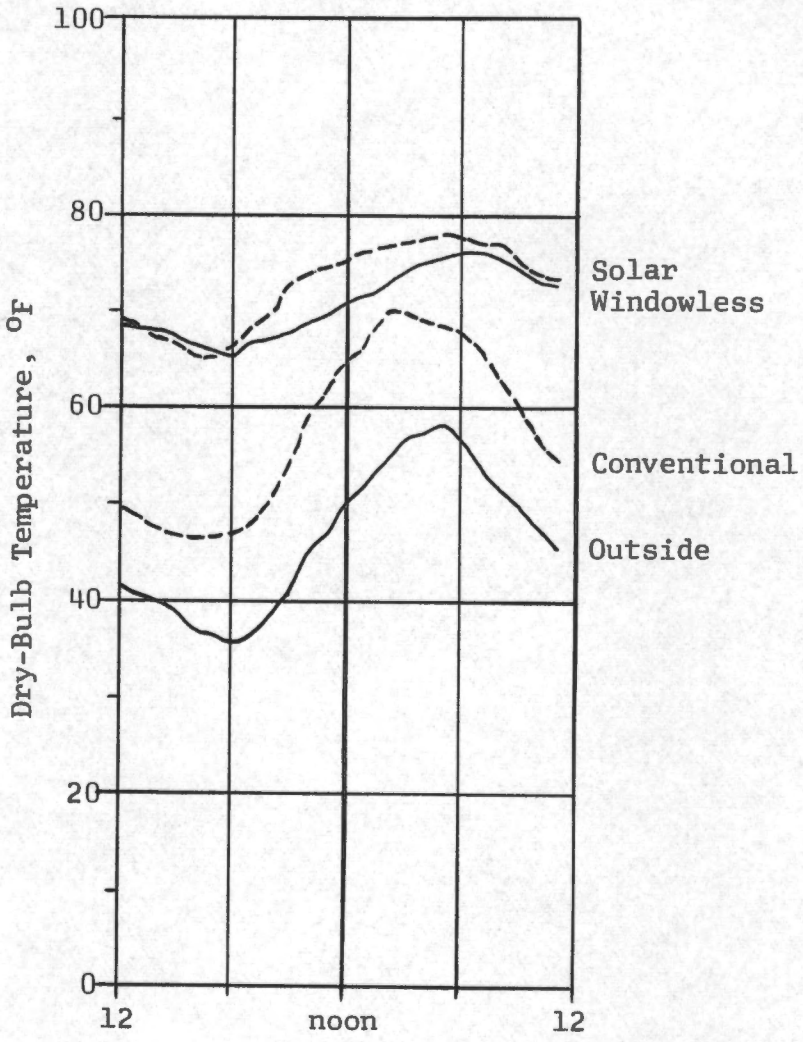


Figure 14. Average daily temperature patterns for the second spring period, March 21-27, 1960.

TABLE VIII

SUMMARY OF THE AVERAGE DAILY TEMPERATURE PATTERNS
SECOND SPRING PERIOD, MARCH 21-27, 1960

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	46.2	58.0	35.7	22.3
Conventional	57.5	70.0	46.4	23.6
Windowless	70.7	76.0	65.4	10.6
Solar	72.5	77.9	65.6	12.3

period, and the normal temperatures for these two periods differed by 5.4 ^{o}F. The average of the mean temperatures was 54.7 ^{o}F, and the average of the departures from normal was 0.05 ^{o}F below normal. There was an average of 54.4 per cent available sunshine and 9.4 miles per hour of wind velocity. The resulting outside weather conditions during the typical daily temperature patterns of the spring season were more representative of normal conditions than either of the two individual spring periods.

The typical daily temperature patterns of the spring season and a summary of these temperature patterns are given in Figure 15, page 55, and Table IX, page 56. The outside pattern was similar to the outside patterns found in the fall and winter typical daily temperature patterns, but the average temperatures of the patterns were below those of the fall and above the winter. The conventional house pattern was again almost parallel to the pattern of the outside. The windowless house pattern was the most constant with a temperature range of 7.7 ^{o}F. The solar house pattern had the highest temperature at all hours and a temperature range of 9.0 ^{o}F. The outside pattern had the greatest temperature range.

The coefficients of correlation between the outside pattern temperatures and those of the houses were again calculated, and the results were:

Between outside and conventional	$r = 0.9810$
Between outside and windowless	$r = 0.9107$
Between outside and solar	$r = 0.9418$

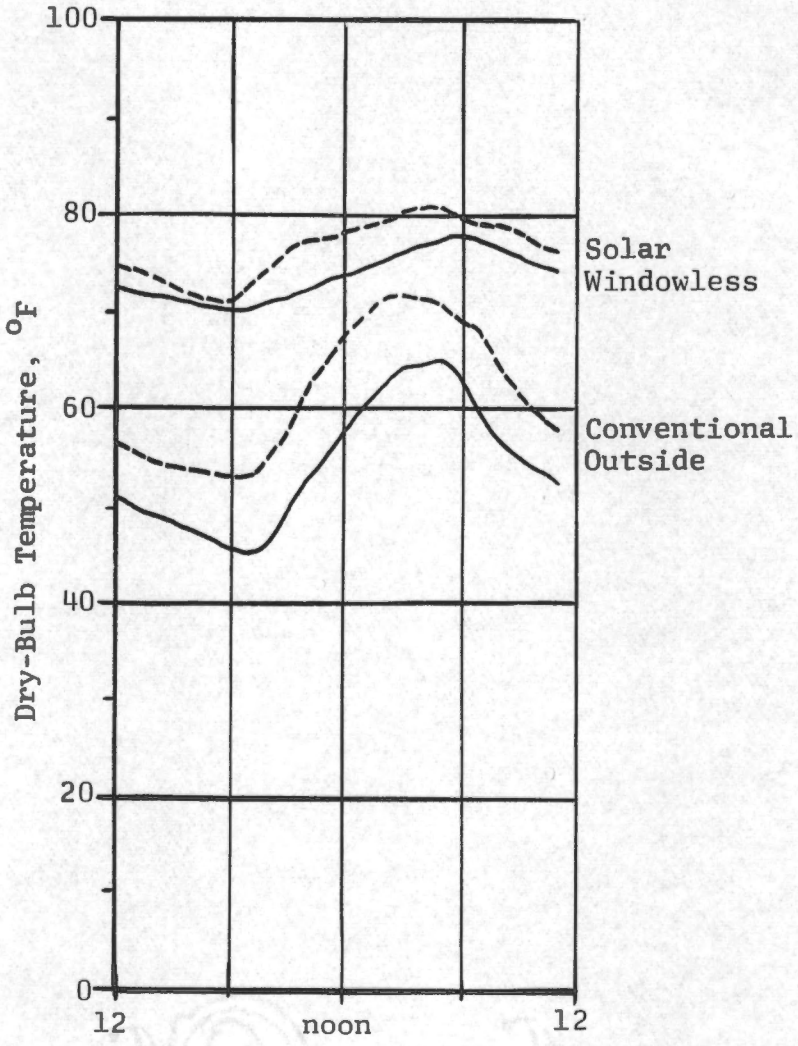


Figure 15. Typical daily temperature patterns of the spring season.

TABLE IX

SUMMARY OF THE TYPICAL DAILY TEMPERATURE PATTERNS OF THE SPRING SEASON

	Dry-Bulb Temperatures, ^{o}F			
	Average	Maximum	Minimum	Range
Outside	54.3	65.0	45.4	19.6
Conventional	61.5	71.9	52.8	19.1
Windowless	73.8	77.8	70.1	7.7
Solar	76.6	80.6	71.6	9.0

The degree of association between the outside and inside temperatures of the houses was again strongest for the conventional house. The second strongest association was for the solar house and third for the windowless. The effects of the different types of housing during the typical daily temperature patterns were indicated by the departures from unity by the coefficients. The conventional house temperatures again had the strongest association due to the natural ventilation and the lack of insulation. The levels of association for the windowless and solar house temperatures were not as strong due to their controlled ventilation system and insulation. The effect of the solar heat collector was again indicated by a stronger association for the solar house temperatures than for the windowless house temperatures. The difference in the levels of association between the outside temperatures and those of the houses during a season were a result of housing, but the differences in the levels for the individual houses between seasons were a result of outside weather and time of year. All three coefficients were again significant above the 1 per cent level.

Broiler production. In each of the six periods under investigation, 400 broiler type chicks were placed in each house. The chicks were sexed, wingbanded, debeaked, and vaccinated for Newcastle and bronchitis diseases at one day of age, and 50 male and 50 female chicks were placed in each of the four pens of the three houses. The chicks were fed an all mash ration throughout the experiment, and during the second year the ration was changed to a high energy

broiler diet. The growing time was of nine weeks duration for the first four trials and eight weeks for the last two trials. Individual body weights were obtained at the end of each trial and feed consumption was determined. The average body weights for each trial are given in Table X. The average body weights for all trials combined was 48.45, 47.72, and 45.99 ounces for the conventional, windowless, and solar houses, respectively. The efficiency of feed utilization was approximately the same for the three houses, and there was not apparent difference in mortality (4).

TABLE X

BODY WEIGHTS OF BROILERS IN OUNCES
FOR SEASONS INVESTIGATED

	House		
	Conventional	Windowless	Solar
Fall 1958	47.29 (1)*	46.83 (2)	43.15 (3)
Winter 1958-59	48.12 (2)	49.32 (1)	45.13 (3)
Spring 1959	46.47 (1)	43.94 (3)	44.38 (2)
Fall 1959	52.36 (1)	52.26 (2)	51.62 (3)
Winter 1959-60**	49.56 (1)	46.72 (3)	47.68 (2)
Spring 1960**	51.18 (1)	48.12 (2)	47.23 (3)
Average	48.45 (1)	47.72 (2)	45.99 (3)

*Numbers in parenthesis indicate order of rank among the three houses.

**Indicates weight at end of 8 weeks.

CHAPTER IV

SUMMARY AND CONCLUSIONS

It was the object of this investigation to determine and compare the inside and outside temperature patterns for conventional, windowless, and solar type broiler houses simultaneously during the fall, winter, and spring growing seasons for two consecutive years. At the time of this investigation there were no known average hourly temperature patterns for these houses at the same location. This investigation provided information on temperature relationships that could be used by the engineer in designing broiler housing and the grower in house management.

Summary. This investigation began in the fall of 1958 and continued through the spring of 1960. Continuous temperature data for the fifth week of broiler growth for each of the seasons was obtained and analyzed. This data was used to develop the average daily temperature patterns for the inside and outside temperatures of each house. The average daily temperature patterns were considered to be more representative of the fifth week conditions than patterns for any single day of that week. It was observed from these average daily temperature patterns that each house had a different degree of similarity to the outside pattern, for the outside weather conditions were different each period. The outside temperature pattern had the lowest average, lowest maximum, and

lowest minimum temperatures of the patterns for all six periods investigated, and it had the greatest temperature range in two of the six periods. The conventional house pattern was similar in form to the outside pattern in all six of the periods and averaged a few degrees warmer than the outside pattern. The conventional house pattern had the greatest temperature range in four out of the six periods. The pattern of the windowless house was least similar to that of the outside. It had the highest average temperatures of the patterns in three of the six periods and the least temperature range in five of the six periods. The solar house average daily temperature pattern had the highest average temperatures of the patterns in three of the periods and the highest maximum temperatures of the patterns in all six periods.

According to data recorded by the local Weather Bureau, the outside weather conditions varied somewhat between the same seasons of the two consecutive years. By averaging the Weather Bureau data on the outside weather conditions for the respective seasons, the results were more representative of the normal conditions for that time of year. Likewise, combining the average daily temperature patterns of the same seasons provided temperature patterns that were more representative of a typical seasonal day.

The typical daily temperature patterns of the seasons allowed comparisons of the inside and outside temperature patterns for these types of broiler housing under near normal conditions for each season. These patterns indicated that the order of similarity to

the outside pattern was conventional, solar, and windowless, respectively for all three typical daily temperature patterns. The conventional house had the greatest temperature range of the house patterns, and the windowless house had the least. The windowless house had the highest average typical daily temperatures of the patterns for the fall season while the solar house had the highest for the winter and spring. The windowless and solar house patterns had a marked similarity in magnitude and form, and they had higher average temperatures than the conventional house patterns at all times.

The coefficients of correlation between the outside and inside pattern temperatures were calculated for the typical daily temperature patterns of each season. These coefficients provided a measure of the association between outside and inside pattern temperatures. The level of the association was strongest for the conventional, second for the solar, and third for the windowless for all three seasons. These coefficients of correlation were significant above the 1 per cent level for all three seasons.

The houses differed in amounts of insulation, type of ventilation system, and utilization of solar energy. The effects of the insulation and type of ventilation system used in the windowless and solar houses were indicated by comparing these two house patterns to the conventional house patterns. The insulation aided in preventing heat losses, and the forced ventilation systems insured the minimum ventilation requirements in addition to

preventing excessively high maximum temperatures. The effect of the solar heat collector was indicated by comparing the solar house patterns to the windowless patterns. The collector caused the temperatures to be higher on sunny days, but it possibly caused the temperatures to be lower during some nights. The heat loss at night through the solar glass would have been greater than the heat loss through an equal area of insulated wall in the windowless house.

Conclusions. The average and typical daily temperature patterns with their respective summary tables provided visual comparisons between the outside and inside temperatures for the houses for each period, and the level of the association that existed between the outside and inside temperatures for each house was indicated by the coefficient of correlation. The departure from unity by these coefficients indicated the effects produced by the different types of housing during each season. The conventional house temperatures were strongly associated with those of the outside due to the natural ventilation and the lack of insulation. The windowless house temperatures had the lowest level of association, for the insulation and controlled ventilation system reduced the effect of the outside temperature fluctuations and direct solar heat gain. The solar house temperatures had a higher level of association to the outside than the windowless house, for the solar heat collector allowed a direct solar heat gain inside the house. The strongest association for the solar house occurred during the

winter. This was the season the collector was designed to be the most beneficial. Seasonal differences in the degree of association to the outside occurred for each house. This was a result of the different outside weather conditions for each season. The coefficients of correlation for the typical daily temperatures were significant above the 1 per cent level for all three seasons, and this level of significance indicated that for a given outside temperature a corresponding house temperature could be predicted that should be within the scatter range of the coefficients. This prediction should hold true 99 per cent of the time under similar conditions of housing, climate, and location.

There was some indication that the interior temperatures influenced the growth rates of the broilers. The conventional house had the highest growth rates with the windowless house second and solar house third. The efficiency of feed utilization was approximately the same for the three houses, and there was no apparent difference in mortality.

It was recognized that there were factors other than those included in this study that could have affected the internal environment, and these factors could have been inter-related with broiler growth.

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APPENDIX

TABLE XI

TEMPERATURE DATA FOR THE FALL SEASON PATTERNS

Time	Dry-Bulb Temperature, °F											
	Outside			Conventional			Windowless			Solar		
	a	b	c	a	b	c	a	b	c	a	b	c
12 a.m.	54.9	68.4	61.7	59.3	71.0	65.2	74.6	79.6	77.1	69.9	79.1	74.5
1	53.3	68.1	60.7	57.9	70.6	64.3	74.6	79.3	77.0	68.7	78.7	74.2
2	52.7	67.7	60.2	57.3	70.1	63.7	74.7	79.1	76.9	69.1	78.6	73.8
3	51.6	67.3	59.5	56.4	70.0	63.2	74.6	79.0	76.8	69.4	78.4	73.9
4	51.4	67.0	59.2	55.4	69.6	62.5	74.3	79.0	76.7	69.7	78.4	74.1
5	51.1	66.6	58.9	55.4	69.4	62.4	74.0	78.9	76.5	69.6	78.1	73.9
6	50.6	66.1	58.4	55.9	69.3	62.6	73.9	78.9	76.4	69.9	78.0	74.0
7	50.7	66.1	58.4	56.1	69.4	62.8	74.7	79.3	77.0	70.6	79.0	74.8
8	52.6	66.9	59.8	59.7	69.9	64.8	75.1	79.6	77.4	71.9	79.4	75.7
9	56.4	68.0	62.2	61.9	70.9	66.4	75.3	80.0	77.7	73.6	79.7	76.6
10	61.0	68.4	65.0	65.9	71.9	68.9	74.4	80.4	77.4	76.4	80.6	78.5
11 a.m.	63.7	71.4	67.6	70.3	74.6	72.5	74.7	80.7	78.2	79.3	81.1	80.2
12 p.m.	66.4	72.3	69.4	72.7	75.6	74.2	76.0	81.3	78.7	79.7	81.9	80.8
1	68.1	74.4	71.3	73.7	77.4	75.6	77.0	81.3	79.2	79.3	82.4	80.9
2	69.7	75.4	72.6	74.1	78.1	76.1	77.3	81.7	79.5	78.6	82.9	80.3
3	71.0	75.4	73.2	74.1	77.6	75.9	78.3	82.3	80.3	78.3	83.1	80.7

TABLE XI (continued)

Time	Dry-Bulb Temperature, °F											
	Outside			Conventional			Windowless			Solar		
	a	b	c	a	b	c	a	b	c	a	b	c
4 p.m.	71.4	75.6	73.5	73.4	77.9	75.7	78.1	82.4	80.3	78.4	83.3	80.9
5	71.1	74.0	72.6	72.0	76.6	74.8	78.1	82.3	80.2	77.6	83.0	80.3
6	66.6	71.7	69.2	70.1	74.7	72.4	77.3	82.4	79.9	75.6	82.0	78.8
7	62.7	70.1	66.4	67.6	72.6	70.1	76.7	82.0	79.4	74.0	81.1	77.6
8	60.4	68.4	64.4	65.4	70.7	68.1	76.3	81.3	78.8	73.4	80.3	76.9
9	58.3	67.0	62.7	62.4	69.4	65.9	75.3	80.6	78.0	70.9	79.1	75.0
10	57.3	66.6	62.0	61.0	69.1	65.1	74.4	80.1	77.3	70.1	78.9	74.5
11 p.m.	56.0	66.1	61.0	60.3	68.3	64.3	74.1	79.7	76.9	69.9	78.6	74.3
Average	59.5	69.6	64.6	64.1	72.3	68.2	75.6	80.5	78.1	73.5	80.2	76.9

[a]First fall period, October 8-14, 1958.

[b]Second fall period, October 8-14, 1959.

[c]Data for the typical daily temperature patterns of the fall season.

TABLE XII

TEMPERATURE DATA FOR THE WINTER SEASON PATTERNS

Time	Dry-Bulb Temperature, °F											
	Outside			Conventional			Windowless			Solar		
	a	b	c	a	b	c	a	b	c	a	b	c
12 a.m.	32.4	44.3	38.4	48.6	66.4	57.5	73.6	69.4	71.5	67.7	80.4	74.1
1	31.7	43.4	37.6	48.4	65.6	57.0	72.9	68.9	70.9	67.6	80.0	73.8
2	30.9	43.0	36.9	48.1	64.7	56.4	72.9	68.9	70.9	67.3	79.6	73.5
3	30.6	42.4	36.5	47.4	64.1	55.8	72.6	68.4	70.5	66.9	79.4	73.2
4	30.6	41.9	36.2	47.0	64.1	55.6	72.5	67.9	70.1	66.1	79.3	72.7
5	30.6	41.6	36.1	46.4	63.9	55.1	72.0	67.9	69.9	65.9	79.4	72.7
6	30.0	42.0	36.0	46.3	64.1	55.2	71.9	68.4	70.1	66.0	79.7	72.9
7	28.9	42.1	35.5	46.9	65.0	55.9	71.7	68.7	70.2	66.0	80.6	73.3
8	28.0	43.1	35.6	46.6	66.0	56.3	72.0	69.1	70.6	66.0	81.1	76.6
9	28.1	45.0	36.6	46.9	67.4	57.1	72.1	69.7	70.9	67.4	81.7	74.6
10	29.6	47.4	38.5	48.7	69.6	59.1	72.7	70.4	71.6	69.4	82.1	75.8
11 a.m.	31.7	49.9	40.8	52.7	71.6	62.1	73.0	70.9	71.9	70.4	83.1	76.8
12 p.m.	34.1	52.6	43.4	56.9	73.6	65.2	73.0	72.0	72.5	73.0	83.7	78.4
1	36.0	54.3	45.1	59.7	75.9	67.8	73.1	72.4	72.8	73.7	84.3	79.0
2	37.4	56.0	46.8	60.0	76.4	68.2	73.1	73.0	73.0	73.9	84.4	79.2
3	38.7	56.6	47.6	60.6	76.9	68.7	73.1	73.0	73.0	73.3	85.0	79.2

TABLE XII (continued)

Time	Dry-Bulb Temperature, °F											
	Outside			Conventional			Windowless			Solar		
	a	b	c	a	b	c	a	b	c	a	b	c
4 p.m.	38.7	56.7	47.7	59.0	76.7	67.9	73.0	73.6	73.3	72.6	85.1	78.9
5	38.0	56.3	47.1	56.9	76.4	66.6	73.4	74.3	73.9	71.3	85.4	78.4
6	36.0	55.0	45.5	55.6	75.6	65.6	73.4	74.3	73.9	71.0	85.3	78.2
7	34.0	52.0	43.0	54.7	74.0	64.4	73.3	74.6	73.9	70.1	84.6	77.4
8	32.9	50.4	41.6	53.7	72.6	63.1	73.1	74.6	73.9	70.3	84.0	77.2
9	32.0	49.7	40.7	52.4	71.3	61.9	72.4	73.4	72.9	68.9	82.6	75.8
10	30.3	48.1	39.2	49.6	70.3	59.9	72.1	72.6	72.4	68.0	81.9	75.0
11 p.m.	30.0	47.1	38.6	49.3	69.1	59.2	71.7	71.7	71.7	67.3	81.1	74.2
Average	32.6	48.4	40.5	51.8	70.1	60.9	72.7	71.2	71.9	69.2	82.3	75.7

[a]First winter period, December 31, 1958-January 6, 1959.

[b]Second winter period, January 7-13, 1960.

[c]Data for the typical daily temperature patterns of the winter season.

TABLE XIII

TEMPERATURE DATA FOR THE SPRING SEASON PATTERNS

Time	Dry-Bulb Temperature, ^{o}F											
	Outside			Conventional			Windowless			Solar		
	a	b	c	a	b	c	a	b	c	a	b	c
12 a.m.	60.3	41.4	50.9	64.0	49.1	56.6	76.3	69.1	72.7	81.0	69.0	75.0
1	59.3	40.3	49.8	63.0	48.3	55.6	76.0	68.0	72.0	80.0	68.1	74.1
2	58.4	39.6	49.0	61.7	47.1	54.4	76.0	67.7	71.9	79.3	67.4	73.4
3	57.7	38.3	48.0	61.3	46.7	54.0	75.7	67.0	71.4	78.6	66.7	72.6
4	57.3	37.1	47.2	60.6	46.4	53.5	75.4	66.1	70.8	78.0	65.6	71.8
5	56.6	36.6	46.6	59.7	46.7	53.2	75.3	65.7	70.5	77.6	65.6	71.6
6	55.0	35.7	45.4	58.9	46.7	52.8	74.9	65.4	70.1	77.3	66.0	71.6
7	54.6	36.6	45.6	58.9	47.3	53.1	74.6	66.4	70.5	78.0	68.1	73.1
8	56.1	38.1	47.1	60.3	50.3	55.3	75.1	67.0	71.1	79.7	69.9	74.8
9	59.3	41.1	50.2	62.4	54.1	58.3	75.6	67.7	71.6	80.6	72.6	76.6
10	61.9	45.0	53.4	65.4	59.6	62.5	76.3	68.7	72.5	81.1	73.9	77.5
11 a.m.	63.9	47.1	55.5	68.9	62.3	65.6	76.6	69.7	73.1	81.1	74.4	77.7
12 p.m.	66.9	50.1	58.5	70.9	65.1	68.0	77.0	71.0	74.0	81.7	75.3	78.5
1	68.6	52.0	60.3	72.3	67.3	69.8	77.4	71.7	74.6	82.0	76.1	79.1
2	70.9	54.1	62.5	73.4	70.0	71.7	78.1	72.7	75.4	82.6	76.6	79.6
3	72.0	56.4	64.2	74.1	69.7	71.9	78.4	74.0	76.2	83.3	77.1	80.2

TABLE III (continued)

Time	Dry-Bulb Temperature, °F											
	Outside			Conventional			Windowless			Solar		
	a	b	c	a	b	c	a	b	c	a	b	c
4 p.m.	72.3	56.9	64.6	74.0	69.0	71.5	78.9	74.9	76.9	83.3	77.6	80.4
5	72.0	58.0	65.0	73.0	68.4	70.7	79.7	75.4	77.6	83.3	77.9	80.6
6	69.3	56.7	63.0	70.4	67.4	68.9	79.6	76.0	77.8	82.3	77.4	79.9
7	65.6	53.9	59.7	66.6	65.3	65.9	78.9	76.0	77.4	81.6	76.9	79.2
8	62.3	51.3	56.8	65.3	62.7	64.0	78.3	75.6	76.9	81.6	76.9	79.2
9	60.4	49.9	55.1	63.0	60.1	61.6	77.4	74.0	75.7	81.3	75.0	78.1
10	59.3	47.6	53.4	61.7	56.7	59.2	76.9	73.1	75.0	80.0	73.7	76.9
11 p.m.	58.6	45.6	52.1	61.1	54.6	57.9	76.3	72.3	74.3	79.6	73.3	76.4
Average	62.4	46.2	54.3	65.5	57.5	61.5	76.9	70.7	73.8	80.6	72.5	76.6

[a]First spring period, April 6-12, 1959.

[b]Second spring period, March 21-27, 1960.

[c]Data for the typical daily temperature patterns of the spring season.