THE USE OF DOUBLE-PANE WINDOWS FOR UTILIZING SOLAR ENERGY IN SWINE HOUSING

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By

Maurice Wayne Brandt

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State College of Agriculture and Applied Science
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AN ABSTRACT

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MAURICE WAYNE BRANDT

ABSTRACT

This study was carried out during the summer of 1953 and the winter of 1954 to determine the differences in the environmental conditions between three types of experimental hog houses as compared to a conventional house and the effect they had on the hogs in each house. The three experimental houses were solar orientated on an east-west axis and were of identical construction. The only difference between the three houses was the amount and type of glass used on the south wall of the structures. One house was equipped with double-pane windows, a second house was equipped with single-pane windows, and a third house was equipped with double-pane windows half the height of the windows in the other two houses. Each house was divided into two pens. The fourth house of conventional construction was located on a concrete slab. This house was used as a control for the study and did not contain any windows.

Each experimental house contained two lots of four pigs each. These pigs were kept in the houses all the time while those in the conventional house were able to go outdoors at will. At intervals of two weeks they were weighed and the total amount of water and feed consumed for the period was recorded. The average weight of the hogs was about 97 pounds at the beginning of the summer study. Conditions in the houses during the summer study were very uncomfortable for the hogs and they were removed after six weeks. The average weight of the hogs was about 35 pounds at the beginning of the winter study. They were kept in the houses until the heaviest ones reached a market weight of 200 pounds.

The total feeding time was 16 weeks.

An automatic potentiometer, was set up to measure and record temperatures. The outside temperature and the wet-bulb and dry-bulb temperatures inside of each house were recorded. The operation of ventilating fans and heat lamps was recorded by means of 24-hour on-and-off recorders. Water consumption of the hogs was determined by a gage located on the side of the water tank in each pen and feed consumption was recorded.

Data from the summer study indicated no advantages in housing hogs in solar orientated houses. The winter study indicated that there was a statistically significant advantage in housing hogs in solar orientated houses having double-pane windows. The investigation should be continued to verify these results.

TABLE OF CONTENTS

INTRODUCTION 1

History of the Project 1
Description of the Project 1
Objectives of the Project 2
Reasons for the Study 4
The Practicality of Solar Heating of Hog Houses 4

REVIEW OF LITERATURE 8

Solar Energy 8

Solar radiation 8
Factors affecting the amount of solar energy reaching the surface of the earth 8
Solar heating of houses 10
The transmission of radiation through glass 11
The transmission of heat energy and solar radiation through double-pane windows 18
Heat losses through glass 18
Comparison of single and double-pane windows 19
Solarization 20

The Effects of Temperature, Relative Humidity, Air Motion, and Solar Radiation on Swine 20

The effect of temperature 21
The effect of relative humidity 21
The effect of increased air motion 22
The effect of solar radiation 22

APPARATUS AND METHODOLOGY 23

Construction and Equipment 23
Instrumentation 32
Procedure 37

PRESENTATION AND ANALYSIS OF DATA 38

Part I - Analysis of the Summer Study 38

Temperature 38
Relative humidity 39
Ventilation 39
Feeding trial 39
Conclusions 41

Part II - Analysis of the Winter Study 41

Temperature 42
Relative humidity 50
Ventilation 50
Heat lamps 53
Frost and moisture condensation 53
Quality of the air 56
Sun patterns 57
Feeding trial 57
The conventional house 67
Chewing the gates 67
Conclusions 69

Part III - Analysis of the periods without any animals in the houses 69

Winter 69
Spring 71
Conclusions 71

CONCLUSIONS 73

SUGGESTIONS FOR FUTURE STUDY 74

CHANGES MADE BEFORE THE SUMMER STUDY OF 1954 76

APPENDIX A - The Temperature, Relative Humidity, and Solar Radiation Data for the Summer Study 77

Explanation of the relative humidity data for the summer study . 78
Explanation of the temperature and solar radiation data for the summer study 79

APPENDIX B - The Temperature, Relative Humidity, Solar Radiation and Ventilation Data for the Winter Study 90

Explanation of the relative humidity data for the winter study . 91
Explanation of the temperature, solar radiation and ventilation data for the winter study 92

GLOSSARY 117

BIBLIOGRAPHY 118

LIST OF TABLES

Table I. Summary of the results for the hog feeding trial of the summer study of 1953 40

Table II. Summary of the results for the hog feeding trial of the winter study of 1953-54 59

LIST OF FIGURES

Figure 1. The two experimental houses used for the summer study . 2

Figure 2. The three experimental houses used for the winter study. 3

Figure 3. The conventional house located on a concrete slab . . . 3

Figure 4. The intensity of solar radiation at different wave lengths 12

Figure 5. Transmission of solar radiation by a single sheet of glass 15

Figure 6. Transmission of solar radiation by two sheets of glass . 15

Figure 7. Absorption of solar radiation by a single sheet of glass 16

Figure 8. Absorption of solar radiation by two sheets of glass when the KL of the inner sheet equals 0.054 16

Figure 9. The plan for the framework of the three experimental houses 24

Figure 10. The framework of the houses with the blanket insulation installed 25

Figure 11. The four stages of the construction of the roof and floor panels 25

Figure 12. A view showing the windows installed and the sun shades. 27

Figure 13. The feed storage box 27

Figure 14. The section of the feeder that is located inside the building 28

Figure 15. The automobile gasoline tank and the type of automatic waterer used in the summer study 29

Figure 16. The type of automatic waterer used in the winter study and the position of the heat lamp 29

Figure 17. A rear view of one of the houses showing the air intakes and the exhaust duct through the roof 30

Figure 18. The electrical wiring system for the three experimental houses and the instrument box 31

Figure 19. The instrument box for housing the potentiometer, the time clock and the connecting plug 32

Figure 20. The placement of the thermocouples in the walls of the houses 34

Figure 21. The placement of the thermocouples in the floor and roof of the houses 34

Figure 22. The box containing the plugs for connecting the thermocouples in the walls to the potentiometer 35

Figure 23. The recorder which kept an on-and-off record of the operation of the ventilating fans 36

Figure 24. The maximum daily temperature in the four test houses from December 15, 1953 to April 6, 1954 43

Figure 25. The minimum daily temperature in the four test houses from December 15, 1953 to April 6, 1954 44

Figure 26. The mean daily temperature in the four test houses from December 15, 1953 to April 6, 1954 45

Figure 27. The difference between maximum and minimum daily temperatures from December 15, 1953 to April 6, 1954 . . . 46

Figure 28. The total amount of solar radiation for each day from December 15, 1953 to April 6, 1954 and the normal amount of solar radiation for each day of the same period . . . 47

Figure 29. The distribution of the air as it enters the house through one of the air intakes in the rear wall 52

Figure 30. The distribution of the air as it moves across the front of the house towards the air intake of the fan 52

Figure 31. A typical view on cold mornings showing how the single-pane windows frosted over while the double-pane windows did not 54

Figure 32. The single-pane windows were covered over with frost up to one-eighth inch thick on nights when the temperature outdoors went below 25° F. 55

Figure 33. The double-pane windows never had any frost on them but moisture did condense on the inside surface 55

Figure 34. The sun pattern in House C on January 21, 1954 58

Figure 35. The sun pattern in House D on January 21, 1954 58

Figure 36. The sun pattern in House C on February 17, 1954 58

Figure 37. The sun pattern in House D on February 17, 1954 58

Figure 38. The sun pattern in House C on March 17, 1954 58

Figure 39. The sun pattern in House D on March 17, 1954 58

Figure 40. The average daily gain per hog for each two week period of the winter study 60

Figure 41. The average daily feed consumption per hog for each two week period of the winter study 61

Figure 42. The amount of feed consumed per pound of gain for each two week period of the winter study 62

Figure 43. The average daily water consumption per hog for each two week period of the winter study 63

Figure 44. The average amount of water consumed per pound of gain for each two week period of the winter study 64

Figure 45. A typical sight in House A during the winter study showing how the hogs all huddled together to keep warm . 67

Figure 46. The gate in House C was all chewed up 68

Figure 47. The gates in both Houses B and D were only chewed a small amount 68

INTRODUCTION

History of the Project

In 1952 a study was made on the effect of environmental conditions on the growth rate and efficiency of gain of hogs in two different types of swine housing. During the study there were variables which could not be controlled or evaluated. It appeared necessary to use smaller houses in which some of these variables could be eliminated and others controlled and evaluated. In 1953 plans were formulated for constructing three identical houses, except for the type and amount of glass used.

Description of the Project

This project was sponsored jointly by the Michigan Agricultural Experiment Station and the Libbey-Owens-Ford Glass Company. Construction was started on three experimental houses in April, 1953. Two of the houses were completed in July, 1953 and were put into use during the following month. The third house was completed in November, 1953. All three houses were used for the winter study starting in December, 1953.

The first phase of this project which was a study of the environmental conditions in two experimental hog houses differing only in the type of glass used was completed in the summer of 1953, Figure 1. Outside air temperature, wet-bulb and dry-bulb temperatures in the houses and the amount of ventilation in the houses were recorded. The amount of solar radiation and outdoor relative humidity were obtained from the

Figure 1. The two experimental houses used for the summer study.

Michigan Hydrologic Research Station. The second phase of the project was completed in the winter of 1953-54. This phase was a study of the environmental conditions in three experimental hog houses differing only in the type and amount of glass used for windows. The houses used during the winter study are shown in Figure 2. Temperature, relative humidity, ventilation and solar radiation data were also collected for the winter study. A house of conventional construction and located on a concrete slab, as shown in Figure 3, was used as a control for the studies.

Objectives of the Project

The objective of this research project was to obtain data which can be used to evaluate the thermal advantages and disadvantages in a given locality for a given type of hog house. The rate of gain in weight and the feeding efficiency of the hogs raised in the houses and outdoors were compared. The water consumption of the hogs in the experimental houses

Figure 2. The three experimental houses used for the winter study.

Figure 3. The conventional house located on a concrete slab.

was also compared. An attempt was also made to determine differences in the quality of the air in the houses.

Reasons for the Study

For the past thirty years there has not been a significant development in the design of hog houses. Fifty years ago the half monitor design was used extensively for hog houses. The loss of heat through the top windows of this type of house was excessive. The usefulness of the sun's energy was realised at that time but efficient methods of utilization were not available. As a consequense emphasis shifted to a hog house design with a minimum amount of glass area. The data from this study will be useful in the design of hog houses where solar energy can be utilized with larger areas of glass.

According to information attributed to D.S. Soutar (54)* of the North of Scotland College of Agriculture, "a happily-housed hog costs far less to fatten than a hog in a hovel." Poor housing may be costing Britain approximately $9.50 more per head to fatten hogs in shabby pens than it costs to fatten those which were well-housed.

The Practicality of Solar Heating of Hog Houses

Solar heating of homes was first started in the U.S.A. about 1930. However, up until the present time (1954) a satisfactory method of utilizing solar energy to the fullest extent has not been developed. Solar houses have been built which use the principle of large south-facing windows. Fuel savings in these homes have amounted to 18 to 30 percent

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*Numbers in parenthesis refer to the appended bibliography.

(57) in some instances while in others, losses up to 16 percent (58) have been reported. This raises the question as to whether or not solar heating of hog houses can be accomplished efficiently.

Hog houses have an advantage in that a constant temperature does not have to be maintained, although temperatures between 50° and 70° F. are desirable. Therefore, the advantage of using solar energy for heating hog houses should be greater than for heating homes.

The purpose of a solar type hog house is to obtain more efficient utilisation of the sun's energy for light and heat. This can be done by using large areas of glass on the south side of the houses. The use of double-pane windows is necessary to eliminate excessive outward heat transfer through the glass.

The maximum gain from solar energy is entirely independent of the outside temperature at any particular latitude. However, the amount of solar energy and outside temperature vary in relation to the latitude. Heating with solar energy will have the least net effect where heat transmission losses through the glass are greatest, that is, where the outside temperatures are low. Solar heating of hog houses will have an advantage in this respect because the temperature difference between the outside and inside temperatures will be less than the temperature difference in a home. Therefore, transmission losses will be less in a hog house while solar gain remains constant all other conditions being the same.

Solar heating has the greatest advantage in relatively cold climates where there is a large amount of solar radiation available at the earth's surface. In areas which have very cold weather the advantage of solar heating will be decreased and may even be eliminated entirely. Solar construction will be the most economical in a cool climate where there is a large quantity of solar radiation available.

Solar-heating of hog houses creates a complex problem. The energy gain depends upon the transmissivity, the absorptivity and the reflectivity of the glass. It is a function of geographical location and climate, the outside air temperature during the winter months, the amount of solar energy and the time of day. Other factors such as wind velocity, type of glass, thermal conductance of the walls of the structure, and amount of ventilation required and the heat produced by the animals also play an important part in the problem. All of these factors must be considered in determining the practicability of using the solar principle for heating of a hog house.

The hog houses that were constructed should not only permit more effective utilization of solar energy, but should accomplish the short-time storage of the energy for use during later hours after the sun sets. They were designed both to capture a maximum quantity of solar radiation and to utilize it for heating purposes.

The affect of solar radiation in reducing the heating requirements for the hog houses should be the same as far as all forms of construction other than the glass are concerned. Both single and double-pane windows have a relatively small effect in intercepting solar radiation through the glass. Approximately ten percent of the solar radiation incident upon each pane of glass may be intercepted. This means that approximately 90 percent of the solar radiation incident on the single-pane windows should pass through, while approximately 80 percent will pass through the double-pane windows. Therefore, it would be expected that the effect of solar radiation should be greater in the single-pane houses. However, a double-pane window is a better heat trap than a single-pane window. Consequently, while slightly less solar radiation will come through a double-pane window, considerably less heat energy can get out by conduction so the net heat gain is greater with double-pane windows.

REVIEW OF LITERATURE

Solar Energy

Solar radiation. Solar energy is emitted by the radiating isothermal layer or photosphere of the sun which has a temperature of 6000° C. according to Koller (40). Outside the earth's atmosphere at the mean solar distance which is the arithmetical mean distance between the greatest and least distances of the earth from the sun, the intensity of solar radiation is 1.5 horsepower per square yard. Approximately two thirds of this energy reaches the surface of the earth after being absorbed, reflected and scattered by the atmosphere. The intensity of solar radiation is primarily a function of the height of the sun above the horizon. The intensity is also affected to a lesser extent by the distance of the earth from the sun and the clearness of the atmosphere. The amount of radiation which the sun emits varies as much as five percent.

Hienton, Wiant and Brown (20) state that from one to five percent of the sun's energy reaching the surface of the earth is in the ultraviolet region (2900 A. to 3800 A). Approximately 40 percent of the sun's energy reaching the surface of the earth is in the infrared region (7600 A. to 150,000 A.) which is readily absorbed by many objects. This absorption or heating effect makes infrared radiation very useful for solar heating.

Factors affecting the amount of solar energy reaching the surface of the earth. Parmelee (47) reports that the loss of direct solar radiation in the atmosphere is caused by: (1) Atmospheric scattering by air

molecules, water vapor and dust (approximately 16 percent) and (2) Atmospheric absorption by oxygen, ozone, water vapor, carbon dioxide and dust (approximately 12 percent).

Laurens (41) states that the intensity of solar radiation at the earth's surface varies chiefly according to geographical position, the season of the year and the time of day. The amount of radiation at the earth's surface is also dependent upon momentary changes in atmospheric transparency, cloudiness, dustiness and humidity. Three general factors therefore determine to a great extent the quantity of solar radiation received at the earth's surface, namely, altitude above sea level, the average degree of cloudiness, and the average purity of the atmosphere.

The depletion of solar radiation due to the longer atmospheric path in winter is approximately offset by the shorter distance between the sun and the earth according to Hutchinson (30). The sea level intensity is almost the same for all seasons of the year. The scattering effect of dust and water vapor in the atmosphere in winter is greater since the winter solar altitude is less. Therefore, the amount of diffuse or sky radiation is considerably greater at sea level in the winter. Summer sky radiation is about one half as much as that in the winter.

A statistical analysis by Clough (12) indicates: (1) that fluctuations in daily, monthly, and yearly mean values of the solar constant are so dependent on the transparency of the atmosphere that they cannot be regarded as even approximate values of changes in solar intensity, and (2) that as short-interval changes in the solar constant become smaller, the dryer, clearer and shorter the air mass through which solar radiation must pass.

Fritz (16) States that the depletion of solar radiation by the atmosphere in the Great Lakes region amounts to 20 to 30 percent of the radiation through a clean atmosphere in the winter, while in the summer it is about 10 to 15 percent. This is caused mainly by large industrial activity in the whole area together with increased haziness due to the lakes. Radiation during cloudless days in the United States decreases in December to about 20 percent of the summer value in the north, and to about 50 percent of the summer value in the south.

Solar heating of houses. Studies made by Hutchinson (28, 30) at Lafayette, Indiana indicate that the performance of a solar house depends upon the construction of the house, the range of outside temperatures, the amount of direct solar radiation and the quantity and quality of indirect or sky radiation received on days when the sun is obscured. The results of a nine week study using two identical houses, except for the areas of glass in each house, show an average reduction of nine percent in the heating requirements for the solar house as compared with the heating requirements for the orthodox house. However, the solar gain in a house of solar construction should not be attributed entirely to the construction since an appreciable amount of the heating effect would be realised even if the glass area of the house was no greater than that in an orthodox house.

An analysis of double-pane windows in south walls (30) shows that the available gain from solar radiation in most cities of the United States is more than enough to offset the excess transmission losses through the larger windows.

The transmission of radiation through glass. Windows differ from most structural elements of buildings in that the principal component, glass, is used in a thin sheet which, in itself, affords very little resistance to heat flow. Glass also transmits large quantities of solar radiation. Miller and Black (44) have found that glass is transparent to solar energy in the visible region but is opaque to all other wave lengths except a narrow band of the longest of the ultraviolet and the shortest of the infrared. The ultraviolet and infrared radiation that is transmitted to some extent is cut off entirely by thick glass and even relatively thin glass cuts off a large part of it. The amount of radiation transmitted is selective for different wave lengths and therefore is not uniform and it never reaches 100 percent, as shown in Figure 4. Approximately five percent of the incident visible light and as much as 19 percent of the invisible infrared radiation is reflected from each surface of the glass. Glass does not transmit any appreciable amount of long wave radiation. This characteristic of radiant energy makes possible the use of solar radiation for heating houses. The short waves of solar infrared radiation pass freely through the glass, are absorbed within the house and are reradiated as low temperature long wave length rays which are trapped within the house. Miller and Black (44) also found that only about 0.0523 percent of low temperature radiation is transmitted by glass.

An investigation made using a test house with south-facing windows (24) lists several sources of heat entering and leaving a house through the windows. Solar and sky radiation impinges on the surface of the glass at various angles throughout the day. Part of this energy passes

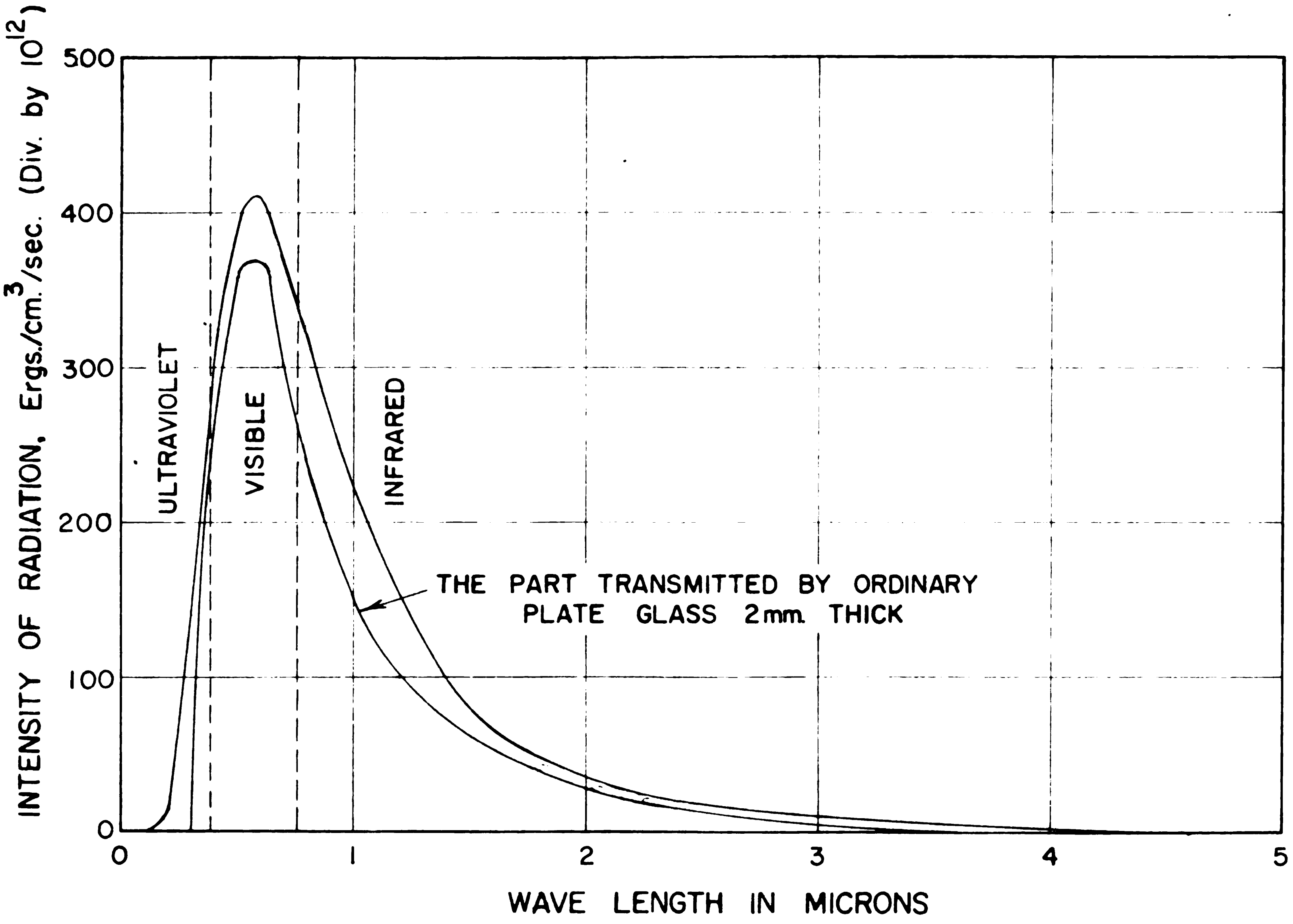

Figure 4. The intensity of solar radiation at different wave lengths. (R.A. Miller and L.V. Black, Trans. Am. Soc. of Heat. and Vent. Engrs., 1932.)

directly through the glass into the room, part of it is reflected and the remaining part is absorbed by the glass. The absorbed energy raises the temperature of the glass so that heat is transferred from both surfaces of the glass to the surrounding air. The temperature of the glass and the air determine the division of heat energy. Heat transfer also takes place between the inside and outside air through the glass depending upon the temperature difference. Indications are that the increased absorption caused by increasing the angle of incidence of the sun's rays is due to the greater thickness of the path of the rays rather than from reflection. Reflection is not an important factor in heat transfer through a window by solar radiation.

Measurements made of solar heat transmission through glass (51) show that the transmittance of normal incident radiation through different glasses may vary as much as 10 percent. These differences are believed to be caused by atmospheric conditions that change the energy distribution of the solar spectrum. Other factors such as wind velocity, low temperature radiation exchange between surrounding buildings and the glass, reflected radiation from the ground and nearby buildings, and radiation exchange between the glass and the atmosphere also affect the heat transmitted by or conducted through the glass.

In an analysis of heat flow through glass windows exposed to solar radiation, Parmelee (47) shows that the important properties of glass are the index of refraction and the absorptivity of the glass. These two properties are functions of the wavelength of the incident radiation. Specific heat, specific weight, and thermal conductivity are of secondary importance. The chemical constituents of glass determine its absorption characteristics. According to Parmelee (47) ferric oxide is strongly absorbant in the ultraviolet region and ferrous oxide in the infrared region. Various degrees of absorption can be obtained by varying the quantities of these two compounds.

Parmelee (47) has also studied the effect of the angle of incidence of the sun's rays on the transmission and absorption of glass. The results of the investigation are shown in Figures 5 through 8. The figures show the transmission and absorption expressed in percentages as functions of both the angle of incidence and the absorption characteristic, KL, of the glass. KL is the product of the absorption coefficient, K, and the thickness of the glass, L. The term is dimensionless, since K is expressed as absorption per inch and L is in inches. The percentage of absorption for any type of glass is seen in Figure 7 to be practically constant between the incident angles of 0 and 70 degrees. Figure 8 gives the fractions absorbed for one particular case, that in which the inner glass has a KL of 0.054. The outer glass may have any characteristic.

In a study with single-pane windows, Houghten and Gutberlet (24) found that window glass placed so that the sun's rays must pass through it before impinging on another surface, reduces the heat absorption of that surface by from 9 to 17 percent when the rays are normal to both the glass and the surface. For smaller angles the glass retards a greater percent of the radiant energy. The effect of the angle of incidence on the absorption of radiant energy was also studied and they found that the larger the angle of incidence, the greater the reflection and the lower the intensity of impingment of radiation per unit area of the surface.

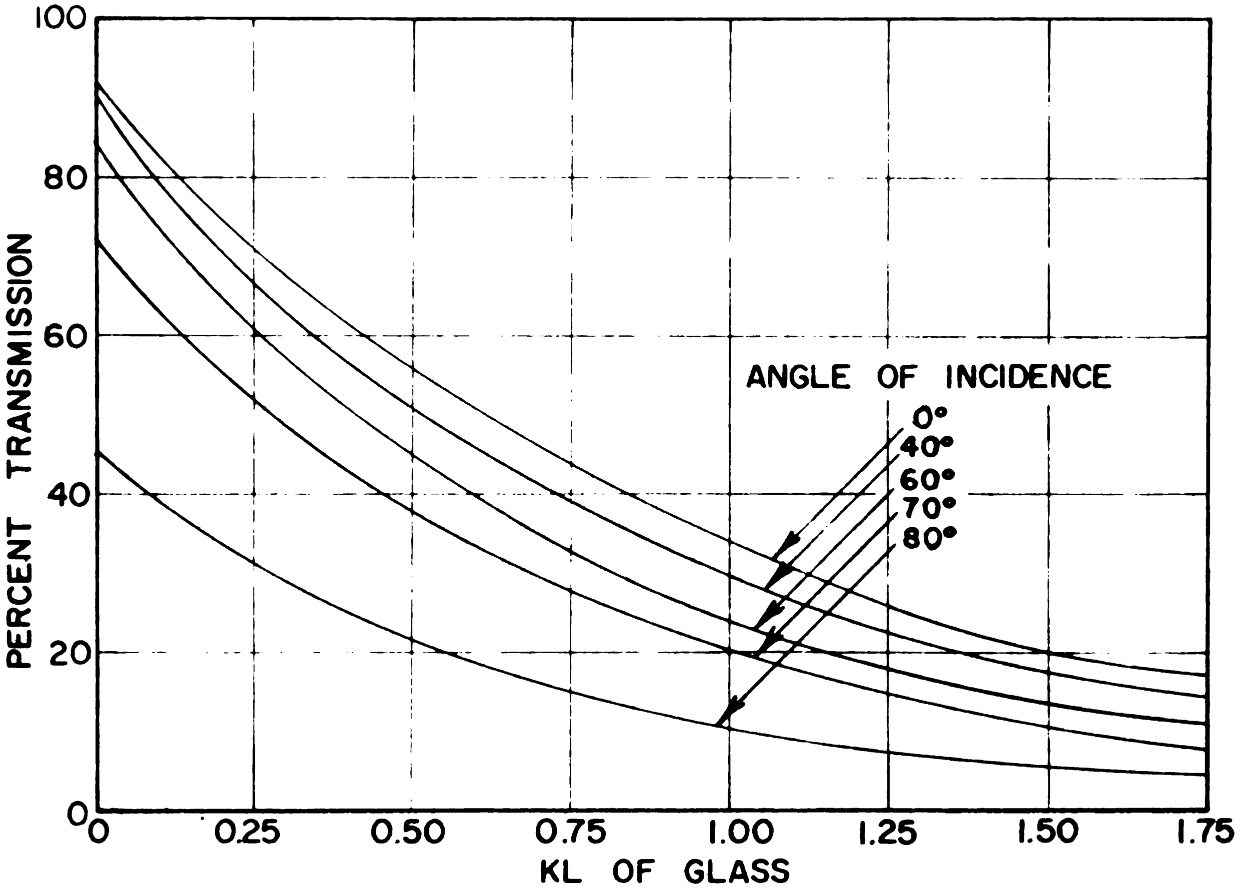

Figure 5. Transmission of solar radiation by a single sheet of glass. (G.V. Parmelee, Trans. Am. Soc. of Heat. and Vent. Engrs., 1945.)

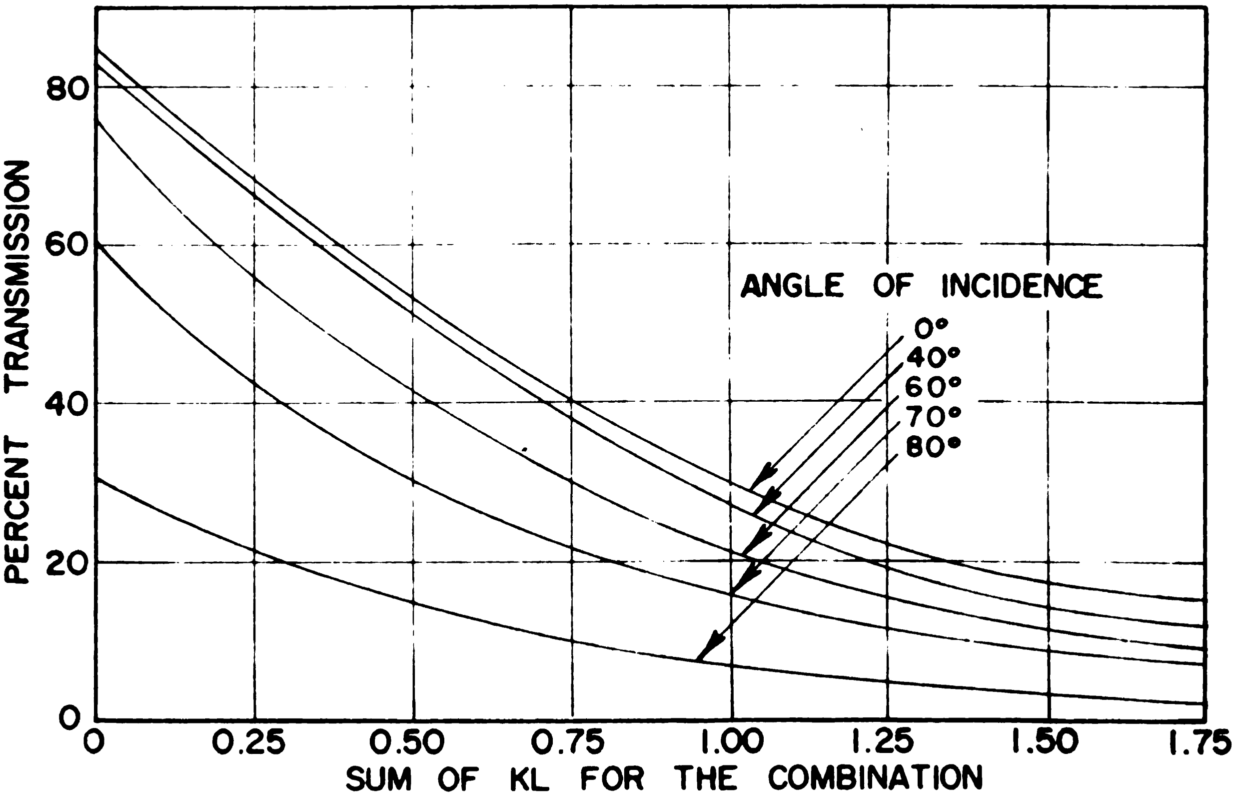

Figure 6. Transmission of solar radiation by two sheets of glass. (G.V. Parmelee, Trans. Am. Soc. of Heat. and Vent. Engrs., 1945.)

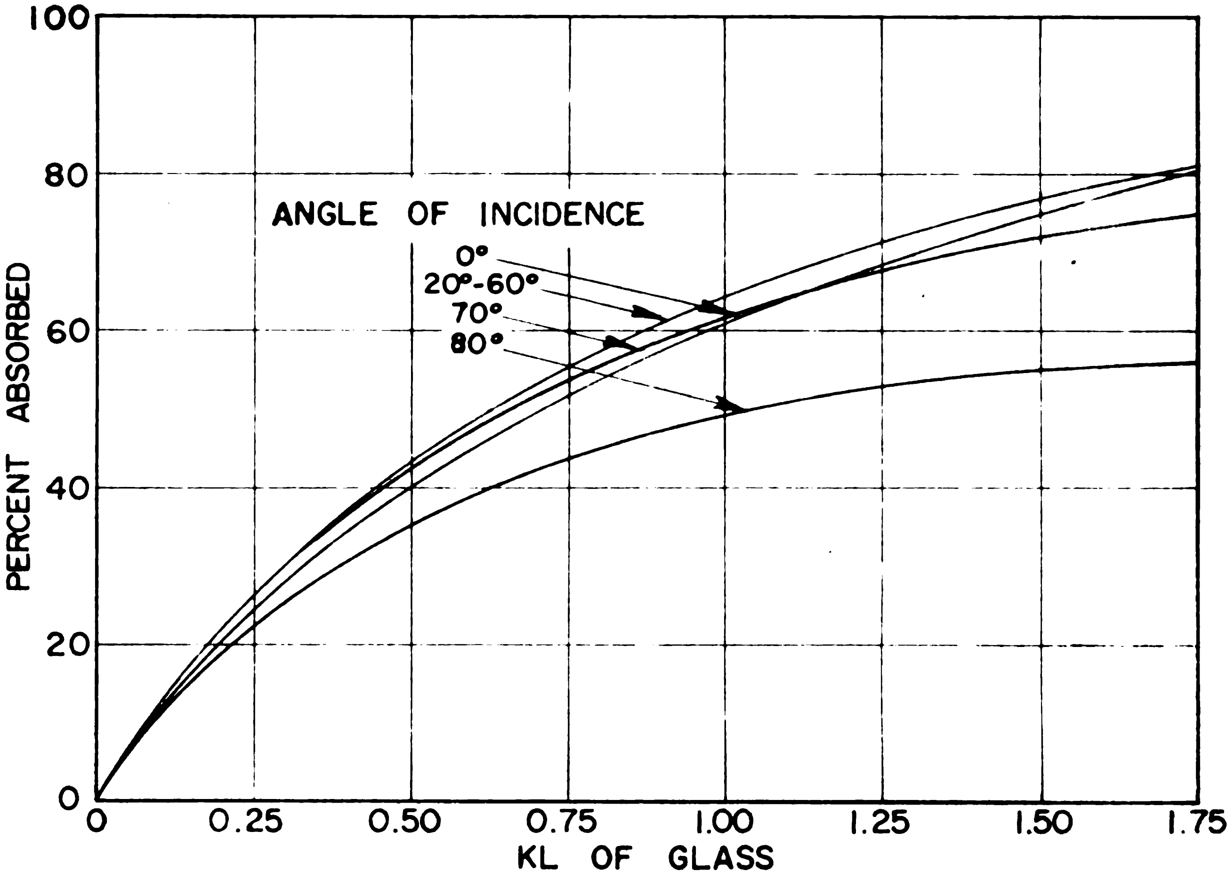

Figure 7. Absorption of solar radiation by a single sheet of glass. (G.V. Parmelee, Trans. Am. Soc. of Heat. and Vent. Engrs., 1945.)

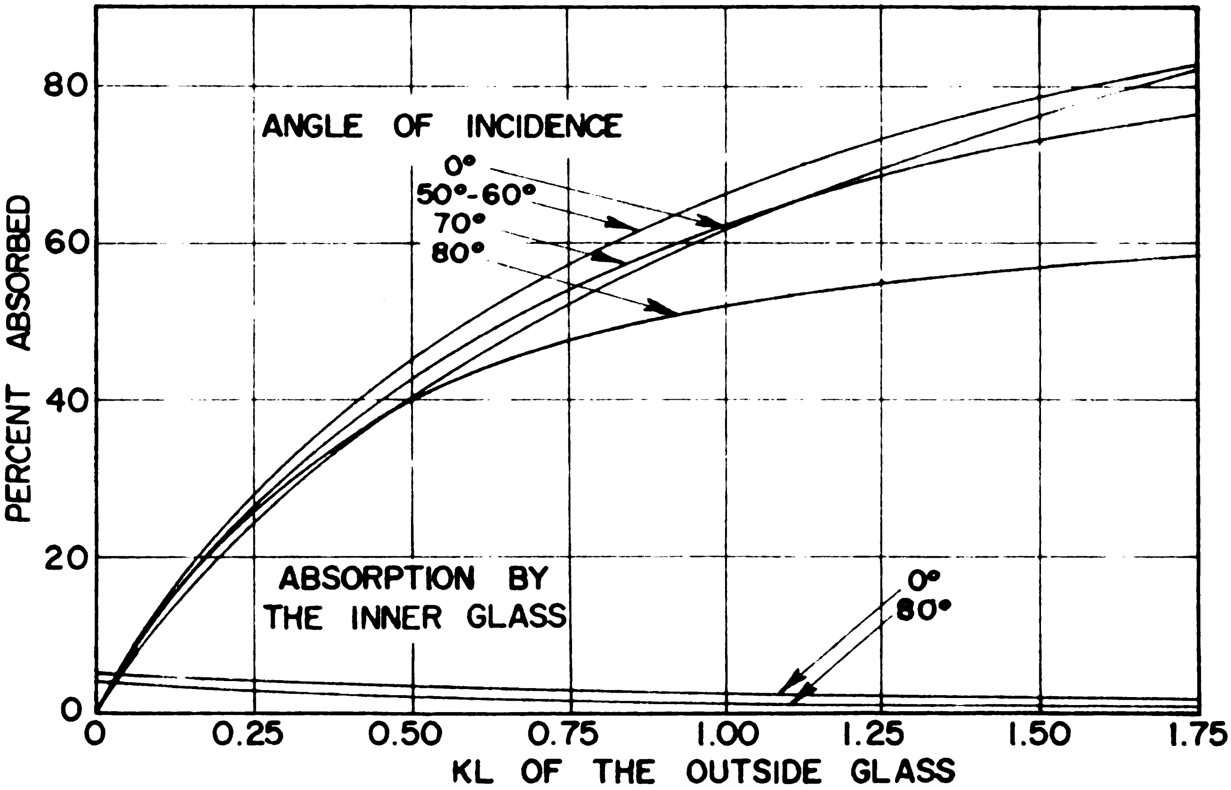

Figure 8. Absorption of solar radiation by two sheets of glass when the KL of the inner sheet equals 0.054. (G.V. Parmelee, Trans. Am. Soc. of Heat. and Vent. Engrs., 1945.)

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This is represented by $Q = H \sin \phi$, where Q is the intensity of radiation falling on the surface at an angle ϕ with the surface, and H is the intensity of radiation on the same surface normal to the direction of radiation.

In their work with shaded windows, Houghten, Gutberlet, and Blackshaw (25) showed that five percent of the solar radiation transmitted through a bare window was transmitted through a window completely shaded with a canvass hung directly in front of the window and 28 percent through an awning. A standard window shade fully drawn on the inside of the window transmitted 53 percent while the same shade outside transmitted only 30 percent.

Hutchinson (30) reports that the quantity of solar energy transmitted through a south exposed window on an average sunny day in winter is considerably more than that received through the same window on an average sunny day in the summer. One reason for this is that there are more hours of possible sunshine in a south-exposed window in winter than in the summer. If the sun is shining, south wall irradiation is possible on the average, for 42 percent of the time during the seven month heating season but only for 37 percent of the time during the three summer months. Another reason for this increase is the fact that the sun is closer to the horizon and as a result the rays strike the window more nearly at right angles. A third reason for this increase is that more than twice as much solar heat enters a south window during a clear winter day than enters during a clear summer day. If the window has a solar designed roof overhang the reception of solar radiation during a winter day will be almost three times as great as during a comparable average summer day.

The transmission of heat energy and solar radiation through double-pane windows. Results of tests on the transmission of heat through double-pane windows (10) indicate that double-panes with a one-quarter inch air space reduce heat losses by about 40 percent compared with the losses through single-panes under the same conditions. The rate of heat transfer decreased as the air space was increased up to three-eights of an inch.

Variations in both solar and sky radiation distribution affect the transmittance of double-pane windows according to Parmelee and Aubele (48). This causes the transmittance of double-panes to be equal or greater than the product of the transmittances of the two panes separately. The transmittance was about five percent greater for standard double-pane glass and about 20 percent greater for standard single-pane glass plus a heat-absorbing glass. A heat-absorbing window outside of a regular single-pane window reduces the transmitted solar radiation considerably.

Parmelee (47) has found that the order in which the sheets of a double-pane window are placed has no bearing on either the amount of solar energy transmitted or the amount absorbed by the combination even if they are of different characteristics. However, the heat flow from the indoor surface of double-panes is complicated by the fact that each pane of glass absorbs a different percentage of the incident radiation.

Heat losses through glass. The chief factors which govern the heat flow through glass windows, as stated by Parmelee and Aubele (49), are the indoor and outdoor surface conductances and the conductance of the air space or spaces of multiple windows. The indoor surface conductance amounts to about 74 percent of the total thermal resistance and the outdoor surface conductance amounts to about 24 percent for a single-pane window. The thermal resistance of the glass accounts for only two percent.

They also state that part of the heat loss from outdoor glass surfaces is due to nocturnal radiation. This radiation exchange between the glass and the atmosphere causes a cooling effect since the incoming low temperature radiation from the sky is insufficient to balance the outgoing radiation from the glass surface. During the day this cooling effect is unnoticeable because short wave solar radiation more than counterbalances the effect.

An increase in wind velocity increases the heat flow through windows by increasing the outside film coefficient according to Carr, Miller, and Shore (11). The increase in wind velocity causes a smaller increase in heat flow through a double-pane window than through a single-pane window because the outside film coefficient is a smaller portion of the overall coefficient for the entire window. Wind velocities beyond 8 miles per hour do not increase the heat flow through glass windows appreciably.

<u>Comparison of single and double-pane windows</u>. A study by Carr, Miller, and Shore (11) revealed that a double-pane house required from 70 to 80 percent as much heat as a single-pane house of identical construction. These figures were affected somewhat by wind velocity, temperature difference and sun intensity. The average temperature of the indoor surface of the single-pane windows was about half-way between the inside and the outside temperatures when there was little or no sunshine and wind. The temperature of the indoor surface of the double-pane windows was about one-quarter of the way between the inside and outside temperatures under

the same conditions. Therefore, the occupants of a double-pane house will feel more comfortable than those in a single-pane house under conditions of identical inside air temperatures. This also means that frost will form more readily on the inside surface of the glass of the single-pane house.

Solarization. Solarization is the result of photochemical stabilization in glass due to exposure to radiation from the sun. Laurens (41) states that transmission of ultraviolet radiation by ordinary window glass is decreased by the effect of solarization. It is caused by the presence of iron in the glass. It takes place rather rapidly at first, then the rate decreases as the exposure is continued until all of the chemically active material has combined. Solarization is attributed to the reoxidation of ferrous to ferric oxide. It causes coloration and spots to develop in the glass. The magnitude of the effect depends upon the kind of glass, the temperature, the time, the wavelength, and the intensity of exposure.

The Effects of Temperature, Relative Humidity, Air Motion, and Solar Radiation on Swine

The design of solar hog houses requires a knowledge of the heat and moisture losses from swine as well as environmental requirements. These factors are all affected by weight, age, and feed consumption of the swine. A scientifically designed hog house utilizes animal heat to help maintain building temperature; while at the same time, providing adequate ventilation to remove products of respiration (especially water vapor), to control relative humidity and aid in maintaining health and sanitation.

The effect of temperature. A study of the effect of ambient temperature on swine (19) revealed that fattening hogs weighing about 200 pounds reach a peak in their average daily growth rate at about 60° F. Pigs that weighed about 100 pounds reached a peak at about 70° F. Both below and above these temperatures efficient utilization of feed declined. High ambient temperatures cause the average daily gain to drop more readily than feed consumption, and therefore, the amount of feed required to produce a certain gain increases rapidly. This is due to the fact that as ambient temperature rises it becomes harder for a hog to lose heat by conduction, radiation, and convection. Thus the animal must rely more heavily on evaporation. At an ambient temperature of 100° F. virtually all of its heat is lost by evaporation. A hog cuts down on feed consumption in order to maintain a normal body temperature. However, if it is unable to dissipate excess heat, body temperatures rises.

Mitchell and Kelly (45) suggest that temperatures in a farrowing house should not be lower than 50° to 55° F. Somewhat lower temperatures are permissible for fattening hogs because of their higher level of nutrition. However, temperatures near freezing should be avoided in any case. Physical regulation of the body temperature of a hog is not sufficient above a temperature of 79° F. The desirable environmental temperature for an average hog is about 68° F. and varies with the level of nutrition, being lower for large hogs.

The effect of relative humidity. For hogs weighing over 200 pounds, Heitman and Hughes (18) have found that only their respiration rate increases when the relative humidity is increased except at high temperatures when their body temperature also increases slightly. At high temperatures and low relative humidities, hogs do not become distressed. However, as the relative humidity is increased from about 30 to 90 percent the respiration rate more than doubles and body temperature increases from two to three degrees.

The effect of increased air motion. Heitman and Hughes (18) also report that at high temperatures an increase in air motion will lower the respiration rate and body temperature of a hog if he is wet. However, if the hog is dry an increase in air motion is of no benefit. This is to be expected of a non-sweating hog when the air temperature is higher than his surface temperature.

The effect of solar radiation. Information is not available on the effect of solar radiation upon swine other than the fact that infrared radition exhibits a heating effect upon man and animals (20). However, Abbott (1) states that a narrow band of rays in the extreme ultraviolet region is necessary for the good health of growing chickens. This group of rays is cut off by glass.

APPARATUS AND METHODOLOGY

Construction and Equipment

The experimental hog houses were constructed according to the plan shown in Figure 9. The only difference in the three houses was in the type and amount of glass installed in the removable window frames. Two of the houses were completed in the summer of 1953 and the third house was finished in the following fall.

The walls of the houses were constructed of 2" x 4" studs 16 inches on center and insulated with one-inch blankets of balsum wool, as shown in Figure 10. Both surfaces were covered with one-quarter inch exterior plywood.

The roofs and floors were built as shown in Figure 11. Strips 1" x 3" were nailed and glued to three-eights inch exterior plywood sheets with waterproof glue. A vapor barrier of 40 pound roofing felt was placed between the ribs. Two and one-half inches of rock wool insulation was then placed on top of the vapor barrier and another sheet of three-eights inch exterior plywood was glued and nailed to the ribs so that both sides were covered. These prefabricated panels were then nailed into position with the vapor barrier towards the inside of the structure. Caulking compound was placed around the edges of both the roofs and floors to prevent water leakage and air infiltration. The floor panels were placed on 4" x 6" skids to facilitate moving.

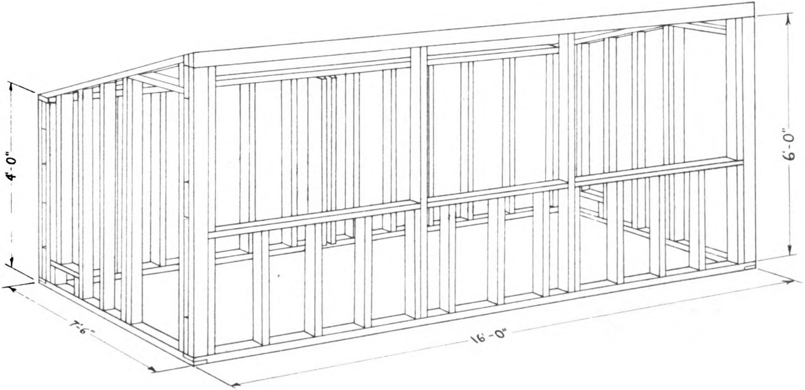


Figure 9. The plan for the framework of the three experimental houses.

Figure 10. The framework of the houses with the blanket insulation installed.

Figure 11. The four stages of the construction of the roof and floor panels.

A 2" x 6" post was placed in the middle of each house. This post supports the ventilating fan and air duct, a shelf for the necessary instruments, and two gates which divide the house into two pens approximately 7' x 8'.

The doors of each house were made of two-inch lumber, covered with one-quarter inch exterior plywood, and filled with rock wool insulation. A vapor barrier was placed under the inside sheet of plywood. Later all the doors were converted to dutch doors, by cutting them in half horizontally.

The window frames were made of two-inch framing lumber. The glass windows are held in place by 1" x 1" strips and glazing compound. The total glass area of the houses with full size windows is approximately 38 square feet. This is equivalent to 36 percent of the floor area. One house has double-pane windows and the other has single-pane windows. The third house has double-pane windows half as high as the full size windows with an area of 18 percent of the floor area. A view of the installed windows is shown in Figure 12.

The sun shades were made of sheets of exterior plywood and are also shown in Figure 12. The adjustable supports allow the shades to be changed as desired. The shades were removed during the winter study except for the last two weeks in late March and early April when the temperatures inside the houses became too high.

A self feeder and an automatic waterer were installed in each pen. Both the feeder and the waterer can be filled from outside. The feeder has a storage box on the outside of the building as shown in Figure 13, which can be emptied from the bottom if necessary. The part of the feeder

Figure 12. A view showing the windows installed and the sun shades.

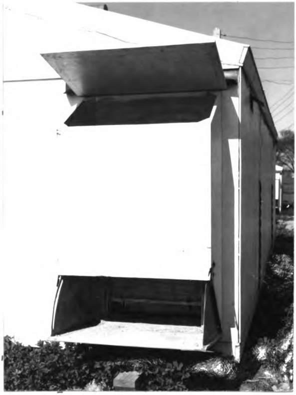


Figure 13. The feed storage box.

that is inside of the building is shown in Figure 14. The adjustable plate shown is on hinges and is attached to a heavy wire frame which agitates the feed in the storage box so that it will keep moving down without bridging. The watering system consists of an automobile gasoline tank which holds approximately 17 gallons and an automatic waterer as shown in Figures 15 and 16. The waterer on the left permitted excessive spillage and was replaced by the type shown on the right.

To insure against freezing the water, 250-watt infrared heat lamps were placed above each waterer during the winter study as shown in Figure 16. A six volt transformer was used to provide a control circuit for turning on the heat lamps. One thermostat in the house with single-pane windows controlled the operation of the heat lamps in that house and a relay switch was located in each of the other two houses. The thermostat would turn on the heat lamps in the single-pane house while at the same

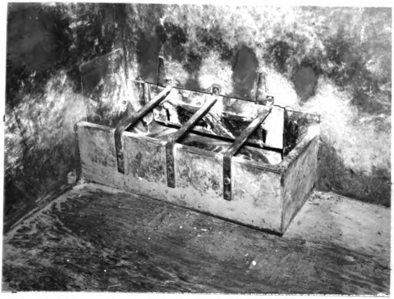


Figure 14. The section of the feeder that is located inside the buildings.

Figure 15. The automobile gasoline tank and the type of automatic waterer used in the summer study.

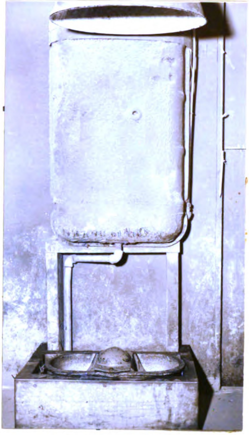


Figure 16. The type of automatic waterer used in the winter study and the position of the heat lamp.

time it would energize the six volt transformer which would close the relay switch and turn on the heat lamps in the other two houses.

Ventilation for each house was provided by a centrifugal fan with an air flow rate of approximately 60-75 cubic feet per minute. The fans exhaust the air through the roof as shown in Figure 17. The air intakes were first installed above the doors but were later moved to the back wall, Figure 17, to permit better circulation of the air. The total area of the air intakes was 30 square inches. During the summer study each fan was controlled by a separate thermostat. However, during the winter study

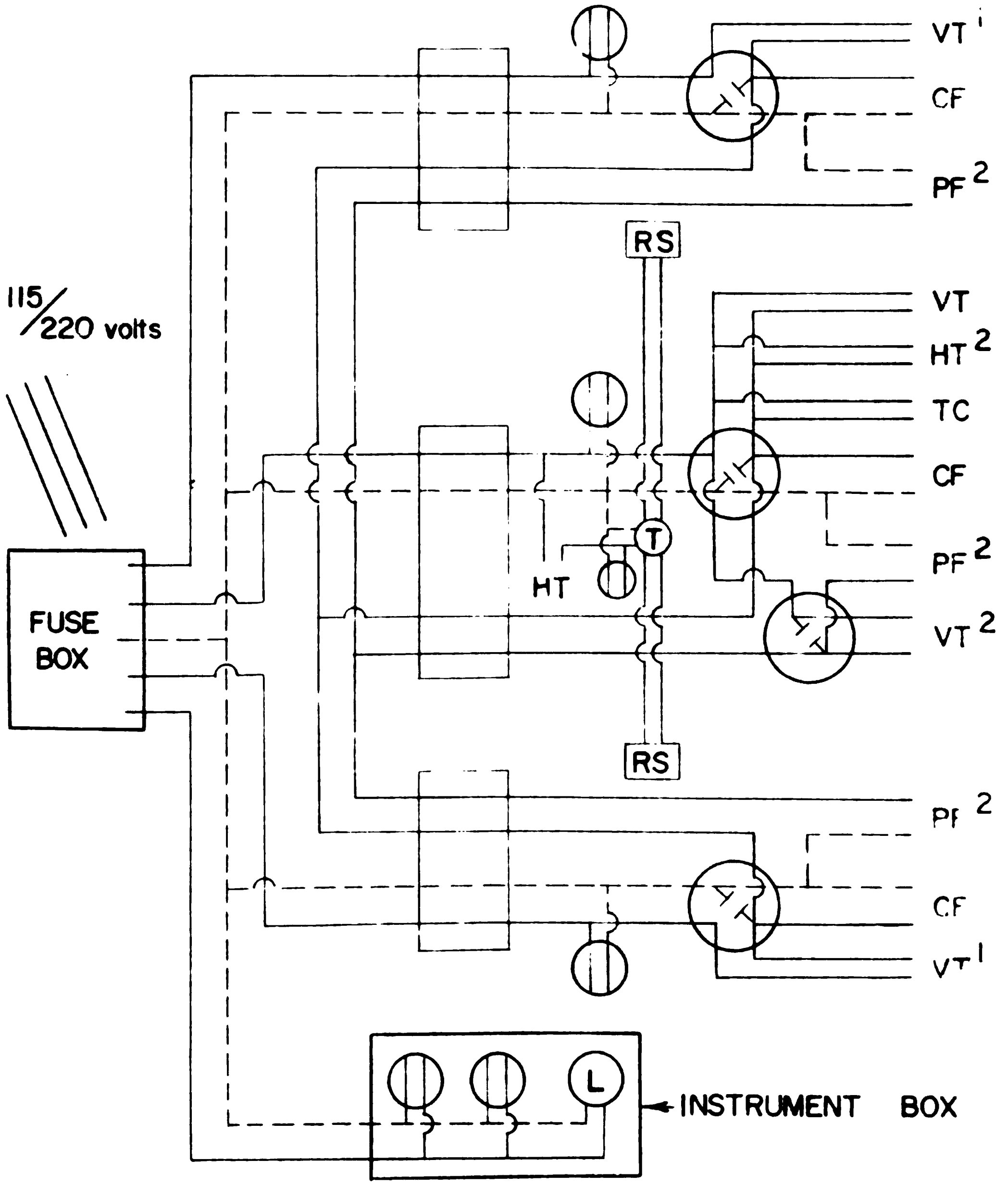
Figure 17. A rear view of one of the houses showing the air intakes and the exhaust duct through the roof.

all the fans were controlled by the same thermostat located in the house with single-pane windows.

The electrical wiring system for the three houses and the instrument box is shown in Figure 18. The system is divided into four circuits so that each house and the instrument box all have a separate circuit. However, there are two additional circuits common to all three houses which permits the use of one control for regulating the ventilating fans or the heat lamps.

Three drains were provided in each house at the beginning of the winter study to eliminate the accumulation of water and to help keep the litter dry. The houses were sloped slightly so that the water would run towards the drains.

Figure 18. The electrical wiring system for the three experimental houses and the instrument box.



LEGEND

Ⓛ - LAMP HOLDER
⊣ ⊢ - RECEPTACLE
Ⓣ - SIX VOLT TRANSFORMER
--- GROUND WIRE
⏀ - CONVENIENCE OUTLET

CF - CENTRIFUGAL FAN
PF - PROPELLER FAN
HT - HEATING THERMOSTAT
VT - VENTILATING THERMOSTAT
RS - RELAY SWITCH

1. Disconnected during the winter study.
2. Added before the summer study of 1954.

Instrumentation

The eight point Brown recording potentiometer used previously for the project was used for both summer and winter studies. The time control for the potentiometer as described by Hinkle (21) was also used. This made it possible to take an hourly temperature record of eight thermocouples.

The potentiometer, the time clock, and the plug for connecting the thermocouple wire to the potentiometer were all housed in an instrument box shown in Figure 19. This box was thoroughly insulated and heated with two electric light bulbs to insure against damage to the standard cell in the potentiometer. The thermocouple wires were suspended from a pole to the potentiometer (Figure 2) from each house.

The thermocouples were made by a method similar to the method used

Figure 19. The instrument box for housing the potentiometer, the time clock and the connecting plug.

by Hinkle (21). A common constantan wire was used for each set of thermocouples. During the summer study the eight thermocouples were used as follows: one was placed underneath the instrument box to record the outside temperature; two were placed in the conventional hog house at heights of three feet and five feet; three were placed in the hog house with full-size double-pane windows, one for dry-bulb temperature and two for wet-bulb temperatures; and two were placed in the hog house with full-size single-pane windows, one for wet-bulb and one for dry-bulb temperature. During the winter study the placement of the thermocouples was the same except that the two previously used in the conventional hog house were used in the third house for wet-bulb and dry-bulb temperatures. The thermocouples in the houses were all located about five feet above the floor.

At the time of building the first two houses 42 thermocouples were placed in the walls, roof, and floor of each house. A sectional view of the placement of these thermocouples is shown in Figures 20 and 21. The thermocouples are numbered from one through forty-two, the lowest number of each set being towards the inside of the building. The thermocouples were connected to plugs in a small box on the end of each house, as shown in Figure 22, in order that they could be connected to the potentiometer, one or two sets at a time. The numbers and location of the thermocouples are indicated in the box.

Relative humidity measurement was also accomplished with the use of thermocouples. The relative humidity unit used was very similar to that used by Hinkle (21). However, a fan was not used to provide air movement across the wet bulbs since it was found that air movement was

Figure 20. The placement of the thermocouples in the walls of tne houses.

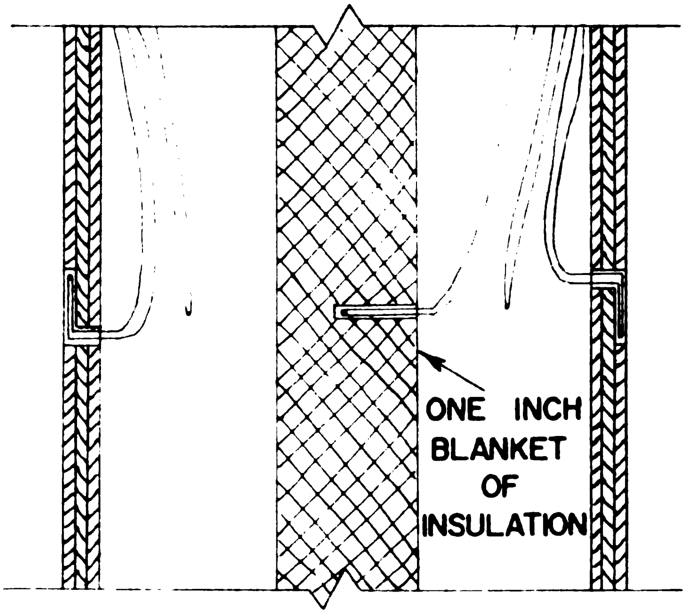
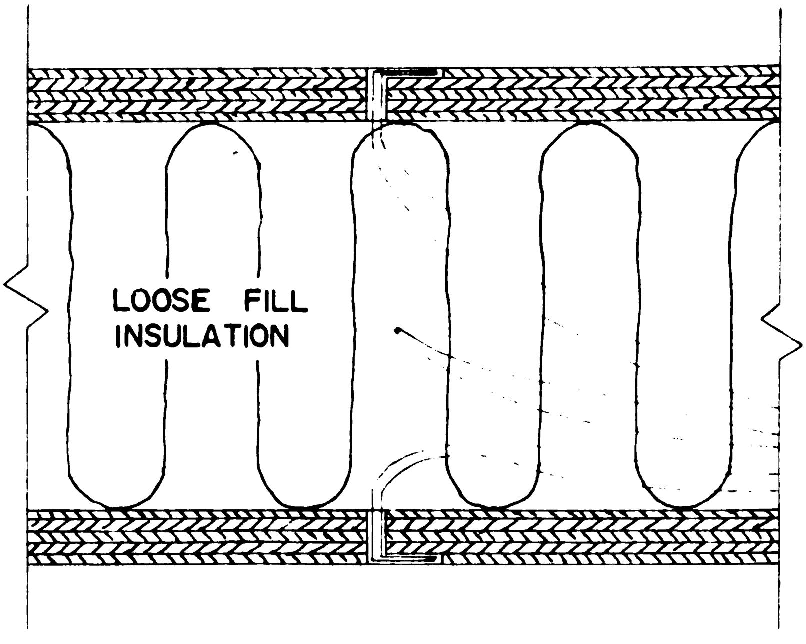


Figure 21. The placement of the thermocouples in the floor and roof of the houses.



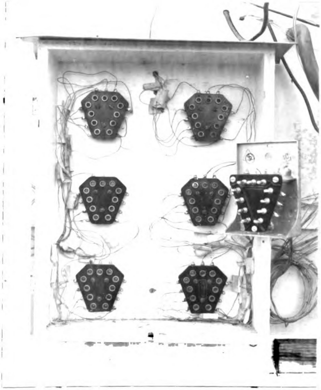


Figure 22. The box containing the plugs for connecting the thermocouples in the walls to the potentiometer.

unnecessary for accurate results. The relative humidity units were placed on a shelf in the center of each house approximately five feet above the floor.

The operation of the ventilating fans and the heat lamps was measured by a "Tempscribe" recorder shown in Figure 23. This instrument kept an on-and-off record for a 24 hour period. They were wired in parallel with the thermostats which controlled the operation of the ventilating fans and the heat lamps.

During a period of three weeks at the beginning of the winter study a Brown two pen dial temperature recorder was used to record the opera-

Figure 23. The recorder which kept an on-and-off record of the operation of the ventilating fans.

tion of the ventilating fans and the heat lamps. One thermometer bulb was placed next to a 25 watt electric bulb which turned on when the fans were on and the other was placed under a heat lamp. Therefore, whenever either lamp was turned on the temperature of the corresponding thermometer bulb went up which in turn was recorded on the chart. The recorder was unsatisfactory because it required a seven day chart which did not permit accurate recording of the time of operation. As a result, no accurate record of the operation of the ventilating fans was available for the first three weeks of the winter study.

At the beginning of the winter study there were long periods of time when the thermostat did not call for ventilation. During these periods there was a considerable buildup of moisture and ammonia fumes in the houses. In order to eliminate this situation a time clock was installed which turned on the ventilating fans for a desired period of time once every half hour even if the thermostat did not call for ventilation.

Procedure

At the beginning of each study the hogs for each lot were selected at random. Following this some of the hogs were moved to other lots so that there would be more uniformity between the hogs in each lot with regard to their weight, sex, and breed. The feed ration fed to the hogs was the same for all the lots. At intervals of two weeks the hogs were weighed to determine their progress. The total amount of feed and water consumed for the two week period was determined at the time of weighing. Feed and water were available at all times. Whenever feed or water supplies were low the necessary amount was added and recorded. The houses were cleaned and bedded every morning.

The operation of the instruments was checked daily and necessary changes such as new charts, additional ink or water for the wet-bulbs, were made and all irregular conditions recorded. The hourly temperature data was plotted on weekly charts along with solar radiation data recorded at the Michigan Hydrologic Research Project. The operation of the ventilating fans was also indicated on the weekly charts. The wet-bulb temperature data was converted to relative humidity readings and also plotted on weekly charts. Maximum, minimum, and mean daily temperatures were plotted on charts that covered the whole 16 week period of the winter study. Maximum daily variation in temperature and total daily solar radiation were also plotted on similar charts for the winter study. Rate of gain and water and feed consumption data for the hogs was computed and plotted.

PRESENTATION AND ANALYSIS OF DATA

In the following discussion the four types of housing used in both the summer and winter studies are referred to as: House A, the conventional house on the concrete slab; House B, the house with double-pane windows; House C, the house with single-pane windows; and House D, the house with double-pane windows half as high as the other windows. The hogs in House A were used as controls for the studies.

Part I - Analysis of the Summer Study

The summer study started on July 24, 1953, but due to a difficulty with the recording potentiometer correct temperature recordings were not available until August 3, 1953. The study was discontinued on September 2, 1953 when it was determined that sufficient data was available so that continuation of the study was unwarranted.

The temperature, relative humidity and solar radiation data for the summer study are shown in Appendix A. The missing data on August 26 and 27 was caused by a failure of the printing mechanism of the potentiometer. The temperatures recorded in House A were essentially the same as the outside temperatures, Appendix A, and were not plotted separately.

Temperature. The difference between the inside temperatures in House B and that in House C was not significant. However, there were slight temperature differences for short periods of time but a definite trend was not noticeable.

Relative humidity. The relative humidity in House A and House B was not appreciably different throughout the summer study. However, on a few occasions there was an appreciable difference in the relative humidity readings. This was due to the improper functioning of the wet-bulb. The main factors contributing to the high relative humidity were the large amounts of water spilled from the waterer onto the floor and insufficient ventilation.

Ventilation. The ventilating fans in both House B and House C ran almost continuously throughout the entire length of the summer study. They stopped for short periods of time on five occasions in both houses.

Observations made during the summer study indicated that it was too warm and humid in both houses. Nearly every morning there was condensation on all the windows. These conditions were caused by inadequate ventilation and circulation. It was very apparent that a good ventilating system was necessary to maintain comfortable conditions.

Feeding trial. The results for the feeding trial of the summer study are compared in Table I. The water consumption data was not reliable because large amounts of water were spilled on the floor by the hogs. Water consumption data was not obtained for the hogs in House A.

The results from the summer study show very little difference in the rate of growth and the feed consumed per pound of gain between the hogs in House B and House C. There was however, appreciable difference between the hogs in Houses B and C and the hogs in House A. The hogs in House A made slightly better average daily gains and they made greater gains per pound of feed consumed.

TABLE I

SUMMARY OF THE RESULTS FOR THE HOG FEEDING TRIAL OF THE SUMMER STUDY OF 1953

	Treatment		
	House A	House B	House C
Number of pigs	16 (in two lots)	8	8
Average initial weight in pounds	98.2	95.8	95.7
Average final weight in pounds	171.1	155.5	158.4
Average daily gain in pounds	1.9	1.6	1.7
Pounds of feed consumed per pound of gain	3.7	4.2	3.9
Total amount of water consumed in gallons	---	900.0	825.0

Conclusions. The results from the summer study indicate no apparent advantage in housing swine in a solar orientated house with large areas of double-pane windows. However, the conditions under which the study was made did not use the double-pane windows to full advantage although they were completely shaded. This can be corrected by improved ventilation or by opening the upper parts of the dutch doors at night and closing them during the day in order to maintain lower inside temperatures.

The lower rates of gain for the hogs in House B and C as compared to the hogs in House A can be attributed to poorer living conditions resulting from higher temperature and relative humidity in Houses B and C, Table I. These conditions can both be traced back to improper ventilation.

The houses were entered for short periods of time each day for purposes of cleaning and to check the operation of the ventilating fans and the wet-bulb apparatus.

Part II - Analysis of the Winter Study

The winter study started on December 15, 1953, continued for a sixteen week period and ended on April 6, 1954. Several of the hogs had reached market weight by the end of the period. The winter study was an investigation of the effect of two types of window glass on the rate and efficiency of gain of hogs and the effect upon their environment. House A, House B, and House C were again used for the winter study. In addition, House D, the house with double-pane windows only half as high as the other windows was also used. Each house contained eight pigs divided into two lots of four pigs each.

The temperature, relative humidity, ventilation, and solar radiation data for the winter study are shown in Appendix B. The relative humidity data was plotted for only eight weeks because there was not enough variation to warrant plotting the data for the entire sixteen week period. The missing data was caused by failures of the potentiometer and the wet-bulb apparatus. The daily maximum, minimum and mean temperatures are shown in Figures 24, 25, and 26, respectively. The maximum daily variation in the temperatures inside Houses B, C, and D are shown in Figure 27. The daily total amount of solar radiation and the normal amount of solar radiation is shown in Figure 28. The missing temperature and relative humidity data was due to instrument failure.

<u>Temperature</u>. The inside temperatures of Houses B, C, and D followed certain definite patterns during the winter study.

In House C the maximum difference in daily temperatures was usually greater than in either House B or House D on the days when there was a large amount of solar radiation as shown in Figure 27. On these same days the maximum temperature in House C was essentially equal to or slightly higher than the maximum temperature in House B. When there was a large temperature rise inside House C due to the reception of large quantities of radiation from the sun the rate of increase in temperature was usually greater than the rate of increase in temperature for either House B or House D. However, the temperature usually decreased faster in House C than in either Houses B or D. The minimum temperature at night and on cloudy days in House C was usually lower than the temperature in either House B or House D except when it was relatively warm outside. This was especially true when the ventilating fans were not running. This greater

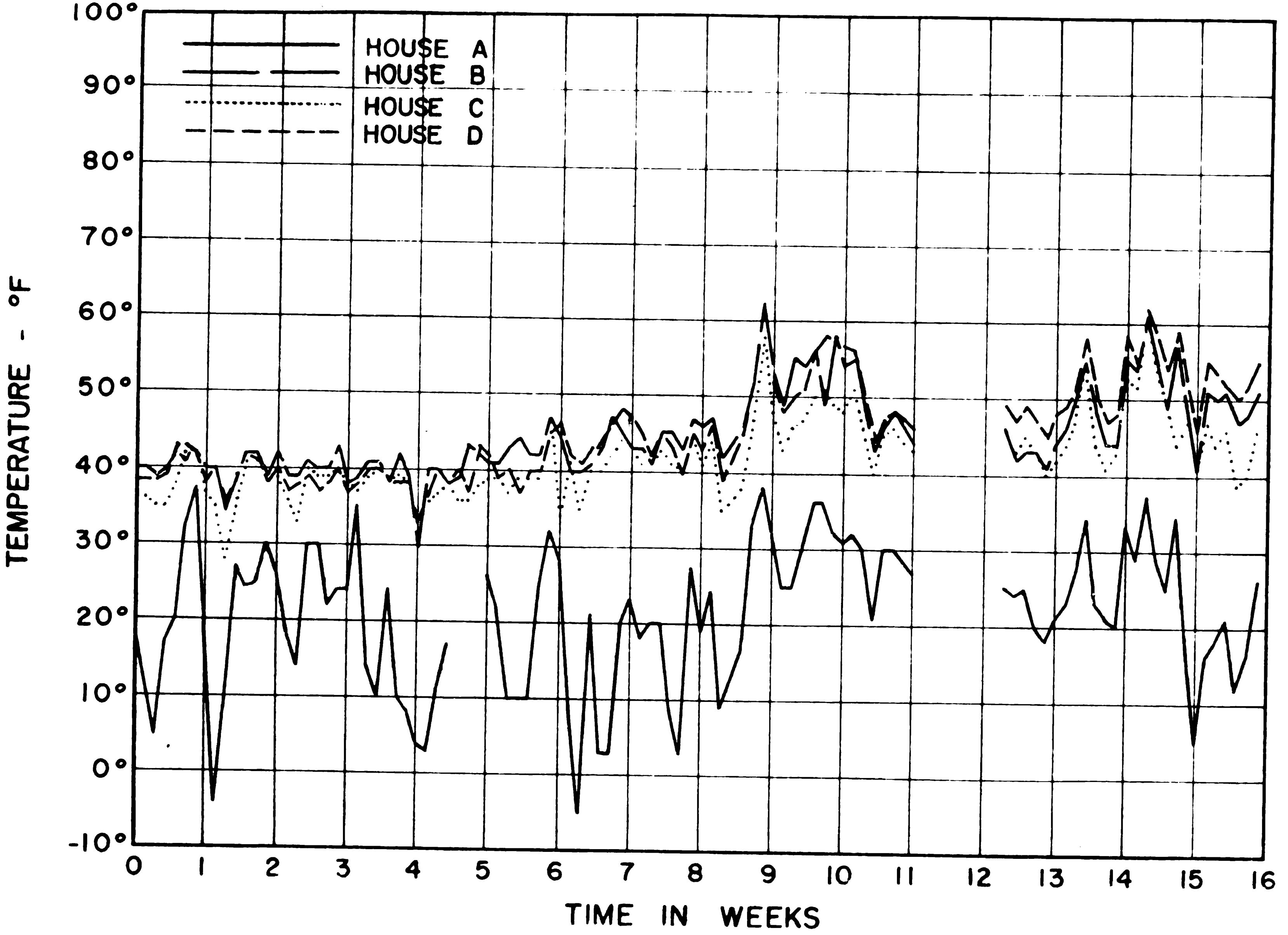


Figure 25. The minimum daily temperature in the four test houses from December 15, 1953 to April 6, 1954.

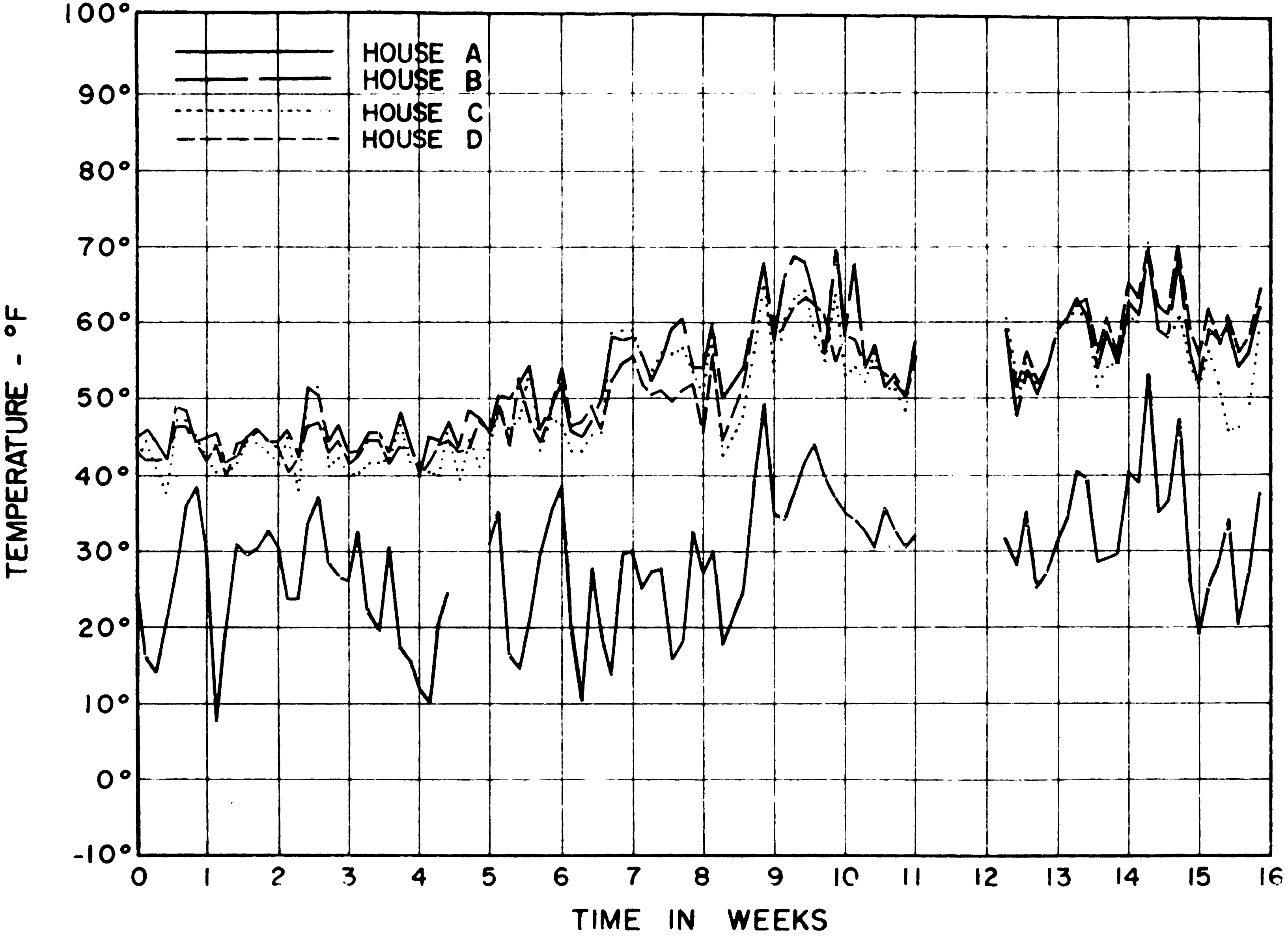


Figure 26. The mean daily temperature in the four test houses from December 15, 1953 to April 6, 1954.

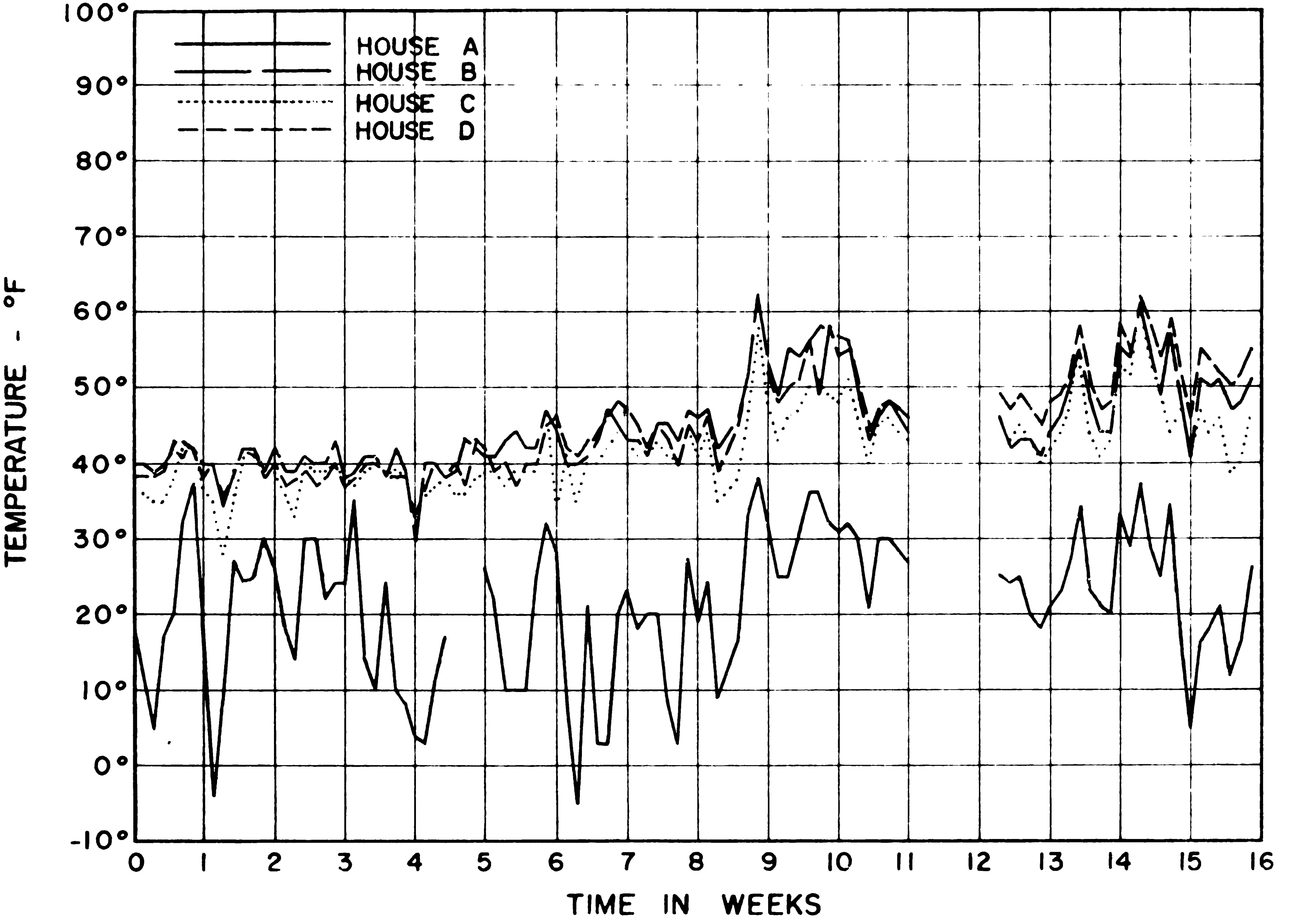


Figure 25. The minimum daily temperature in the four test houses from December 15, 1953 to April 6, 1954.

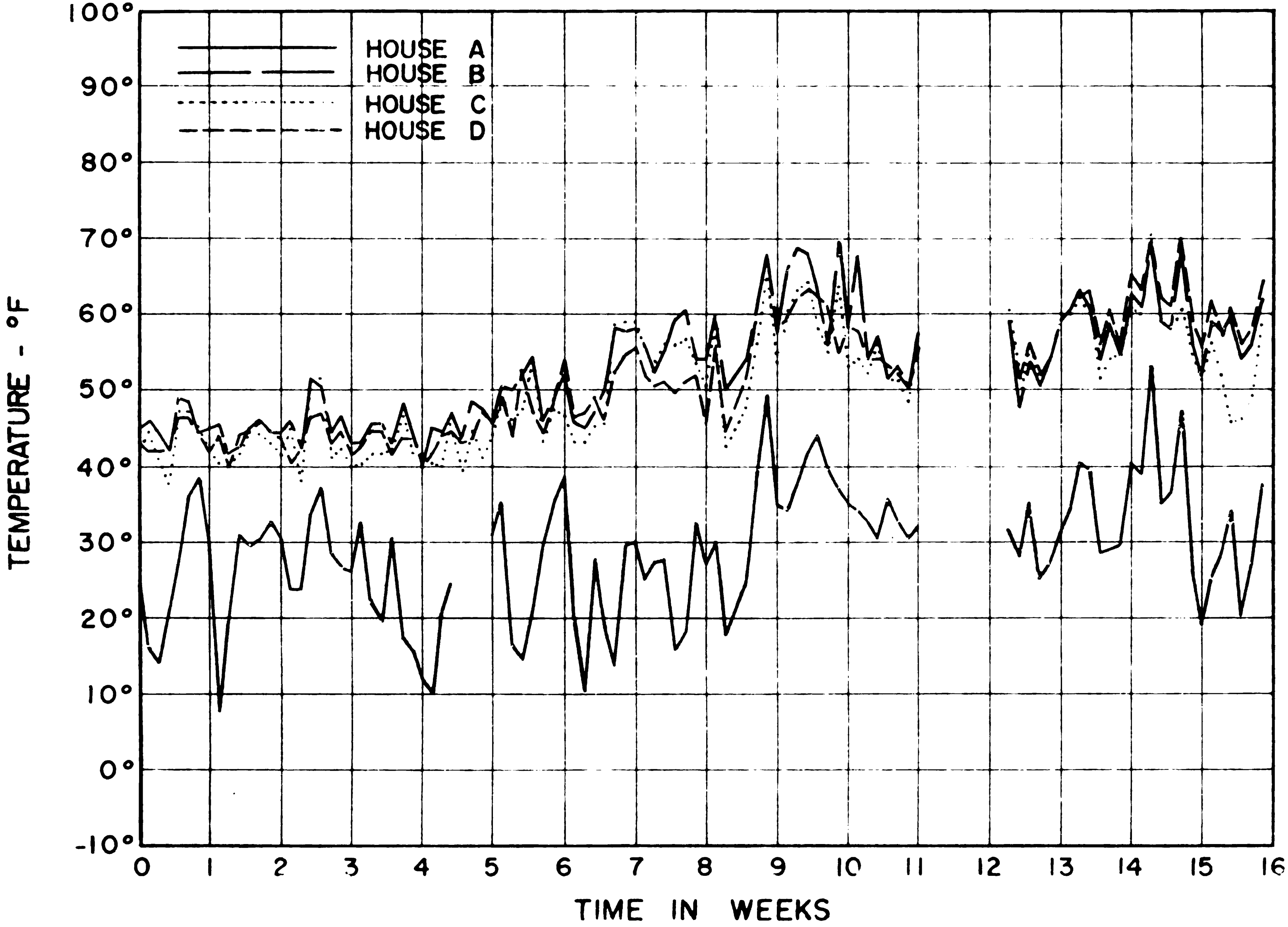


Figure 26. The mean daily temperature in the four test houses from December 15, 1953 to April 6, 1954.

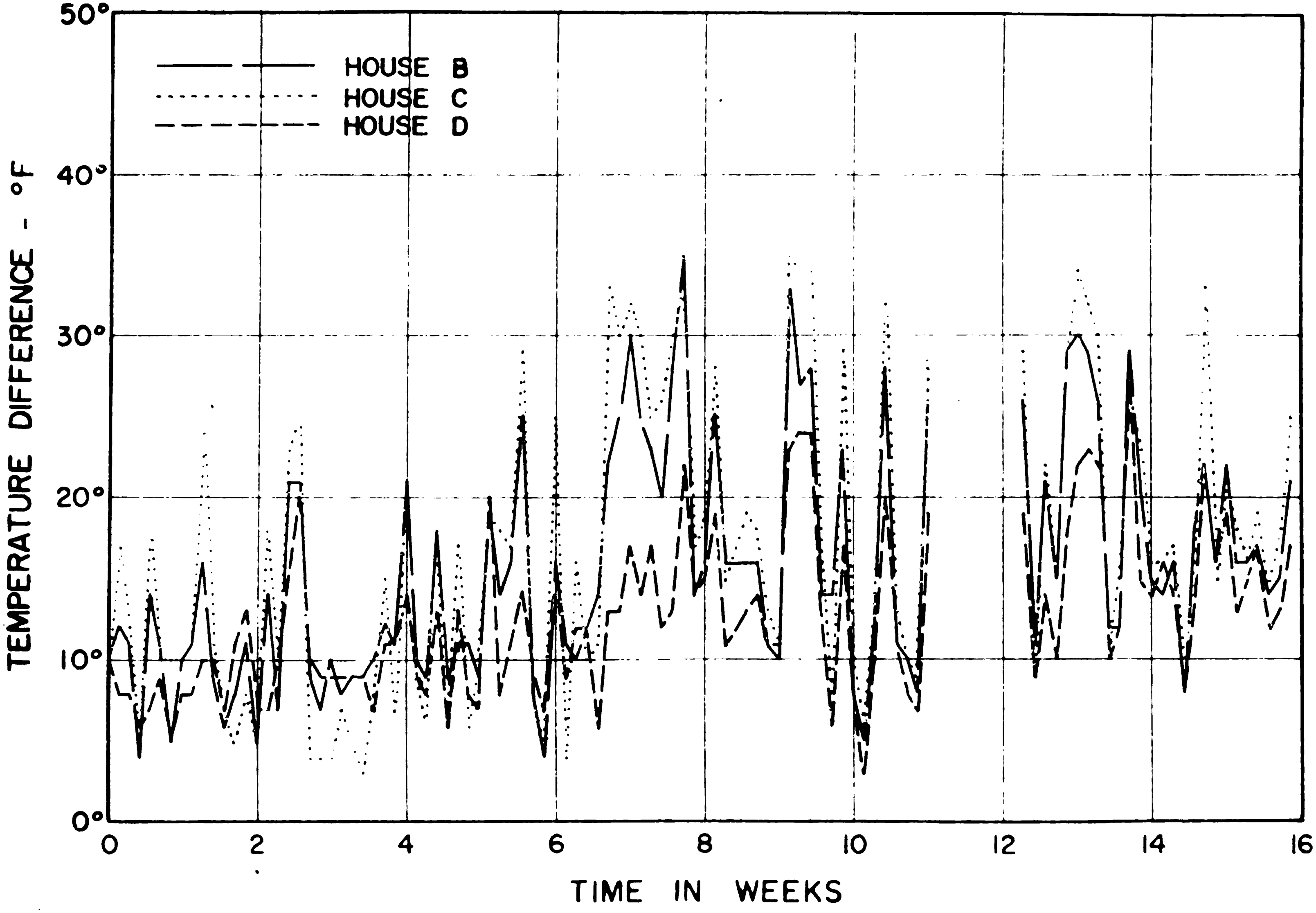


Figure 27. The difference between maximum and minimum daily temperatures from December 15, 1953 to April 6, 1954.

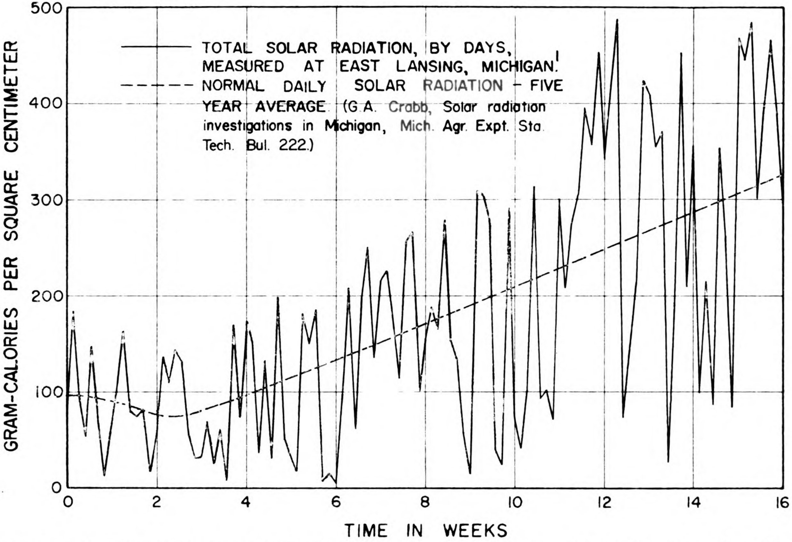


Figure 28. The total amount of solar radiation for each day from December 15, 1953 to April 6, 1954 and the normal amount of solar radiation for each day of the same period.

[1] The Michigan Hydrologic Research Station, Michigan Agricultural Experiment Station in cooperation with the Bureau of Plant Industry, Soils, and Agricultural Engineering of the United States Department of Agriculture.

range in maximum and minimum temperature in House C was caused by the ability of the single-pane windows to transmit greater quantities of both short wave-length radiation and heat energy through the glass. There was more heat trapped in House C even though there was greater heat losses through the single-pane windows as compared to Houses B and D. However, when the source of incoming radiation was eliminated the heat losses through the single-pane windows caused the temperature to be lower when there was no solar radiation and when the temperature differences between outside and inside was large. When the ventilating fans were off there was no heat loss by ventilation. The conditions inside the houses were such that heat was lost only through the walls, roof, floor, and the glass windows. The heat losses were about the same except for the losses through the windows. Since the heat losses were greatest through the glass in House C the temperature was usually several degrees below the temperature of the other two houses when the ventilating fans were off.

In House B the maximum difference in daily temperatures was less than in House C and greater than in House D. The daily fluctuation in temperature in House B was very similiar to that in House C. The maximum daily temperatures were usually higher than in either House C and D except on the days when large quantities of solar radiation were received and then the temperatures in House C were higher. The mean daily temperatures were also slightly higher in House B as shown in Figure 26. When there was a large temperature rise inside the house due to the reception of large quantities of radiation from the sun the rate of increase was greater than the rate of increase in temperature for House D. The rate of decrease in temperature was also greater than that of House D.

These trends were caused mainly by the greater insulating value of the double-pane windows. The heat trapped inside House B was not lost as readily as in House C. As a result the temperatures remained higher at night time causing less temperature fluctuation throughout the day.

In House D the maximum difference in daily temperatures was usually less than in either House B or House C. When ever there was an appreciable increase or decrease in the temperature in either of the other two houses the temperature in this house lagged behind. On the days when large quantities of radiation were received from the sun the maximum daily temperature was always lower than the maximum daily temperature in either House B or House C. The minimum daily temperature was usually slightly below that of House B and slightly above that of House C. These conditions can be attributed mainly to the fact that there was a smaller area of glass in House D. Consequently, less solar radiation was allowed to enter the house and be utilized as heat energy. This kept the temperatures lower than those in Houses B and D. On the other hand, the smaller glass area maintained more uniform temperatures than in the other houses. Also, the total insulating value of the glass and the wall section that took the place of the larger windows was higher, thus causing smaller overall heat losses in the house. However, House D was at a disadvantage because the heat losses were not small enough to offset the decrease in glass area. As a consequence, when Houses B and D were at higher temperatures and the temperatures began to drop, the temperature in House D also dropped considerably and often remained below the temperature in Houses B and C. Eventually the temperature in House C would go lower than the temperature in House B.

A positive correlation was found between the inside temperature in Houses B, C, and D and the temperature in House A or the outside temperature. An analysis of the regression lines showed no marked difference in slope, however.

Relative humidity. The relative humidity inside Houses B, C, and D did not vary according to any specific pattern as shown in Appendix B. There was, however, a tendency during the night time for the relative humidity in Houses C and D to be higher than the relative humidity in House B. During the day time the relative humidity in Houses B, C, and D was not appreciably different.

The higher relative humidity in Houses C and D as compared with the relative humidity in House B was caused mainly by differences in the temperature in the houses. Lower daytime temperatures in House D did not permit as much evaporation of the moisture from the floor and litter as in Houses B and C. This caused the relative humidity to be higher in House D during the night because of the greater quantities of moisture being evaporated than in Houses B and C. Lower night time temperatures in House C caused the relative humidity to be higher than in House B.

Ventilation. At the start of the winter study the thermostat which controlled the operation of the ventilating fans was set at 50° F. At this setting the fans were shut off for as long as 16 hours or more on a few occasions. During these long periods there was a large moisture buildup in the houses. In some instances the walls were completely covered with moisture. The ventilation was therefore, inadequate and the setting was gradually lowered to 40° F. Ventilation was still inadequate, but

40° F. was considered to be a practical minimum; so, a time clock system of control was proposed.

On February 3, 1954, a time clock was installed to control the operation of the ventilating fans when the thermostat did not call for ventilation. The time clock turned on the fans for a desired period of time from 0 to 30 minutes once every half hour. It was first set so the fans operated for seven and one-half minutes once every half hour. This did not provide enough ventilation so the setting was changed after two weeks to operate for ten minutes once every half hour. This period of operation provided a sufficient change of air when the thermostat did not call for ventilation so this setting was maintained throughout the remainder of the study.

During the winter study there were a number of days when the temperatures in Houses B and C reached 70° to 80° F. even though the outside temperatures usually remained below 50° F. These high temperatures were undesirable because a maximum temperature of 60° - 65° F. is desired for hogs. The hogs would lay in the shade at these temperatures while at lower temperatures they would lay in the sun light. It was apparent that the capacity of the ventilating fans was inadquate even under winter conditions.

A very important part of ventilation is proper circulation. A ventilating system with inadequate circulation does not take full advantage of the ventilation. In order to determine whether or not there was good circulation in the experimental houses a smoke bomb test was made. The results of this test are shown in Figures 29 and 30. These pictures show that there was fairly good circulation in the houses. However,

Figure 29. The distribution of the air as it enters the house through one of the air intakes in the rear wall.

Figure 30. The distribution of the air as it moves across the front of the house towards the air intake of the fan.

there is clearly room for improvement so that the air will circulate more uniformly through the houses.

Heat lamps. The heat lamps placed above each waterer were not turned on by the thermostat during the whole winter study. The heat produced by the hogs and the heat stored from solar radiation was sufficient to maintain the temperature in House C, the house where the thermostat was located, so that heat from the infrared heat lamps was not required to keep the water in the drinking fountains from freezing.

Frost and moisture accumulation. Frost and condensation on windows is very common in farm structures. This is particularly true of single-pane windows. However, moisture does not condense on double-pane windows nearly as soon as it does on single-pane windows. This was particularly noticeable in the winter study. There was frost formation on the single-pane windows whenever the outside temperature went below about 25° F. The frost usually was melted by noon of the following day. However, there was never any frost formation on the double-pane windows. A typical instance of when this happened is shown in Figures 31, 32 and 33. There was moisture on the double-pane windows but the inside surface temperature was not low enough to cause frost to form.

Moisture condensation and frost formation are very objectionable. The moisture will cause wood window frames to rot. It will also eliminate some of the radiation which would otherwise be transmitted through the glass. The condensed moisture on the windows cannot be eliminated by ventilation. The moisture within the houses cannot be entirely eliminated. These factors make it almost impossible to completely eliminate condensation on the windows. The moisture content of the air can be

Figure 31. A typical view on cold mornings showing how the single-pane windows frosted over while the double-pane windows did not.

reduced only by replacing the moisture laden air in the houses with relatively dry air from outdoors.

Double-pane windows have definite advantages with high moisture conditions such as prevail in hog houses. They are the most effective means of increasing the inside surface temperatures by increasing the resistance to heat flow through the glass itself. Leonhard and Grant (42) state that the prevention of frost and condensation by constructional means is more applicable where high relative humidities prevail. The benefit derived from even a few degrees increase of the inside surface temperature of the glass is very great considering the fact that condensation and frost appear on the coldest days of winter.

Ventilation and circulation are also a partial answer to this problem. When condensation and frost formation are the greatest the outside

Figure 32. The single-pane windows were covered with frost up to one-eight inch thick on nights when the temperature outdoors went below 25° F.

Figure 33. The double-pane windows never had any frost on them but moisture did condense on the inside surface.

temperature is low, therefore the moisture content of the outside air is also low. Drawing this air into the house will lower the inside relative humidity and help prevent condensation on the windows. However, if the incoming air is very cold and the inside relative humidity is high, the incoming air will immediately condense and there will be rain in the house. This condition will have a detrimental effect on the environment in the house by making the litter and floor very wet, causing the relative humidity to eventually increase. On several mornings during the winter study this happened but it only lasted for a short period of time as it was cold and clear outside. The morning sun soon heated the houses and corrected the situation. Air circulation over the inside surface of the glass reduces the inside surface resistance and the inside surface temperature is increased thus permitting a higher relative humidity without condensation on the windows. However, there is also an increase in the heat loss through the windows resulting from the increase in air motion.

The chief factors influencing the deposition of moisture and the formation of frost are the dew-point temperature of the inside air and the temperature of the inside surface of the glass (42). The dew-point temperature is determined solely by the moisture content of the air. It varies directly with the change in moisture content. If it were possible to keep the dew-point temperature of the inside surface of the glass above the dew-point temperatures of the inside air, frost or condensation would never form on the glass.

Quality of the air. Observations made during the winter study indicate that the quality of the air in House C was usually better than the quality of the air in either House B or House C. Ammonia fumes were not as strong in House C as they were in the others. In some instances no difference could be detected between House B and House C. However, the quality of the air in House D was usually inferior to the quality of the air in both House B and House C.

The fact that the quality of the air in House D was inferior to the others may be due to the decreased amount of radiation available to heat up the house and help vaporize the moisture in the litter so that it could be removed by ventilation. This would allow greater quantities of ammonia fumes to be formed. The differences in the quality of the air of the houses was also due in part to the different amounts of water consumed and excreted by the hogs. The hogs in both House B and House D consumed more water and therefore excreted more water which increased the formation of ammonia fumes. Also, differences in the amounts of straw in each house would have an effect on the moisture in the litter and may have caused some differences in the quality of the air in the houses.

Sun patterns. During the winter study a series of three sets of pictures were taken at intervals of four weeks to show how the sun pattern changed in the houses. All the pictures were taken at noon. One series was taken in House C and the other series in House D. These pictures are shown in Figure 34 through 39. The sun patterns in House C are on the left and the patterns in House D are on the right. It is evident that there was a much greater area exposed in Houses B and C than in House D for reradiating long wave infrared radiation to heat the houses.

Feeding trial. The results for the feeding trial for the winter study are compared in Table II. These are average values for the entire 16 week period. The data for each weigh period is shown in Figures 40 through 44.

Figures 34 and 35. The sun patterns in Houses C and D, respectively, on January 21, 1954.

Figures 36 and 37. The sun patterns in Houses C and D, respectively, on February 17, 1954.

Figures 38 and 39. The sun patterns in Houses C and D, respectively, on March 17. 1954.

TABLE II

SUMMARY OF THE RESULTS FOR THE HOG FEEDING TRIAL OF THE WINTER STUDY OF 1953-54

	Treatment			
	House A	House B	House C	House D
Number of pigs	8	8	8	8
Average initial weight in pounds	34.2	34.6	34.6	34.6
Average final weight in pounds	175.5	202.4	174.7	199.6
Average daily gain in pounds	1.26	1.50	1.25	1.48
Average daily feed consumption per pig in pounds	5.33	6.00	5.11	5.84
Pounds of feed consumed per pound of gain	4.23	4.01	4.09	3.97
Average daily water consumption in gallons	-	1.68	1.36	1.54
Gallons of water consumed per pound of gain	-	1.13	1.08	1.04
Gallons of water consumed per pound of feed	-	0.28	0.26	0.27

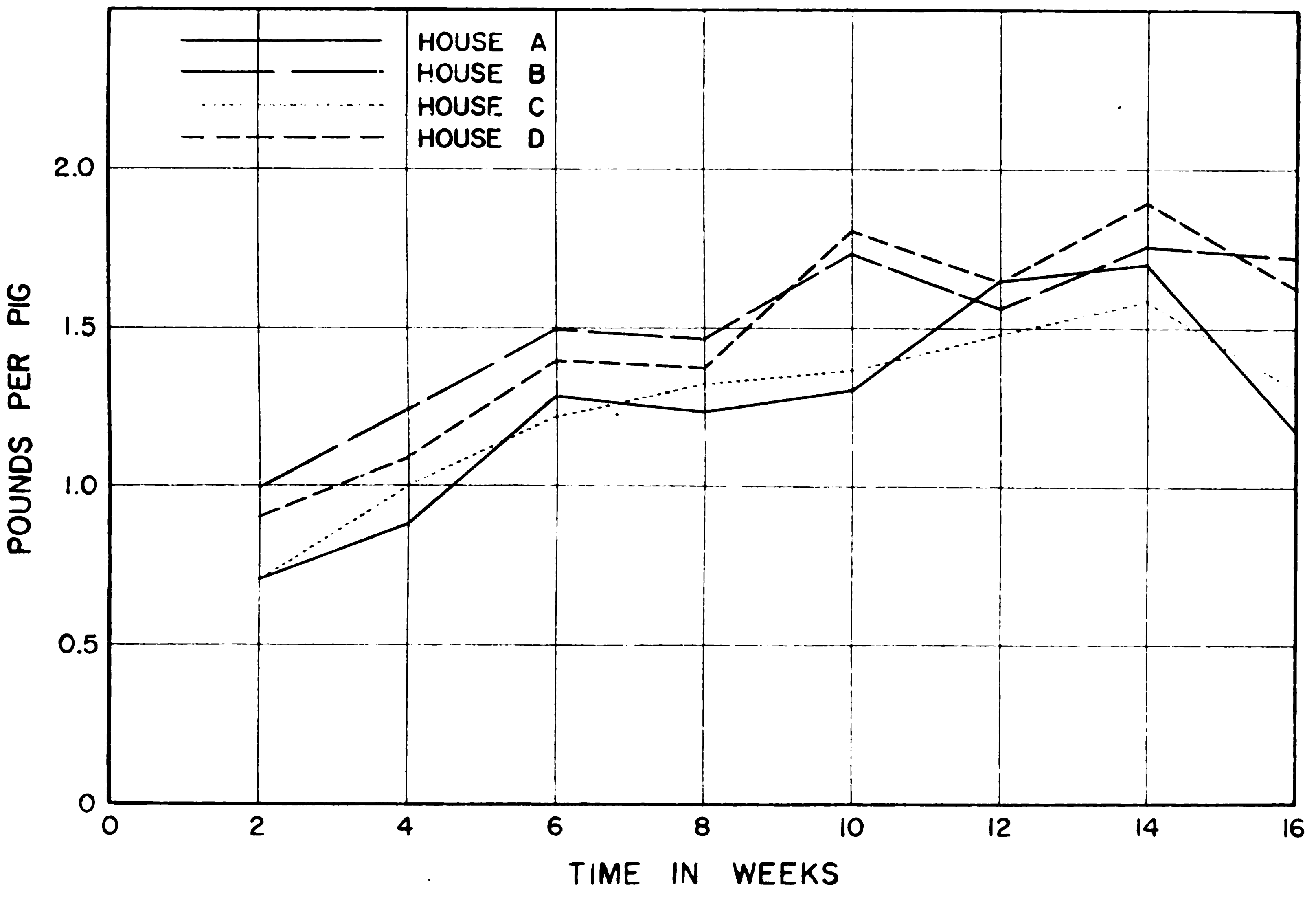


Figure 40. The average daily gain per hog for each two week period of the winter study.

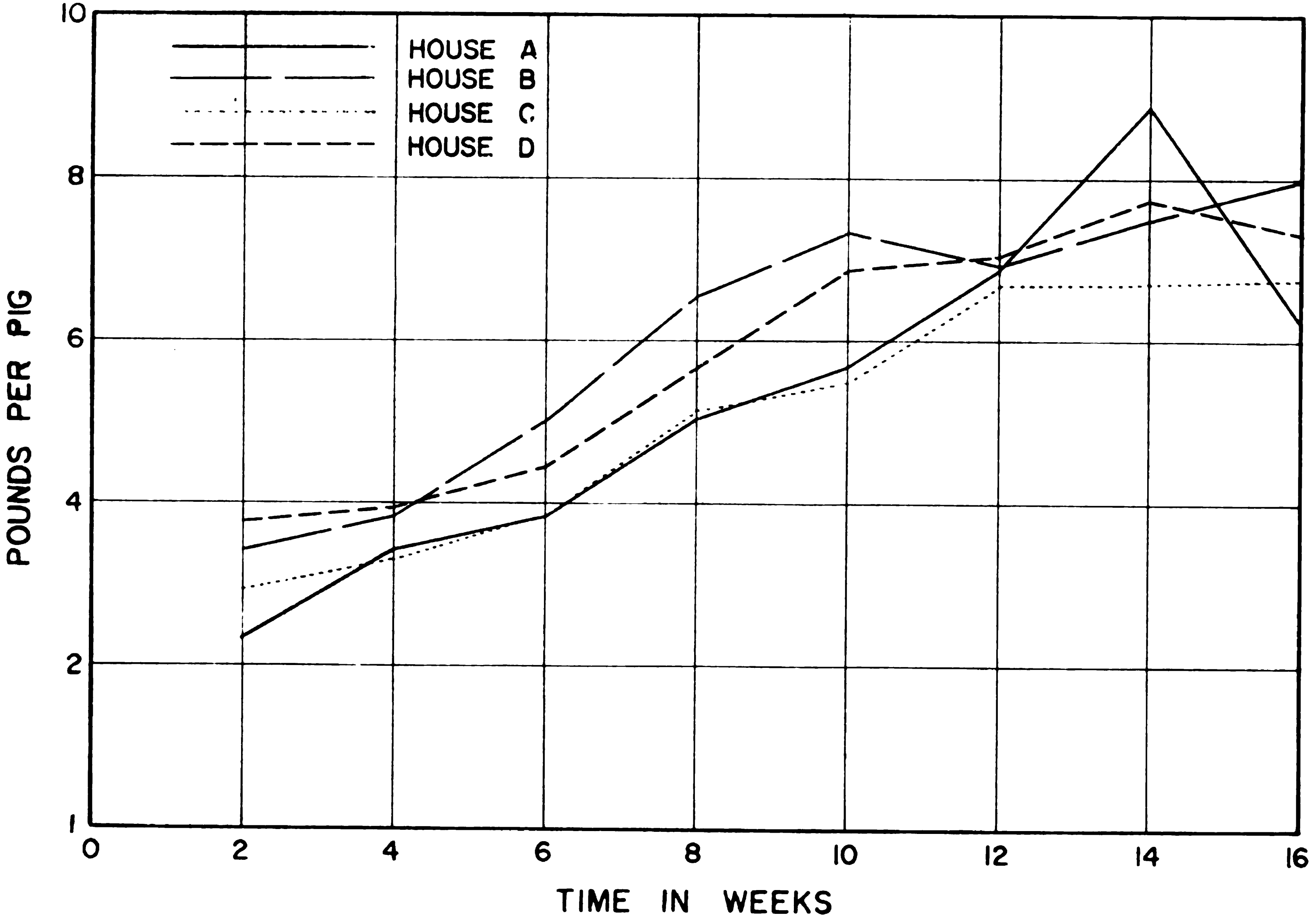


Figure 41 The average daily feed consumption per hog for each two week period of the winter study.

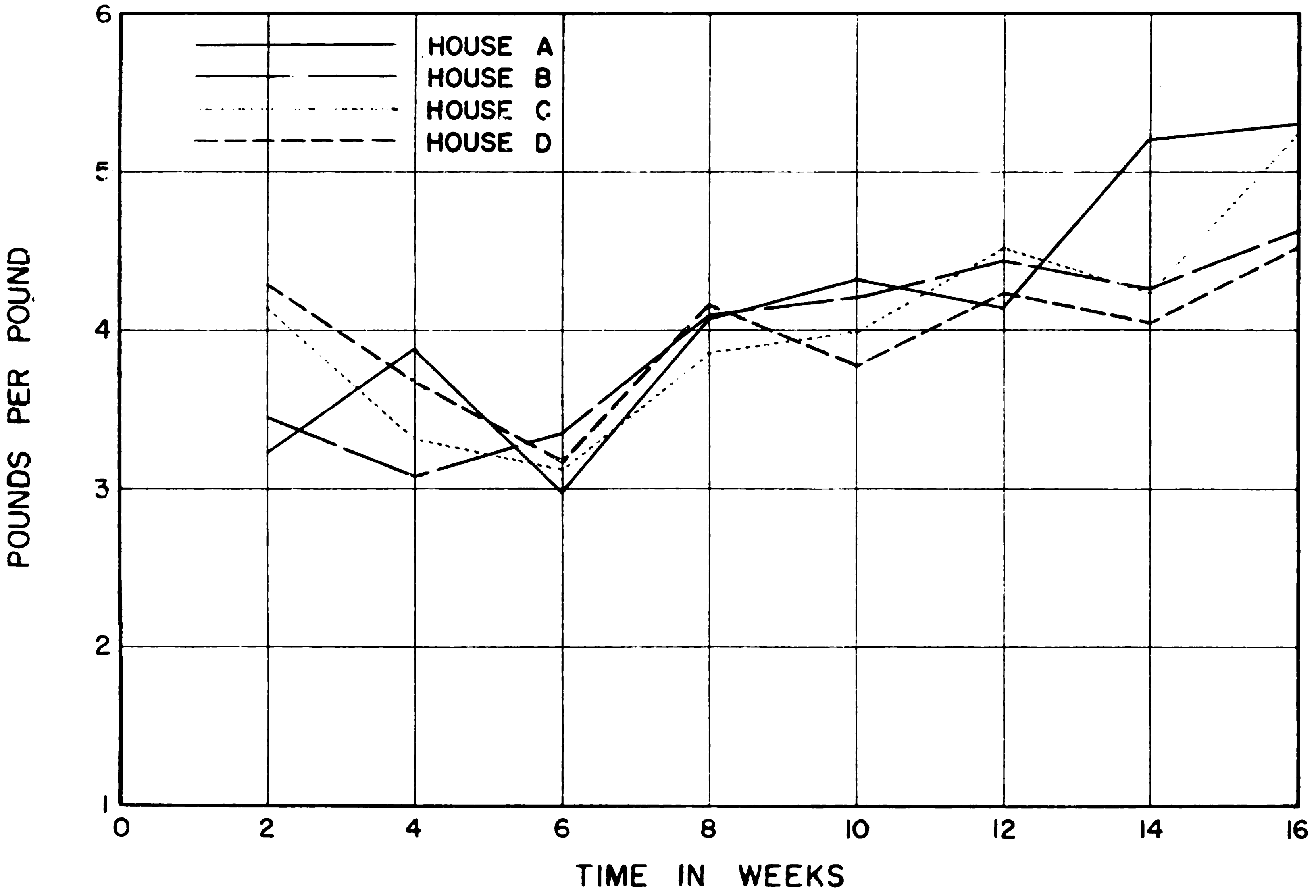


Figure 42. The amount of feed consumed per pound of gain for each two week period of the winter study.

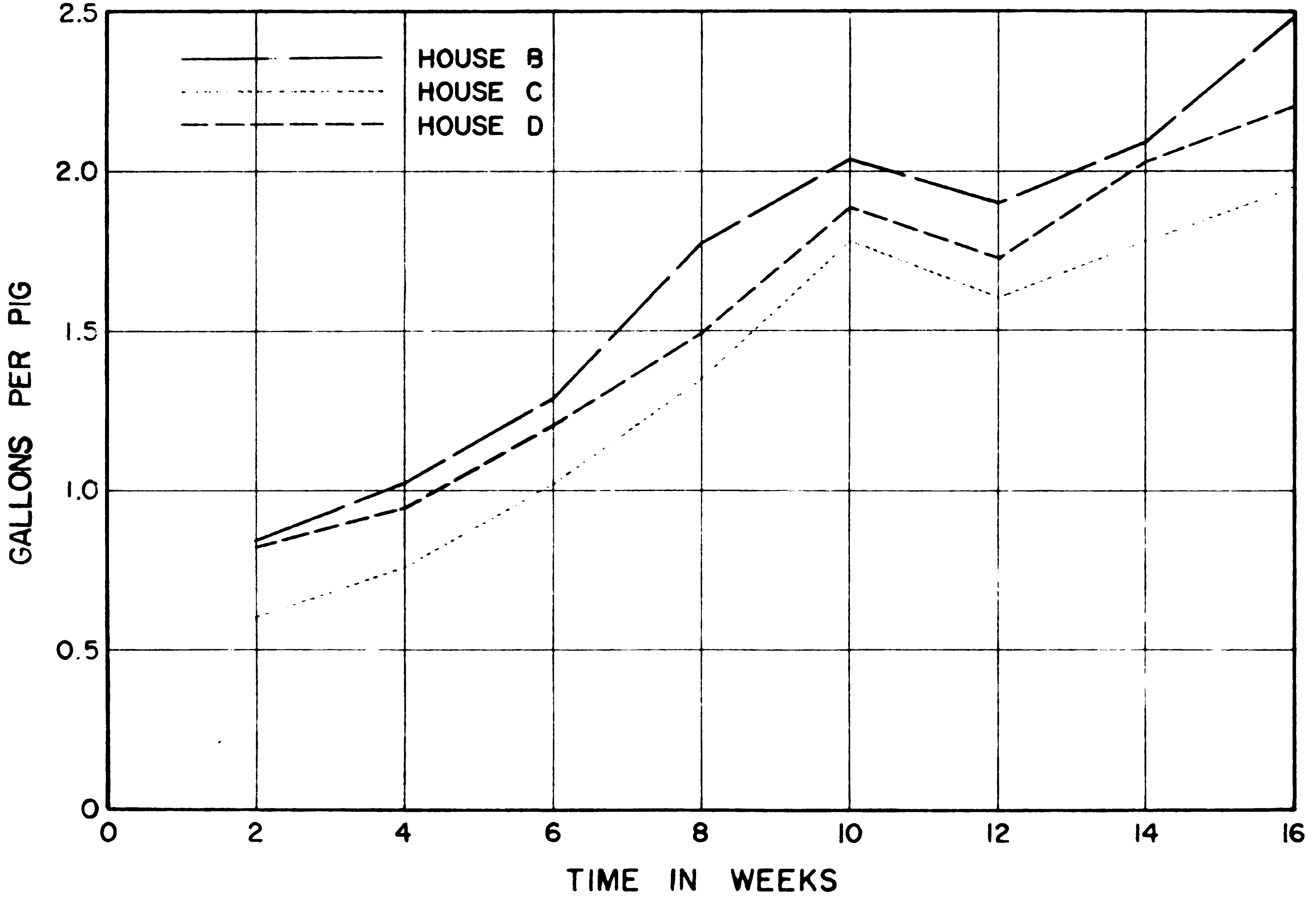


Figure 43. The average daily water consumption per hog for each two week period of the winter study.

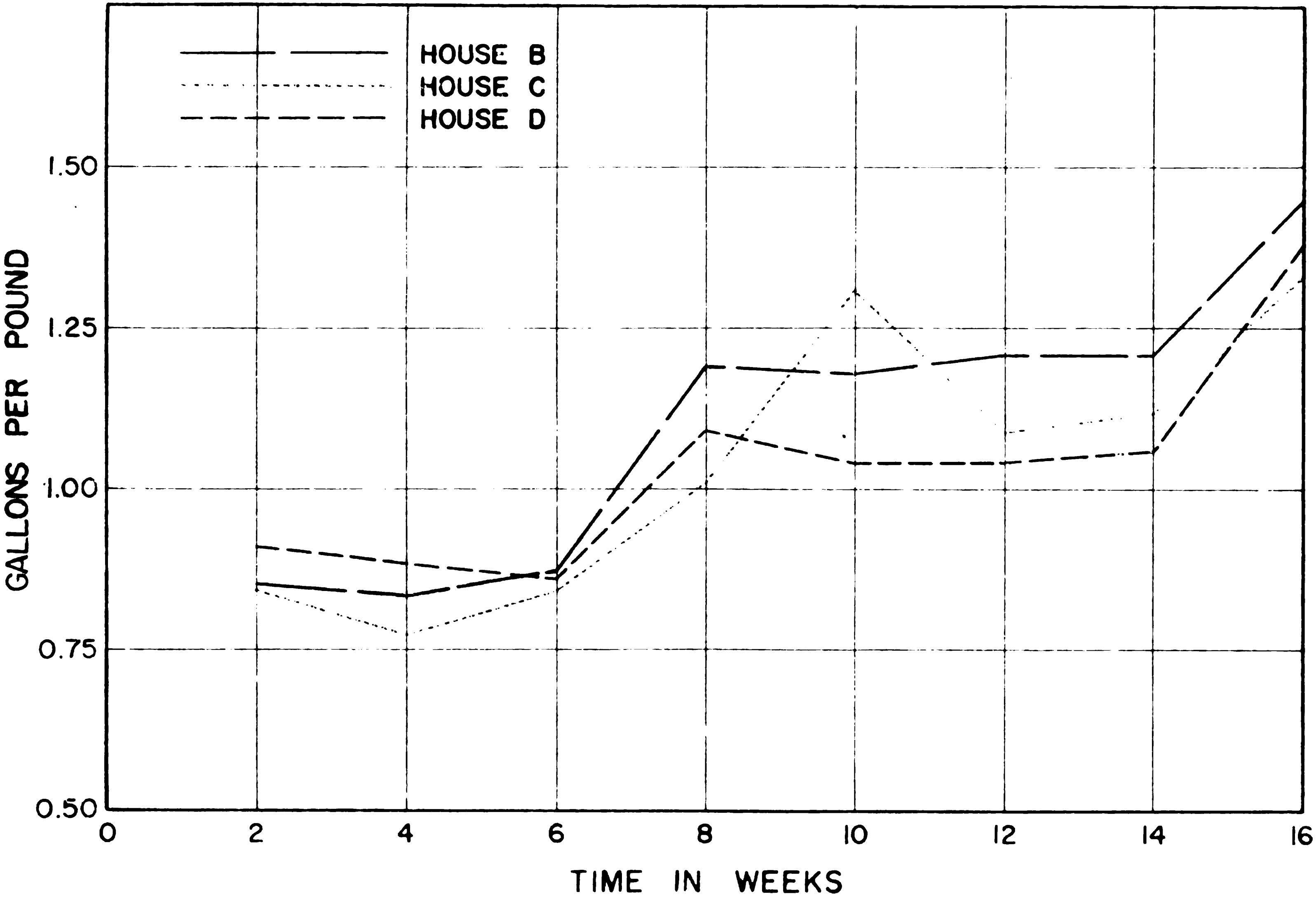


Figure 44 The average amount of water consumed per pound of gain for each two week period of the winter study.

The hogs in Houses B and D made faster gains than those in either of the other two types of housing for the entire study period except during the eleventh and the twelfth weeks when the hogs in House A made about the same gains as those in Houses B and D, as shown in Figure 40. Table II shows that the hogs in House B made the highest daily gain of 1.50 pounds while the hogs in House C had the lowest average daily gain of 1.25 pounds. The final average weight figures in Table II show that for the entire period the hogs in House C gained no more than those in House A. The increase in the average daily gain per pig as the study progressed was due to the increase in the size of the animals and the higher temperatures which prevailed in all the houses. No direct relationship was found between the variations in gains and the temperatures in the houses. The difference between the hogs housed in the houses with double-pane windows and the others amounted to about 25 pounds or about two weeks growth. In other words, the hogs in Houses B and D reached market weight two weeks earlier than the hogs in Houses A and C.

The final weights were analyzed statistically by an analysis of covariance. There was a significant difference between the means of the weights of the hogs in House B and House D and the hogs in House A and House C. The difference was significant at the five percent level. The least common difference found to be significant was 21.03 pounds. There was no significant difference between the hogs in House B and those in House D. Likewise, there was no significant difference between the hogs in House A and those in House C. No definite pattern was found for the efficiency of gain.

The hogs in Houses B and D consumed more feed per pig than did the hogs in both of the other two types of housing except during the thirteenth and fourteenth weeks when the average daily feed consumption per pig for the hogs in House A was higher, Figure 41.

The feed consumption per pound of gain as shown in Figure 42 did not follow any certain trend. The differences during the first two weeks of the study were due primarily to excessive wastage of the feed. After this was corrected there was little variation between the hogs with different types of housing except during the last four weeks of the study when the hogs in House A showed a large increase in the amount of feed consumed per pound of gain. This was also due to excessive feed wastage, hence this part of the feed data is not reliable. The high amount of feed consumed per pound of gain by the hogs in House A was also due to the increase in the amount of feed necessary to maintain body temperature under the colder conditions that existed in this house.

The hogs that made the greatest gains consumed the greatest quantities of water per day as shown in Figure 43 and Table II. This was also partly true for the average amount of water consumed per pound of gain especially for the hogs in House B as shown in Figure 44. The average amount of water consumed per pound of gain by the hogs in House D was less than that consumed by the hogs in House C, Table II. The average amount of water consumed per pound of feed was practically the same for the hogs in Houses B, C, and D. This indicates a direct relationship between the amount of feed consumed and the amount of water consumed. No water consumption records could be made for the hogs in House A.

The conventional house. The hogs in House A were hardly ever as active as the hogs housed in the experimental houses. Many times they were observed all huddled together, as in Figure 45, in order to keep warm. In contrast, the hogs in the other houses were very active and were obviously much more comfortable.

Chewing the gates. During the winter study a very marked difference was noticed in the tendency of the hogs in Houses B, C, and D to chew at the gates which divided the houses into two pens. The hogs in House C showed a much greater tendency to chew the gates than did the hogs in either of the other two houses. This is clearly shown in Figures 46 and 47. The hogs in House C nearly chewed through parts of the gates whereas the gates in the other two houses were virtually untouched.

Figure 45. A typical sight in House A during the winter study showing how the hogs all huddled together to keep warm.

Figure 46. The gate in House C was all chewed up.

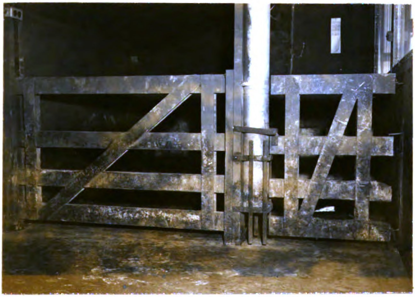


Figure 47. The gates in both Houses B and D were only chewed a small amount.

Conclusions. The results from the winter study indicate a definite advantage in housing swine in solar orientated houses with large areas of double-pane windows. It was clearly evident that the hogs in both houses with double-pane windows made better gains than those in either of the other two types of housing. The hogs in House C did not gain any more than those in House A.

The environmental temperatures in House B and D were less variable than those in House C. This was especially true of House D. Furthermore, the minimum temperatures in House C were usually lower than minimum temperatures in either House B or House D. The differences in the gains of the hogs in the experimental houses can be attributed to these facts.

The hogs in House A were definitely at a disadvantage. The temperatures outdoors and in this house were considerably lower than those in the experimental houses. Therefore, it was necessary for the hogs to utilize more feed to maintain body temperature and consequently they were unable to make gains in weight as fast as those in the other houses. As the outside temperatures became warmer the hogs made better gains but the gains were still less than the gains of the hogs in Houses B and D.

Part III - Analysis of the periods without any animals in the houses.

Winter. Prior to the start of the winter study a two week study was made using the three experimental hog houses without any animals. During this period the houses were tightly closed and neither mechanical ventilation nor sun shades were used. Wet-bulb temperatures were not taken due to the possibility of freezing and because the relative humidity was not considered to be important in such a study.

Several very noticeable trends were observed during the two week period. On the days when there was an appreciable amount of solar radiation the temperature in House C was four to seven degrees above the temperature in House B. On these same days the temperature in House D lagged behind the temperature in House B by as much as 12 degrees. The temperatures in Houses B and C rose as much as 30 to 35 degrees above the temperatures outdoors. These trends were somewhat reversed when the temperatures began to fall in the afternoon. The temperature in House C was as much as five degrees below the temperature in House B. The temperatures in all the houses gradually dropped until they were the same as the outside temperature. It took from six to ten hours for the temperatures in the houses to return to the outside temperature.

The differences in the temperature inside the houses depends mainly upon the outside temperature and the quantity of solar radiation. The smaller the difference between inside and outside temperatures the greater the difference in the rate of heating and the smaller the difference in the rate of cooling and vice versa.

The effect of nocturnal radiation was noticeable on clear nights. On these nights the radiation exchange with the atmosphere made the inside temperature of both House B and House C drop below the outside temperature as much as three degrees. No detectable effect was noticed in House D.

During four days of the study without animals in the houses, a trial run was made in House D with the heat lamps that were placed above each waterer. The inside temperature remained from ten to fifteen degrees above the outside temperature during the daytime as well as at night.

Spring. A second study without any animals in the houses was also made prior to the summer study of 1954. During this three week period the houses were completely closed, no mechanical ventilation was used and the windows were shaded. Wet-bulb temperatures were not recorded during this period.

A few noticeable trends were also observed during this period. The temperature fluctuation which occured in the winter when no animals were in the houses and the windows were not shaded was eliminated. When the outside temperature dropped the temperature lagged behind about the same in all three houses. The temperature difference was about eight degrees. When the outside temperature increased it was as much as eight degrees above the inside temperature of House C, the temperature in House B was usually one to two degrees lower than the temperatures in House C and the temperature in House D was usually one to two degrees lower than the temperature in House B.

A thermocouple was placed about an inch above the floor in House B to determine the difference, if any, in the temperatures at different heights above the floor. It was found that the temperature next to the floor was as much as five degrees below the temperature at a height of five feet above the floor.

Conclusions. The differences between the amount and type of glass used in the houses as it affected the temperature in the houses was very noticeable. Both the differences in the insulating values and the differences in the transmission of radiant energy were also very noticeable. The single-pane windows transmitted more radiant energy than did the double-pane windows and they also caused greater heat losses. The smaller area of double-pane windows excluded a large amount of solar radiation which occured in the other houses.

CONCLUSIONS

Since the data reported in this thesis is based on only one years results, the following conclusions must be considered tentative and subject to revision when additional data has been collected.

1. Double-pane windows used in solar orientated houses for winter housing of hogs, provided a more favorable temperature environment which was more conducive to higher rates of gain in weight.

2. Double-pane windows utilize solar radiation more efficiently than do single-pane windows for use in heating hogs houses by conserving more of the long wave radiation that is trapped in the houses and converted to heat energy.

3. Single-pane windows cause wider fluctuations in temperature in the hog house than do double-pane windows because they transmit more solar radiation during the day and cause greater heat losses at night.

4. Ventilating fans in solar hog houses should have enough capacity to keep the temperature below the maximum desirable. This will permit the use of a maximum amount of solar energy.

5. The area of double-pane windows on the south wall of a solar hogs house should be a maximum for any particular design in order to take advantage of as much solar radiation as possible.

SUGGESTIONS FOR FUTURE STUDY

1. The recording of temperature and relative humidity data in the three experimental hog houses should be continued for at least three years since one year's data does not represent a sufficient sample of climatic variability. A longer period of record is needed before recommendations for the use of double-pane windows in a solar hog house can be developed.

2. A study should be made using large areas of triple-pane windows in hog houses. Miller and Black (44) state that a triple-pane window with the glass spaced one-half inch apart is equivalent to a 12 inch brick wall in insulating value. A window such as this would conserve a greater percentage of the heat trapped in a hog house from solar radiation than conventional windows.

3. Heat-absorbing glass used as the outside pane of a double-pane window with ordinary window glass for the inside pane reduces the summer cooling load considerably. Shaver (52) states that a heat-absorbing glass will transmit only 42 percent of the incident solar radiation as compared with 88 percent for ordinary window glass. The amount of visible light transmitted and the amount of solar radiation reflected is approximately the same for both types of glass. Heat-absorbing double-pane windows of this type would reduce the summer cooling load in a hog house considerably, especially if some type of mechanical cooling is used, while the amount of visible light would be the same. An investigation should be made using this type of window in the experimental houses during the summer.

4. Ultraviolet rays are not transmitted through glass. However, beneficial effects have been observed on some animals from ultraviolet rays. The use of ultraviolet light from a low pressure mercury vapor lamp should be investigated to see if there are beneficial effects on hogs.

5. The orientation of solar houses has been in every case, south-facing. A study of heat gains through walls and roofs as affected by solar radiation (26) has shown that the heat inflow through the east, south, and north walls was 83, 75, and 46 percent, respectively, of that for the west wall. That is, the heat gain due to absorption of solar radiation by the outside surface of the structure was greatest in the west orientation. This should also be true of the transmission of solar radiation through glass. Therefore, a west or southwest orientation for solar hog houses should utilize more solar radiation for heating the houses. A study should be made to see if this is true.

6. The windows of the experimental hog houses were all set in a vertical position. This made it impossible for the sun's rays to be normal to the glass surface. The greater the angle of incidence the smaller the amount of solar radiation transmitted through the glass. A study should be made with the windows at an angle which will decrease the angle of incidence of sun's rays. The windows could either be adjustable or set at an angle which would allow the maximum transmission of solar radiation for the period under study.

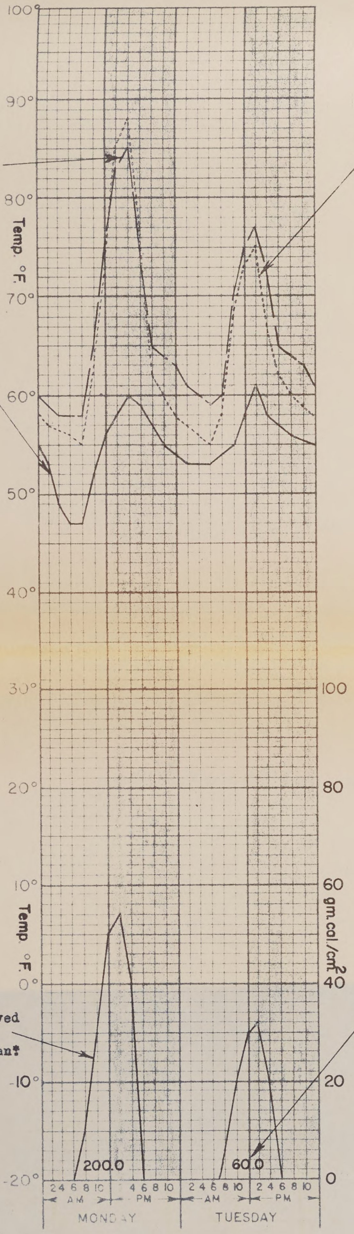
CHANGES MADE BEFORE THE SUMMER STUDY OF 1954

At the end of the winter study it was found necessary to make several changes in the houses. A new floor was required because the three-eighths inch plywood would not last for another study. Vertical grain tongue and groove fir flooring was laid in all three experimental houses. A tar paper vapor barrier was placed underneath the flooring. The floor was covered with a non-skid floor mastic which was put on with a trowel. A ten inch propeller fan with an air flow rate of about 300 cubic feet per minute was also installed in each house. The air intakes in the rear wall of the houses were enlarged and two more were added. The air intakes above the doors were reopened. This gave a total area of 100 square inches for the air intakes in each house. The section of the feeder that was inside of the houses was made one and one-half inches deeper in order to help eliminate some of the feed wastage. House D, the house with half-size double-pane windows, was changed so that there was no light coming into the house except through the air intakes and exhaust. This was done by placing a panel of insulating sheathing next to the inside surface of each window. A sheet of aluminum covered roofing was placed between the glass and the sheathing with the aluminum next to the glass to reflect the radiation incident upon it.

APPENDIX A

The Temperature, Relative Humidity, and Solar Radiation Data for the Summer Study

Explanation of the temperature and solar radiation data for the summer study.



Temperature in House B, the house with full size double-pane windows.

Temperature in House C, the house with single-pane windows.

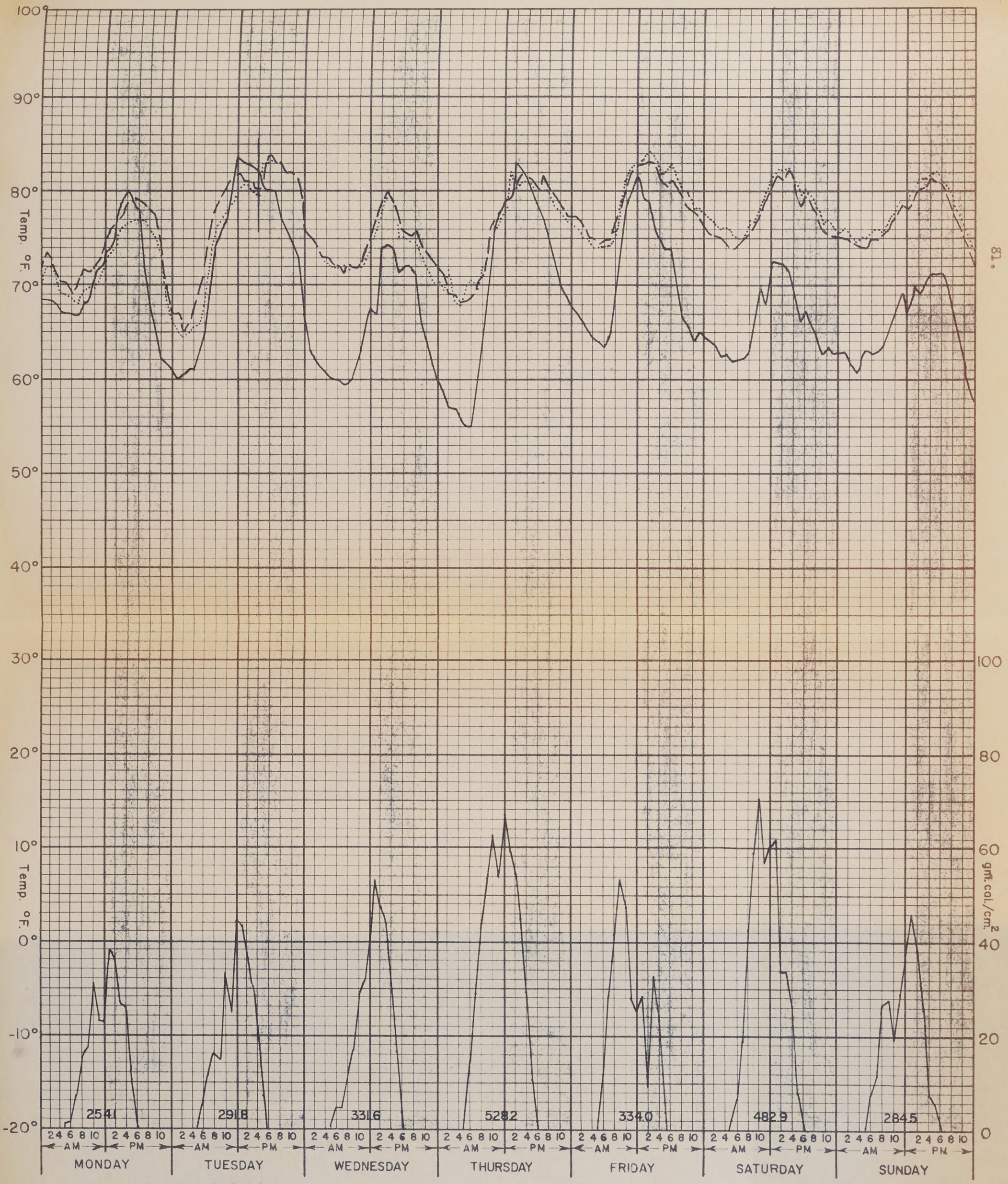
Temperature outdoors or the temperature in House A on the concrete slab.

Hourly totals of direct and sky radiation received on a horizontal surface at East Lansing, Michigan*

Daily total of direct and sky radiation received on a horizontal surface at East Lansing, Michigan*

TEMPERATURES AND SOLAR RADIATION

*Received from the Michigan Hydrologic Research Station, Michigan Agricultural Experiment Station in cooperation with the Bureau of Plant Industry, Soils, and Agricultural Engineering of the United States Department of Agriculture.



WEEK OF AUG. (3-9)

TEMPERATURES AND SOLAR RADIATION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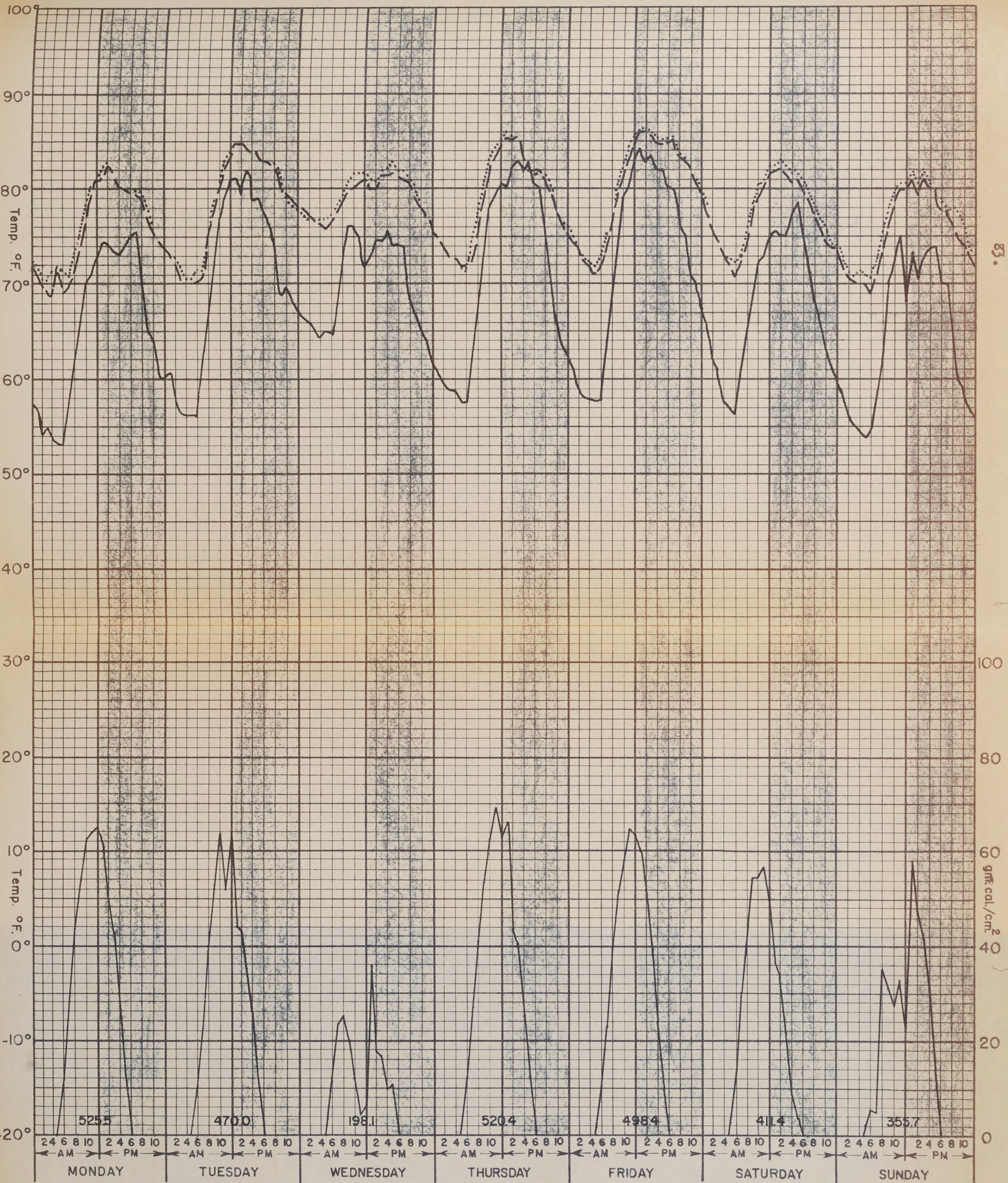
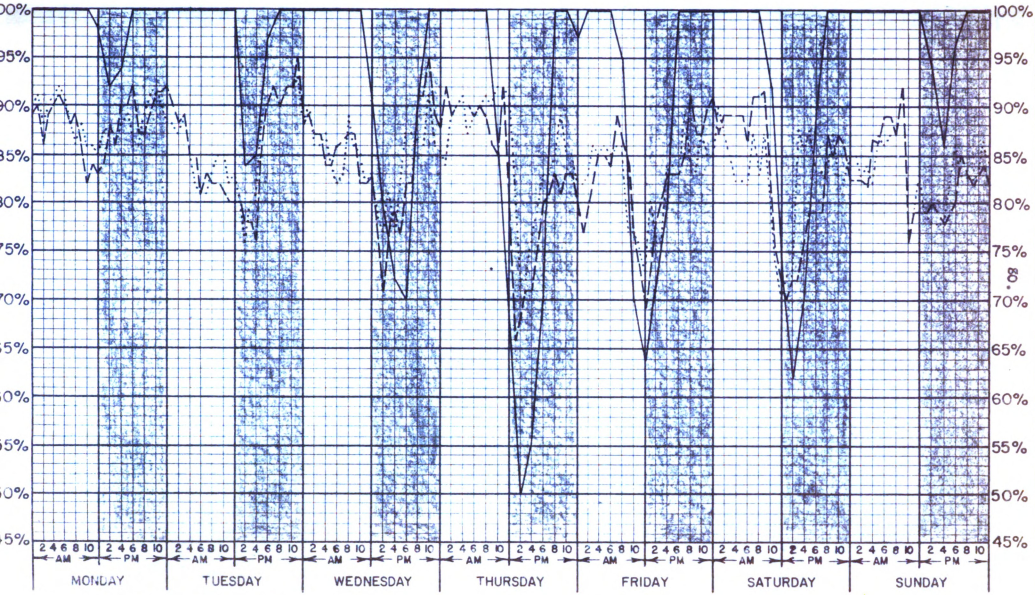


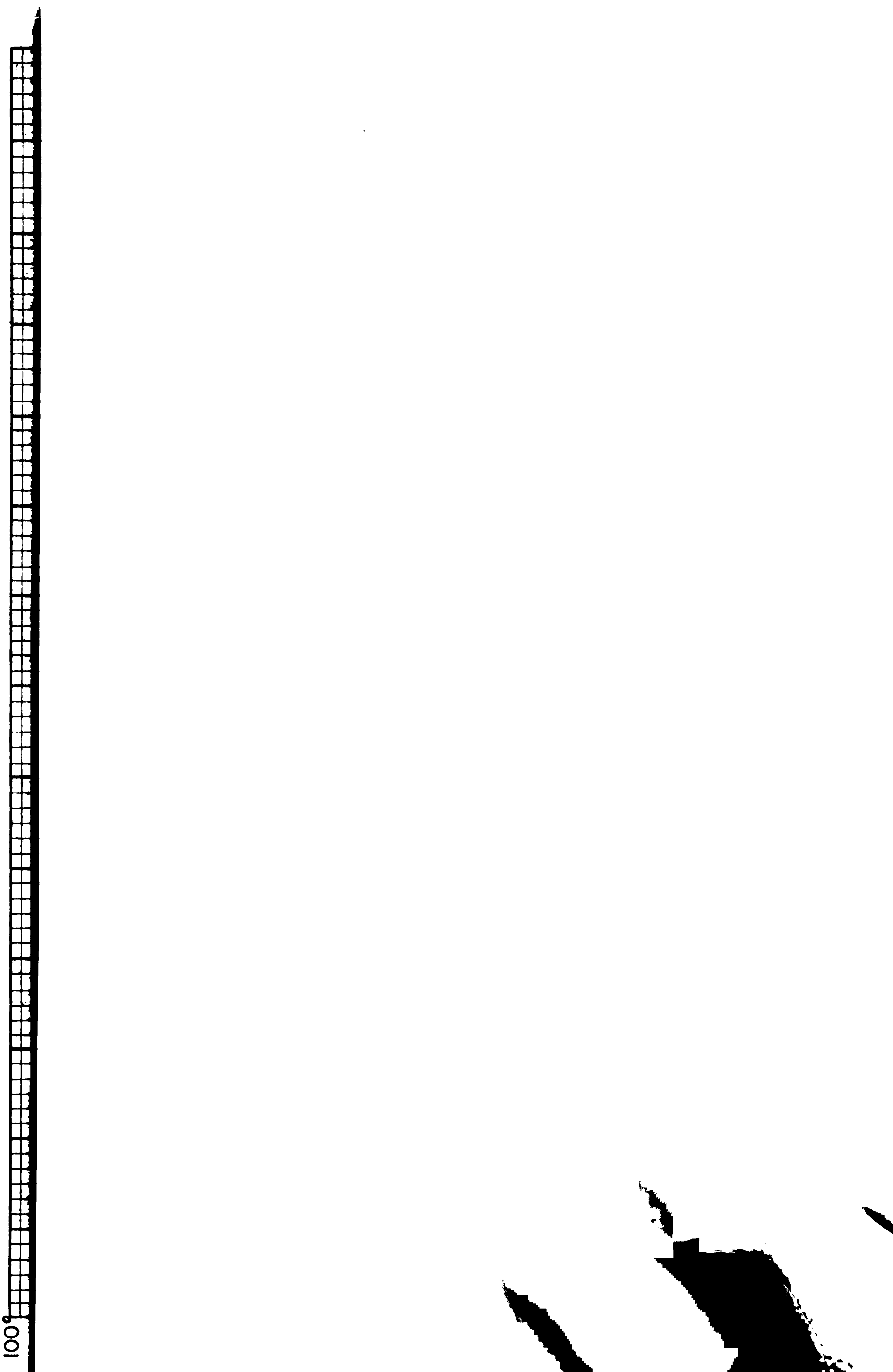
WEEK OF AUG. (10-16)

TEMPERATURES AND SOLAR RADIATION



WEEK OF AUG. (3-9)

RELATIVE HUMIDITY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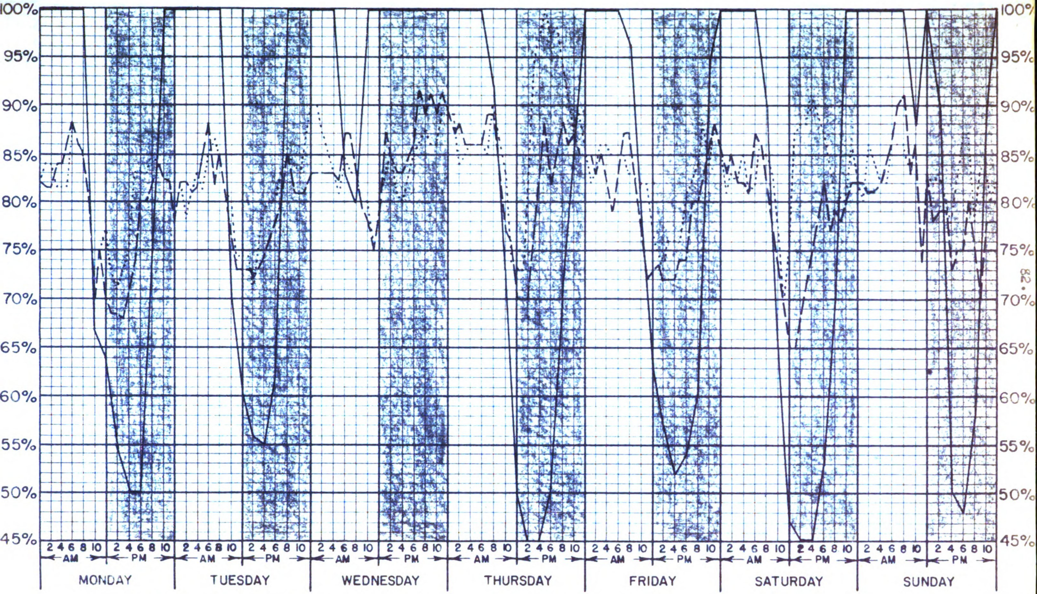
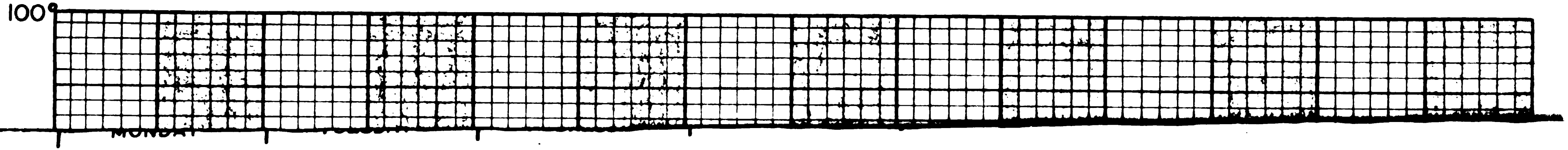
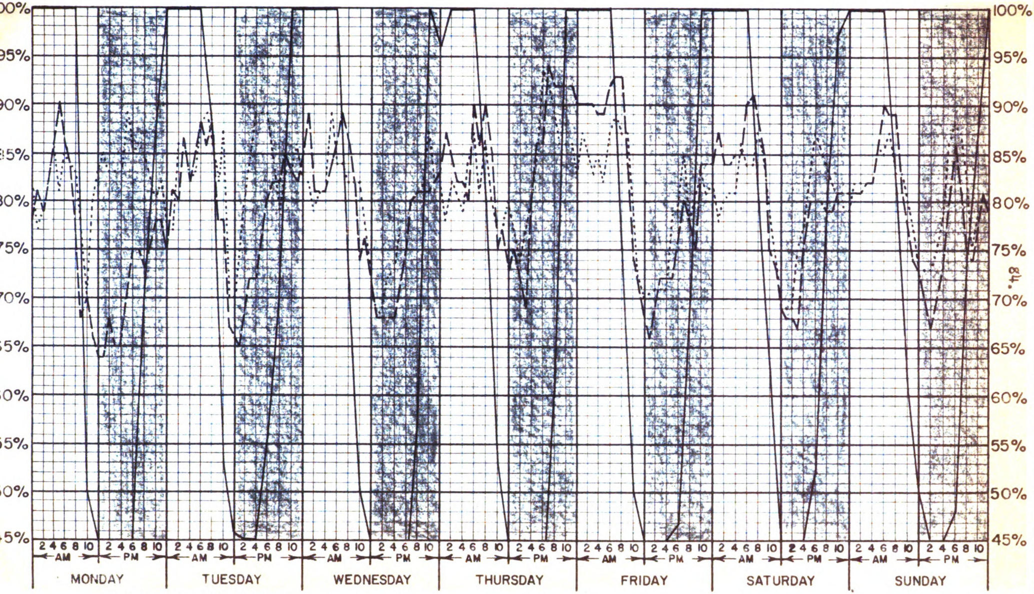


WEEK OF AUG. (10-16)

RELATIVE HUMIDITY

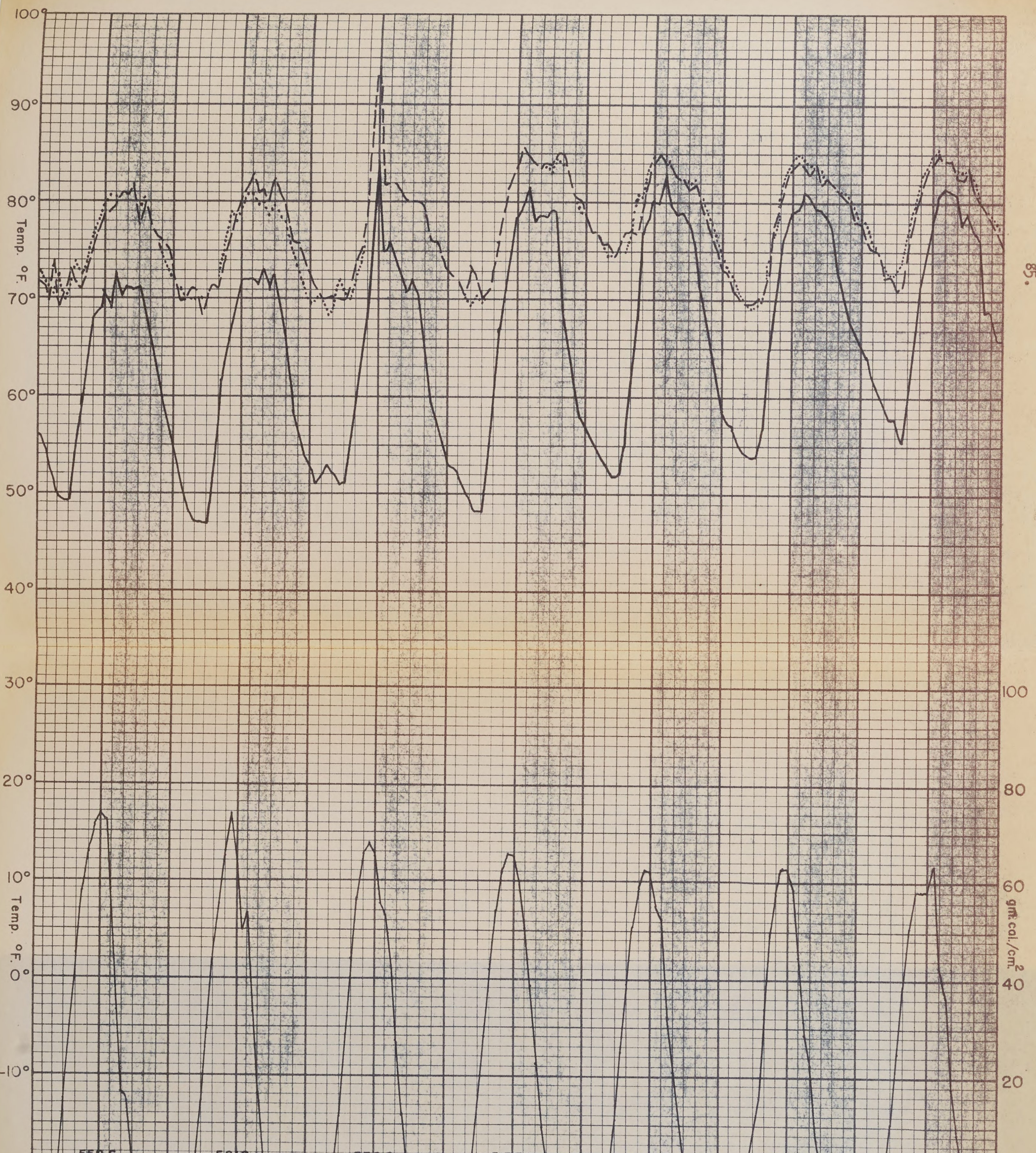


WEEK OF AUG. (10-16) TEMPERATURES AND SOLAR RADIATION



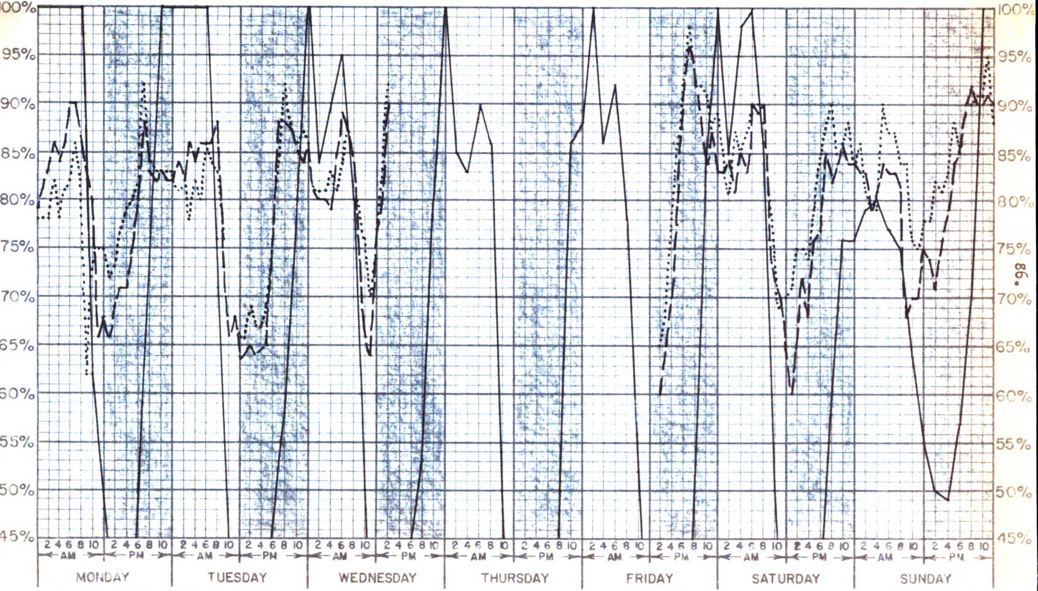
WEEK OF AUG. (17-23)

RELATIVE HUMIDITY



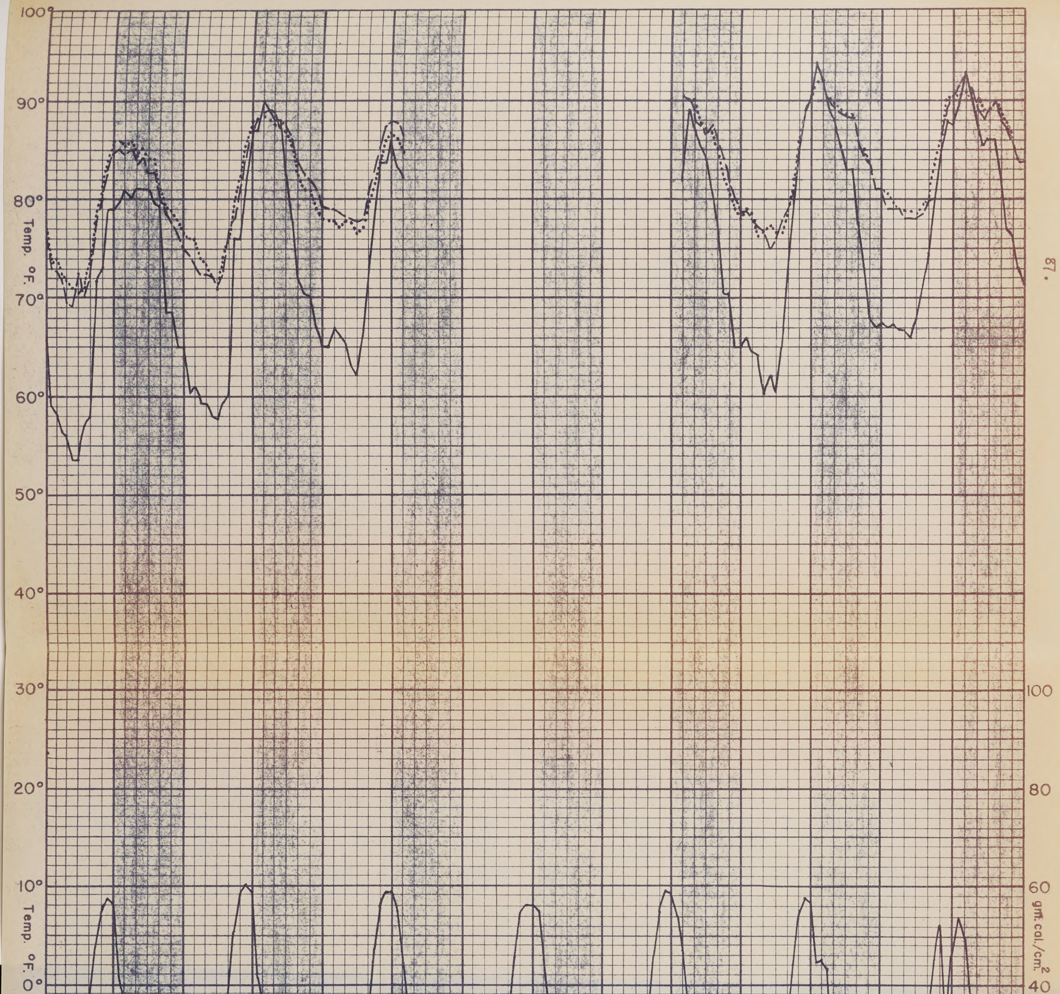
WEEK OF AUG. (17-23)

TEMPERATURES AND SOLAR RADIATION



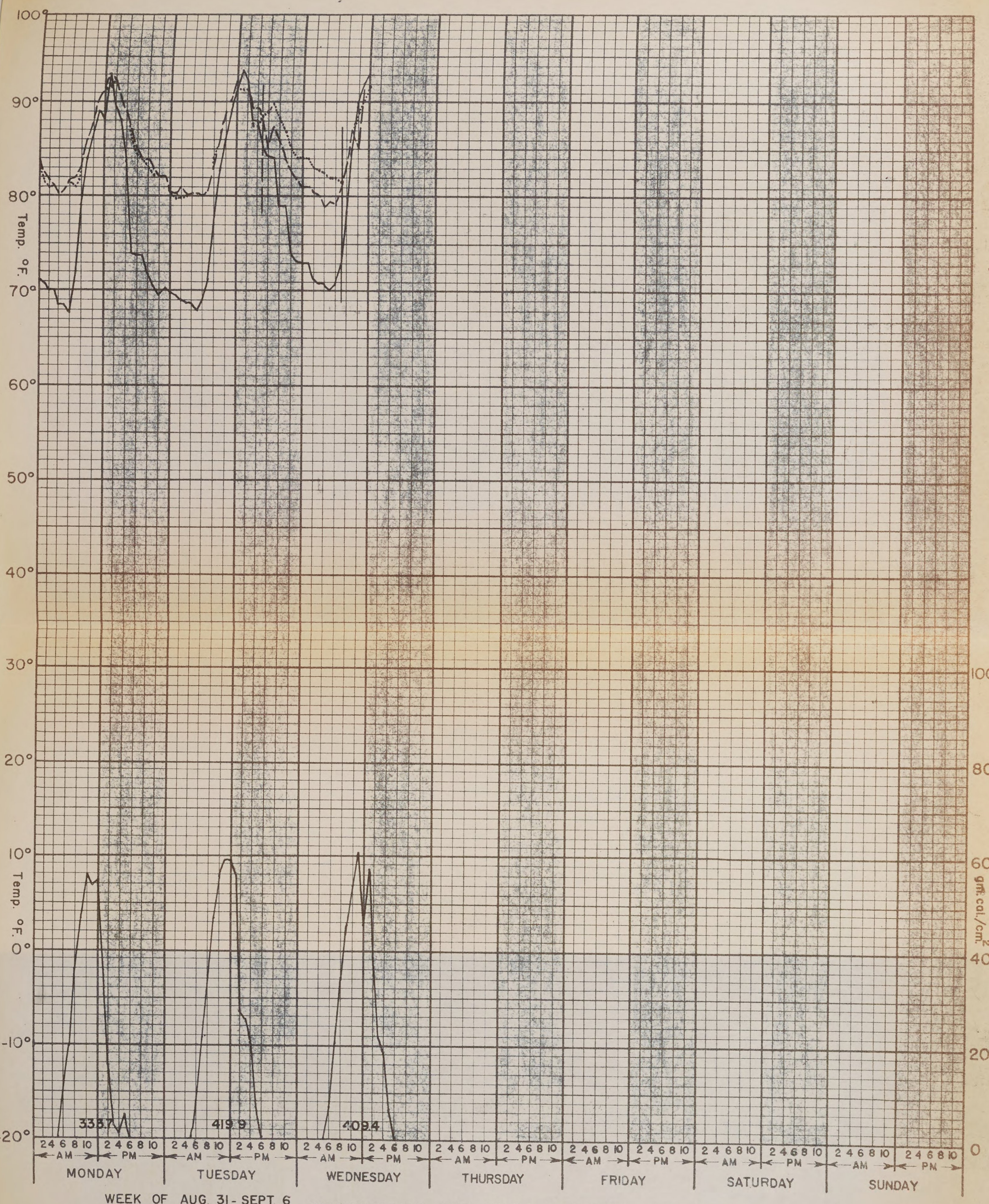
WEEK OF AUG. (24-30)

RELATIVE HUMIDITY



WEEK OF AUG. (24-30)

TEMPERATURES AND SOLAR RADIATION

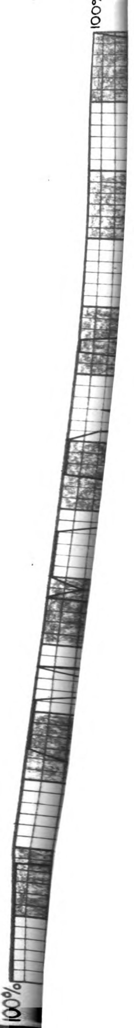


WEEK OF AUG. 31 - SEPT. 6

TEMPERATURES AND SOLAR RADIATION

[illegible] Relative humidity

Relative humidity in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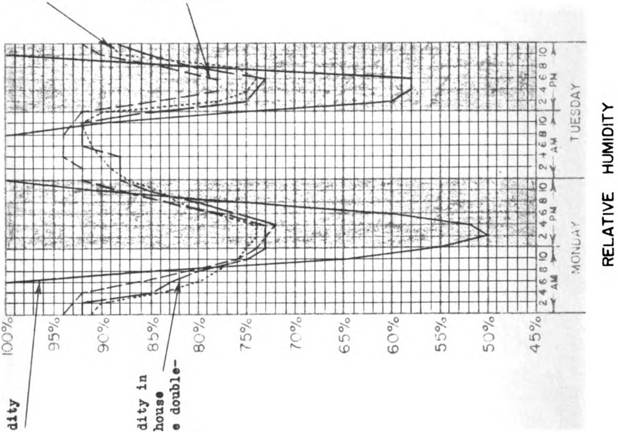
APPENDIX B

The Temperature, Relative Humidity, Solar Radiation, and Ventilation Data for the Winter Study

Explanation of the relative humidity data for the winter study.

Relative humidity in House C, the House with single-pane windows.

Relative humidity in House D, the house with double-pane windows half as high as the windows in the other experimental houses.



Relative humidity outside.*

Relative humidity in House B, the house with full size double-pane windows.

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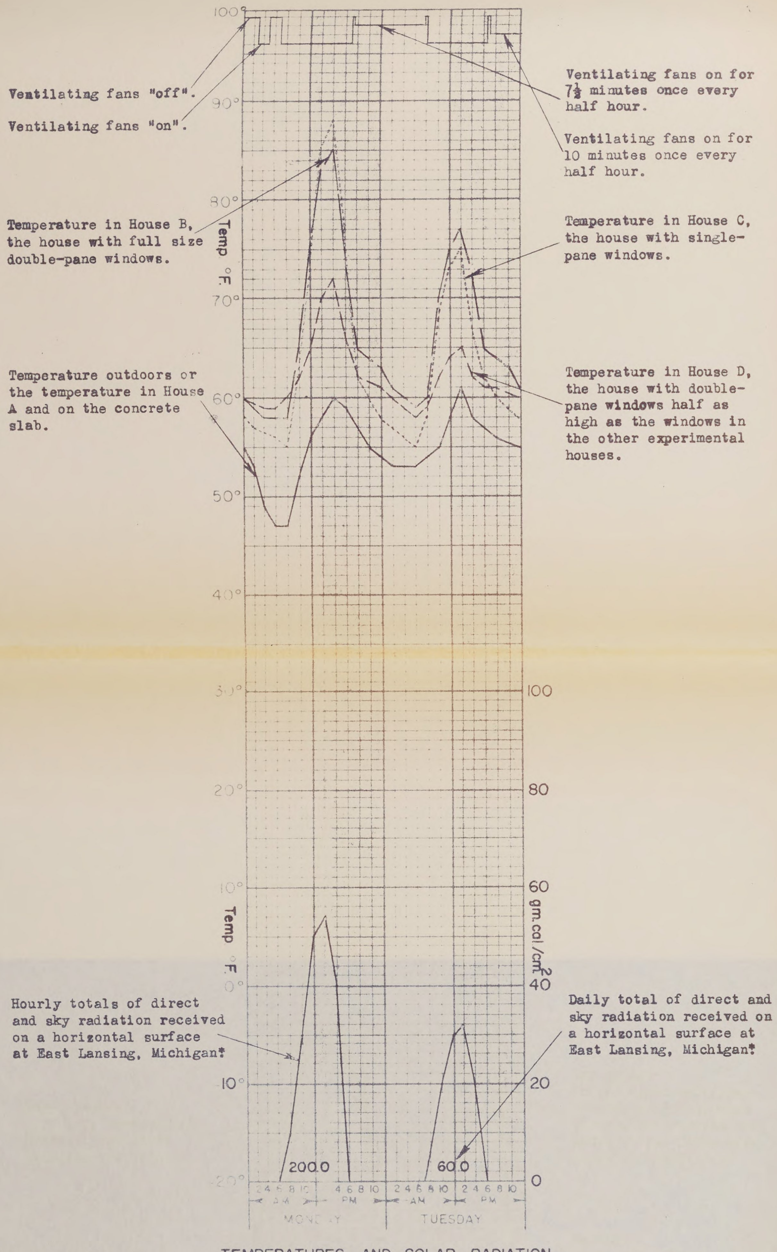
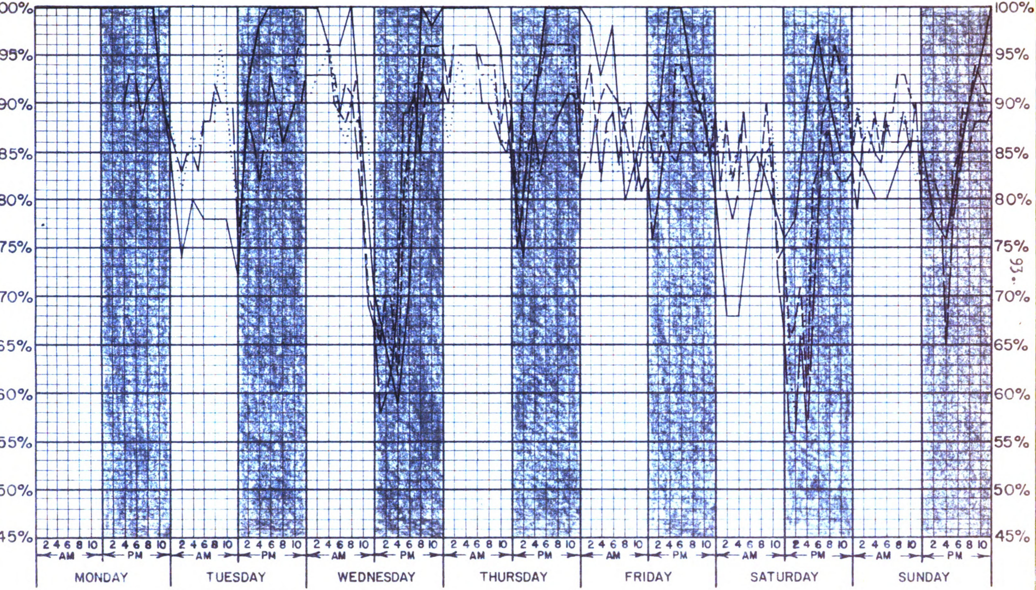
*Received from the Michigan Hydrologic Research Station, Michigan Agricultural Experiment Station in cooperation with the Bureau of Plant Industry, Soils, and Agricultural Engineering of the United States Department of Agriculture.

Explanation of the temperature, solar radiation and ventilation data for the winter study.



TEMPERATURES AND SOLAR RADIATION

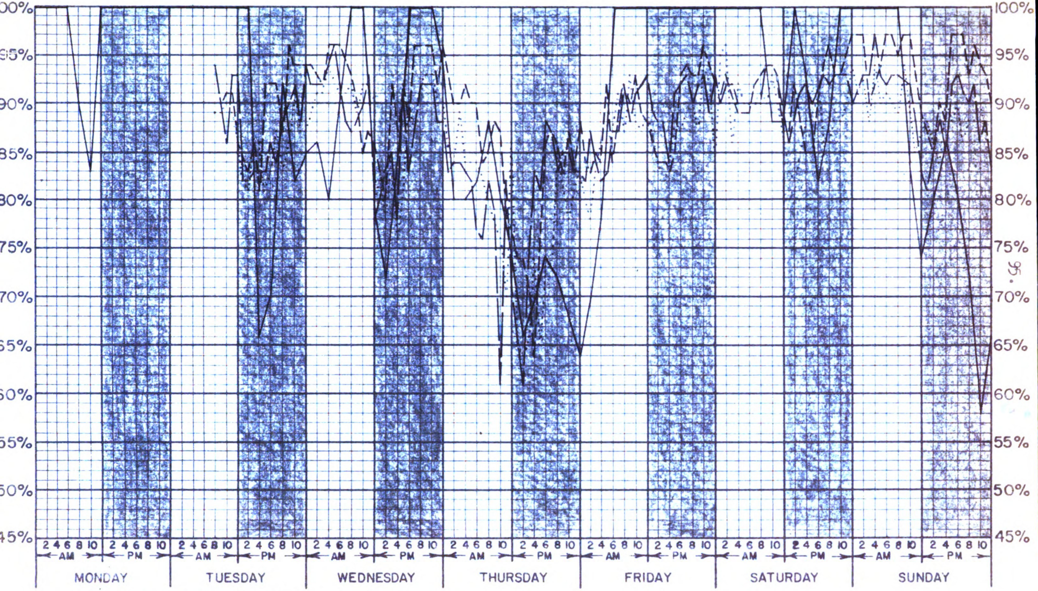
*Received from the Michigan Hydrologic Research Station, Michigan Agricultural Experiment Station in cooperation with the Bureau of Plant Industry, Soils, and Agricultural Engineering of the United States Department of Agriculture.



WEEK OF DEC. (14-20)

RELATIVE HUMIDITY

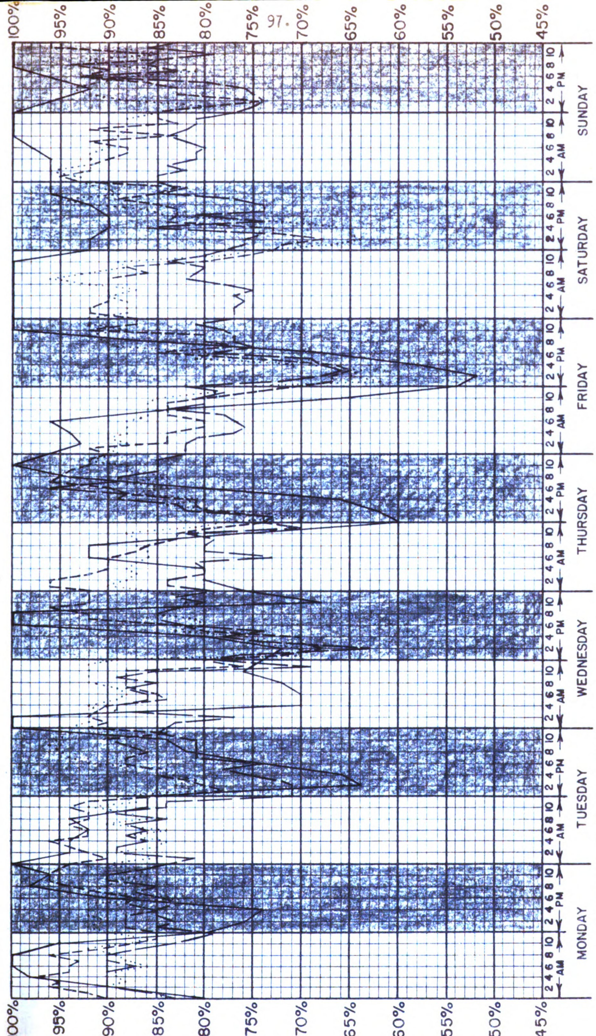
100



WEEK OF DEC. (21-27)

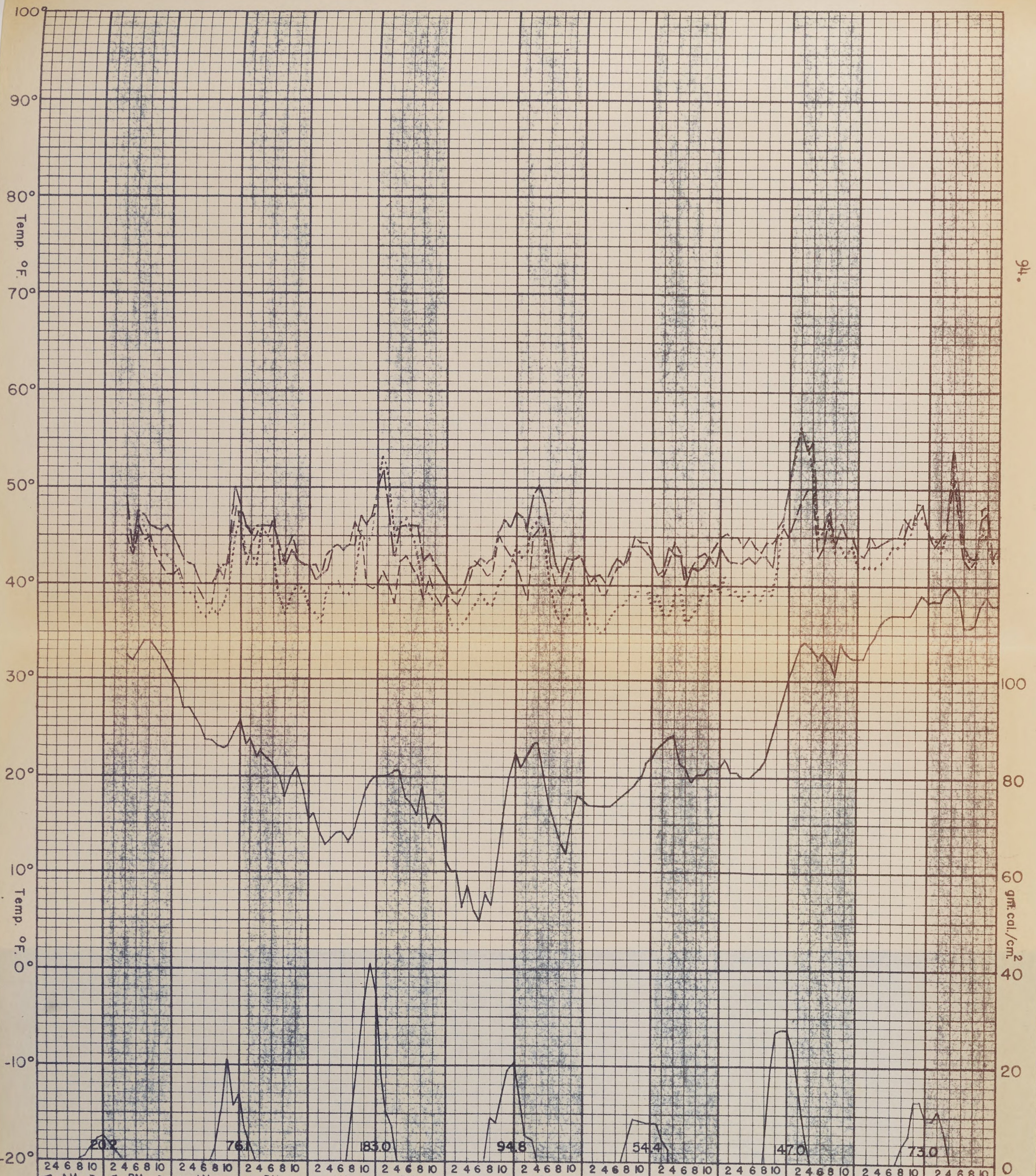
RELATIVE HUMIDITY

00



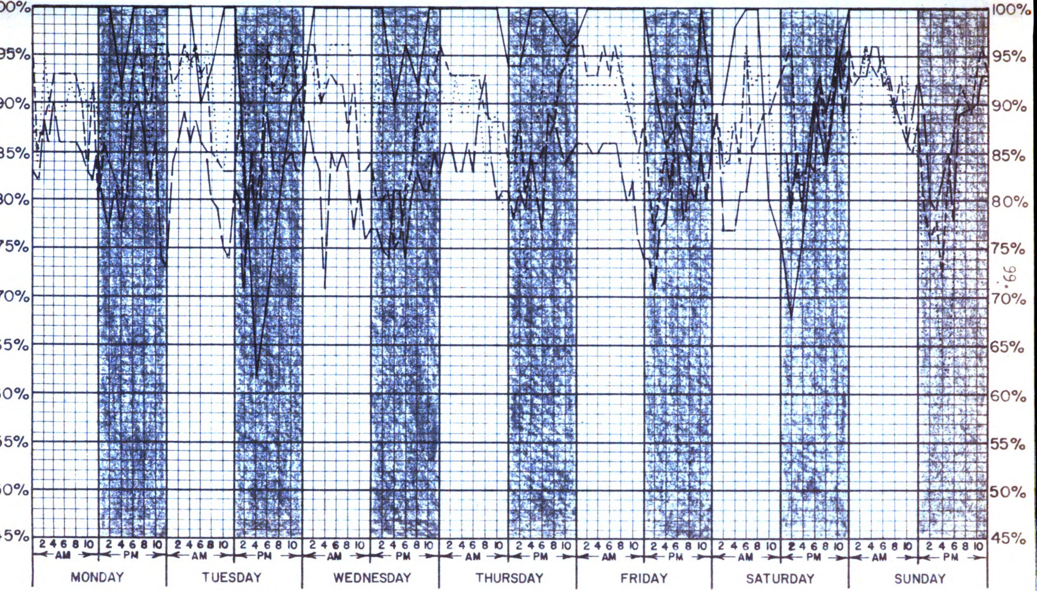
RELATIVE HUMIDITY

WEEK OF DEC. 28-JAN. 3



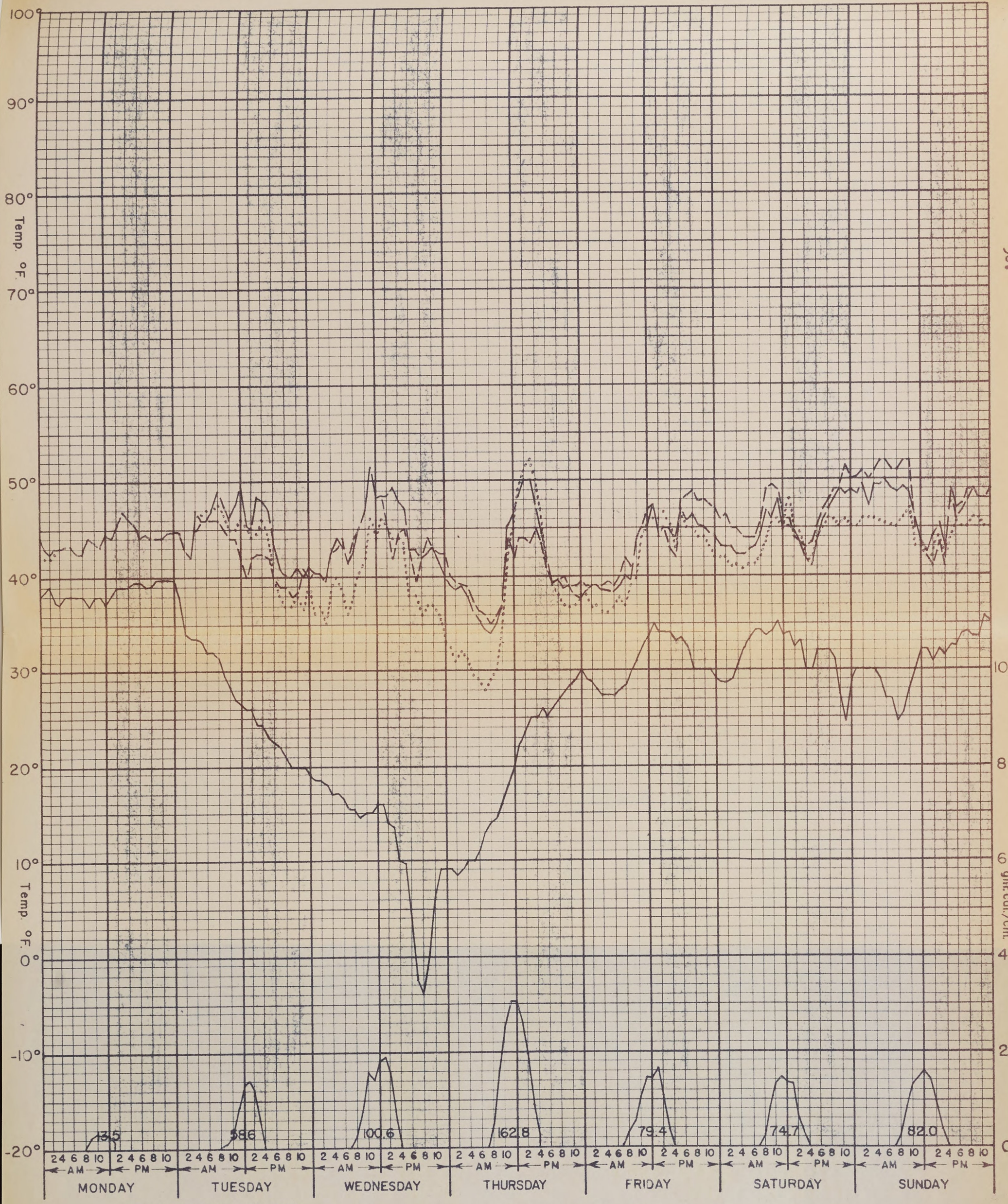
WEEK OF DEC. (14-20)

TEMPERATURES AND SOLAR RADIATION



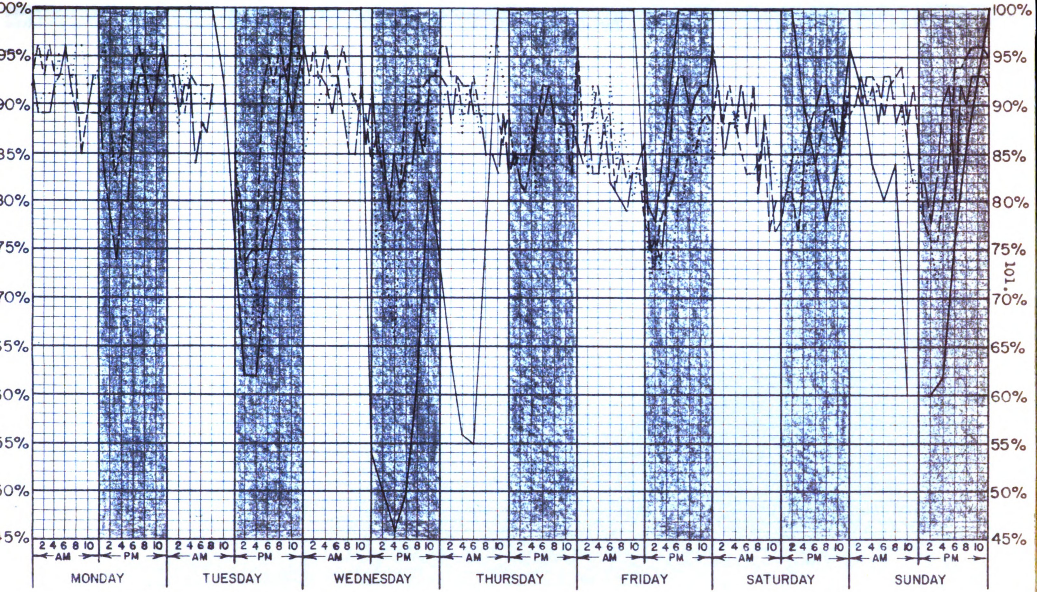
WEEK OF JAN. (4-10)

RELATIVE HUMIDITY



WEEK OF DEC. (21-27)

TEMPERATURES AND SOLAR RADIATION

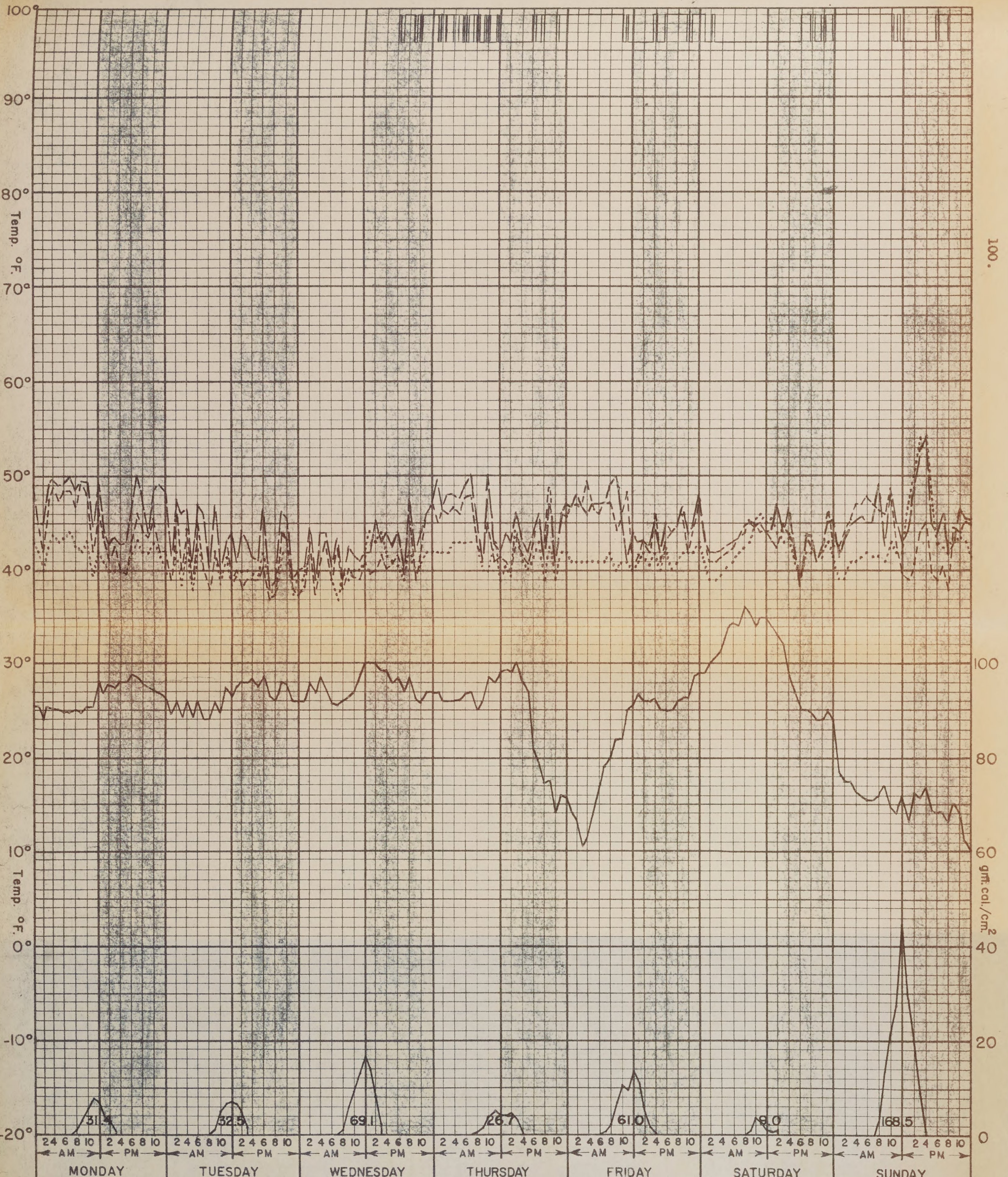


WEEK OF JAN. (11-17)

RELATIVE HUMIDITY

WEEK OF DEC. 28 - JAN. 3

TEMPERATURES AND SOLAR RADIATION

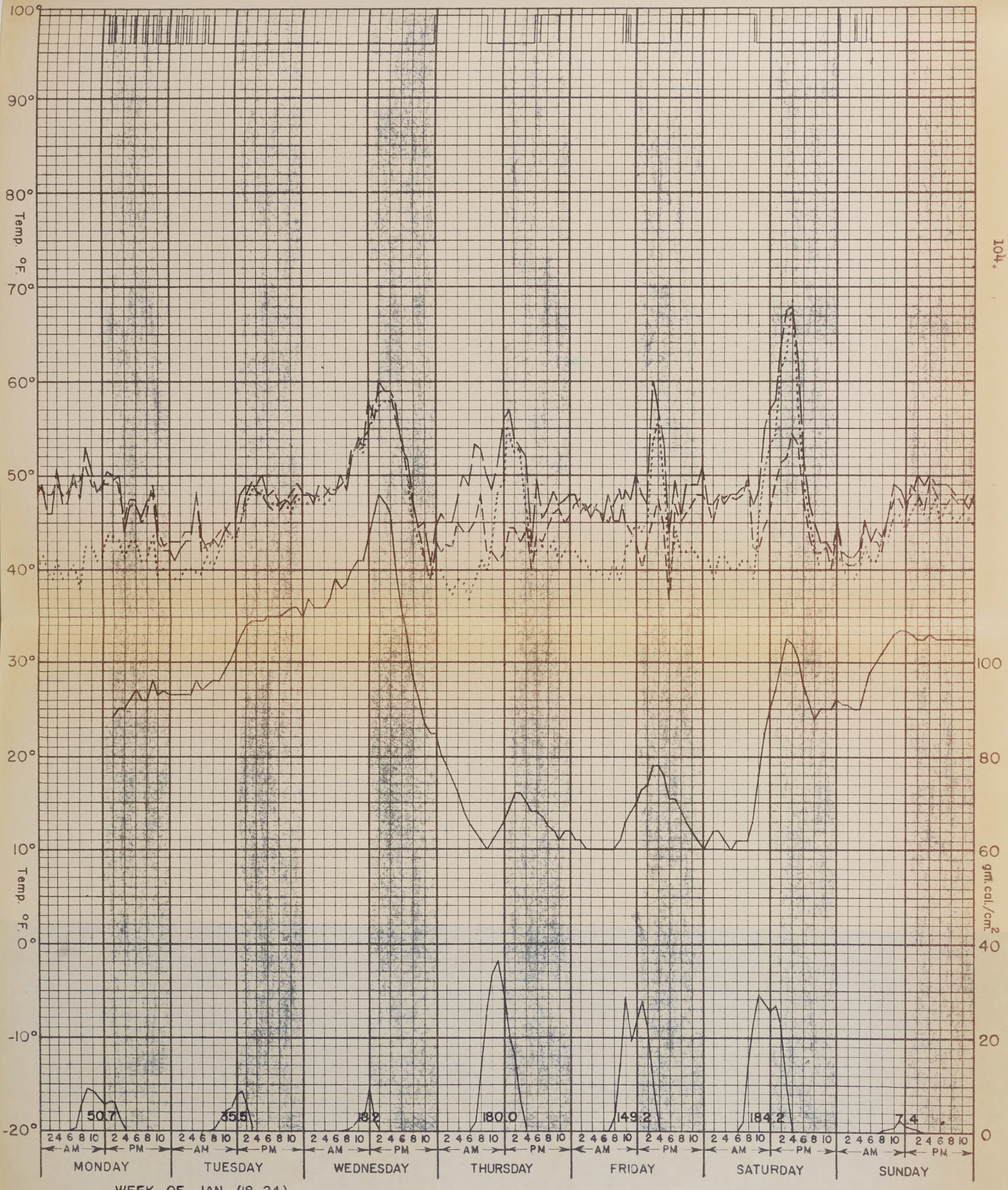


WEEK OF JAN. (4-10)

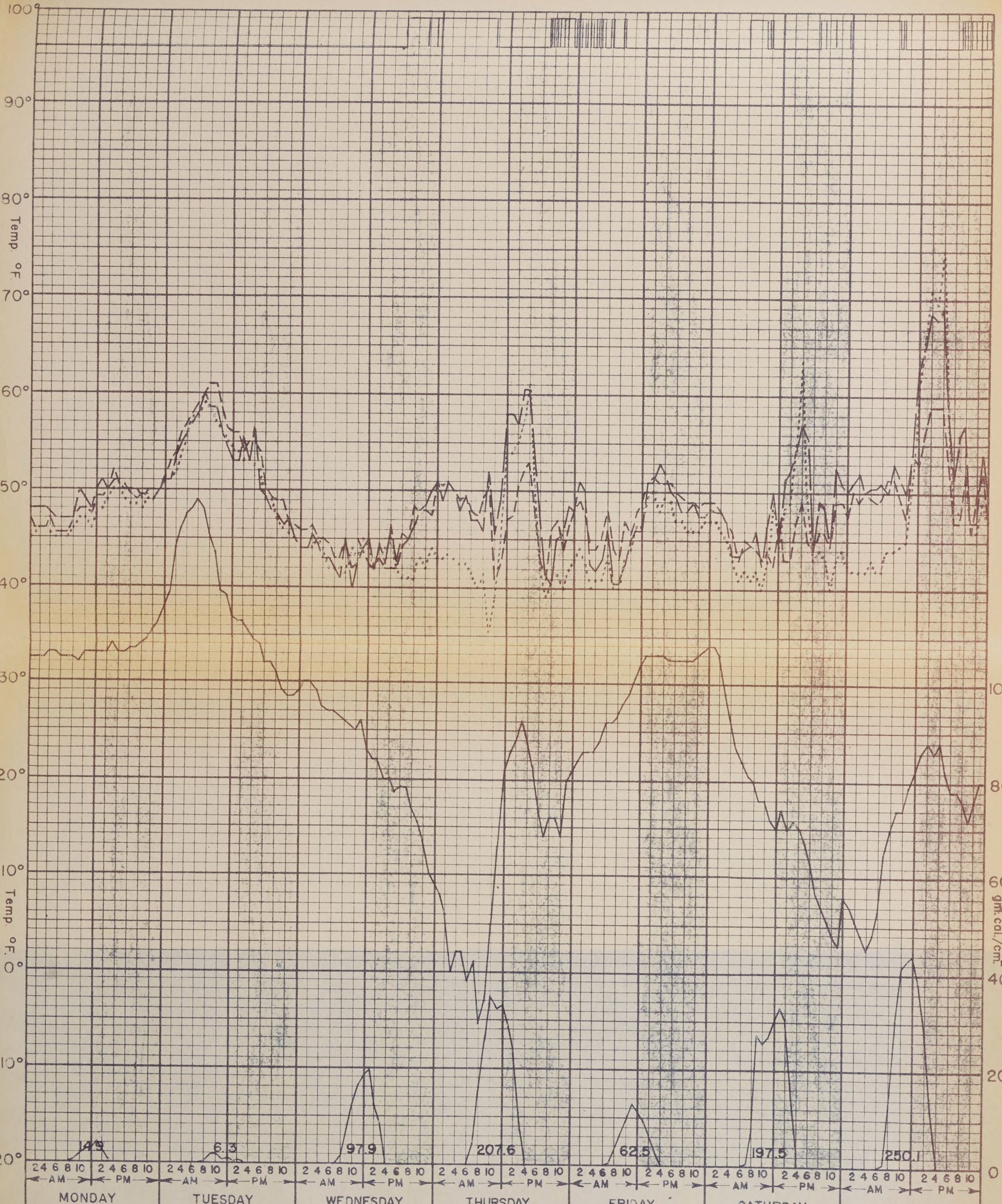
TEMPERATURES AND SOLAR RADIATION

WEEK OF JAN. (11-17)

TEMPERATURES AND SOLAR RADIATION

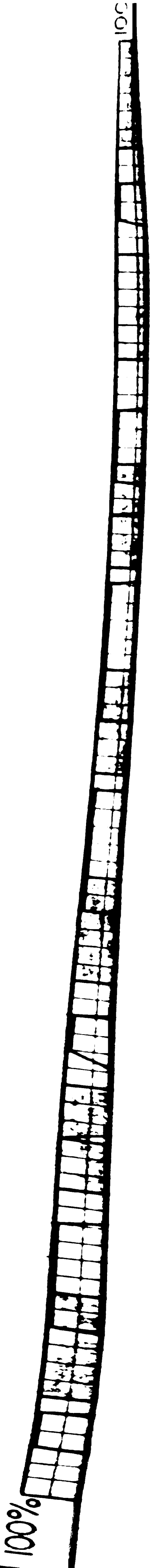


TEMPERATURES AND SOLAR RADIATION



WEEK OF JAN. (25-31)

TEMPERATURES AND SOLAR RADIATION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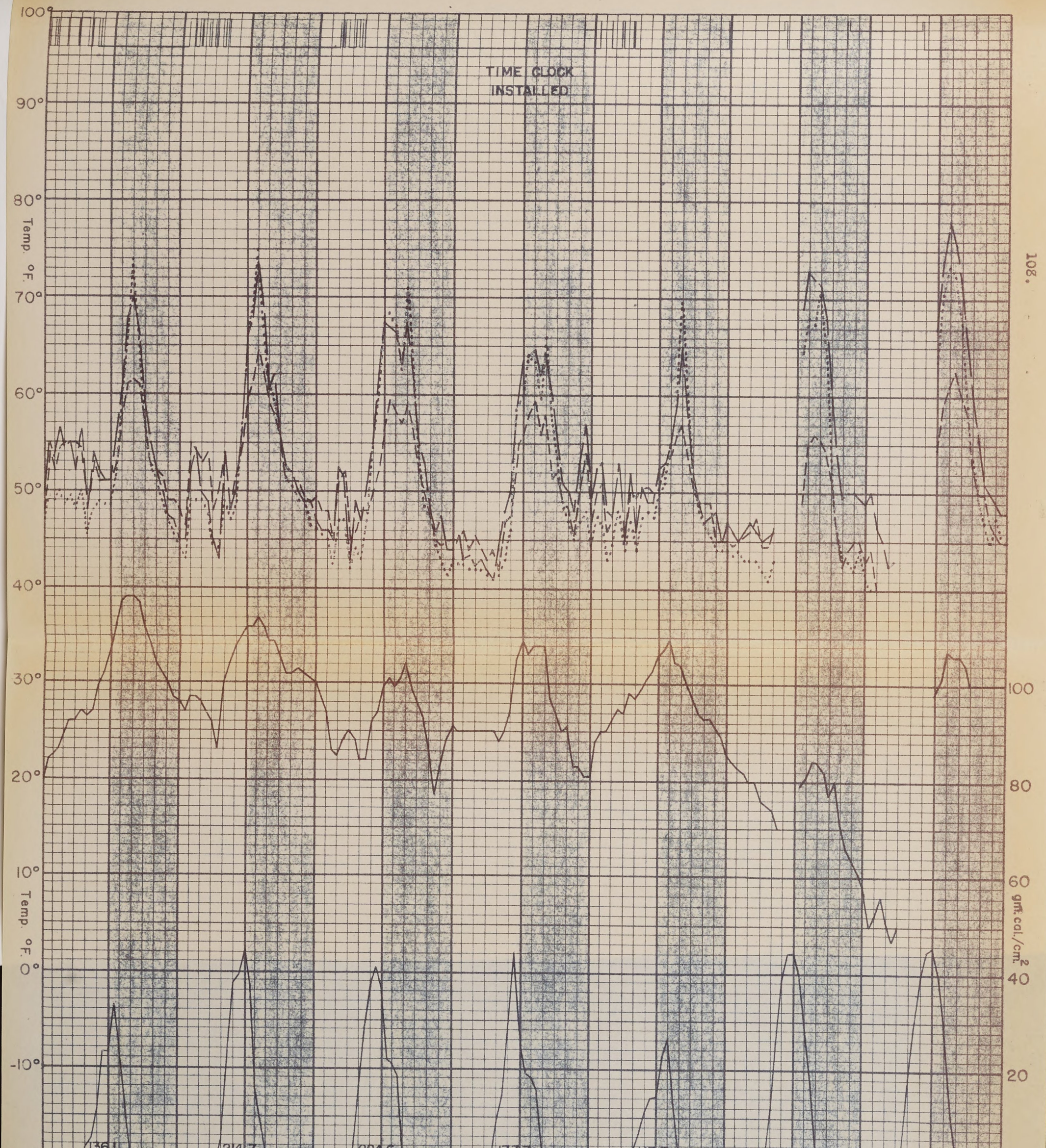
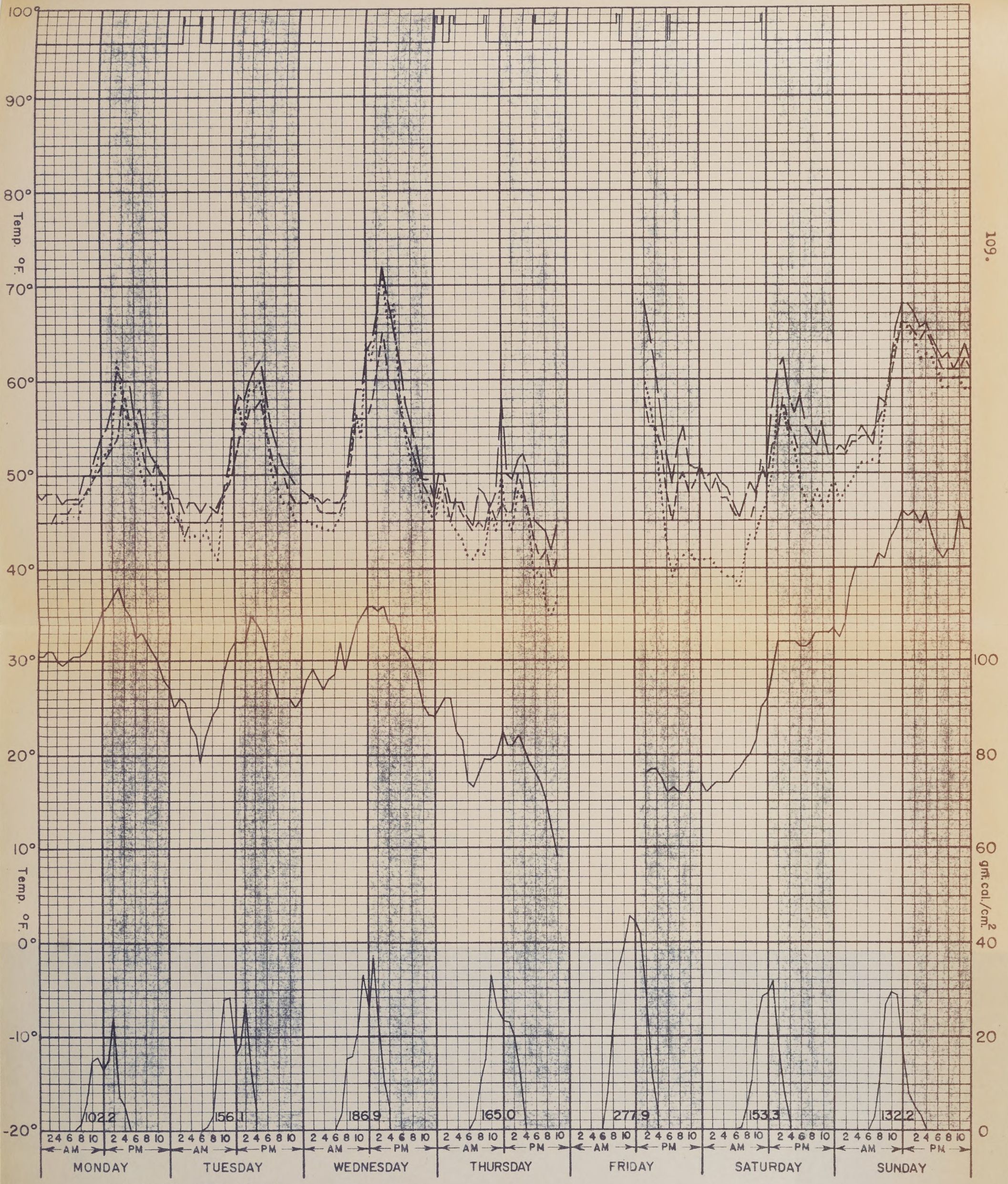


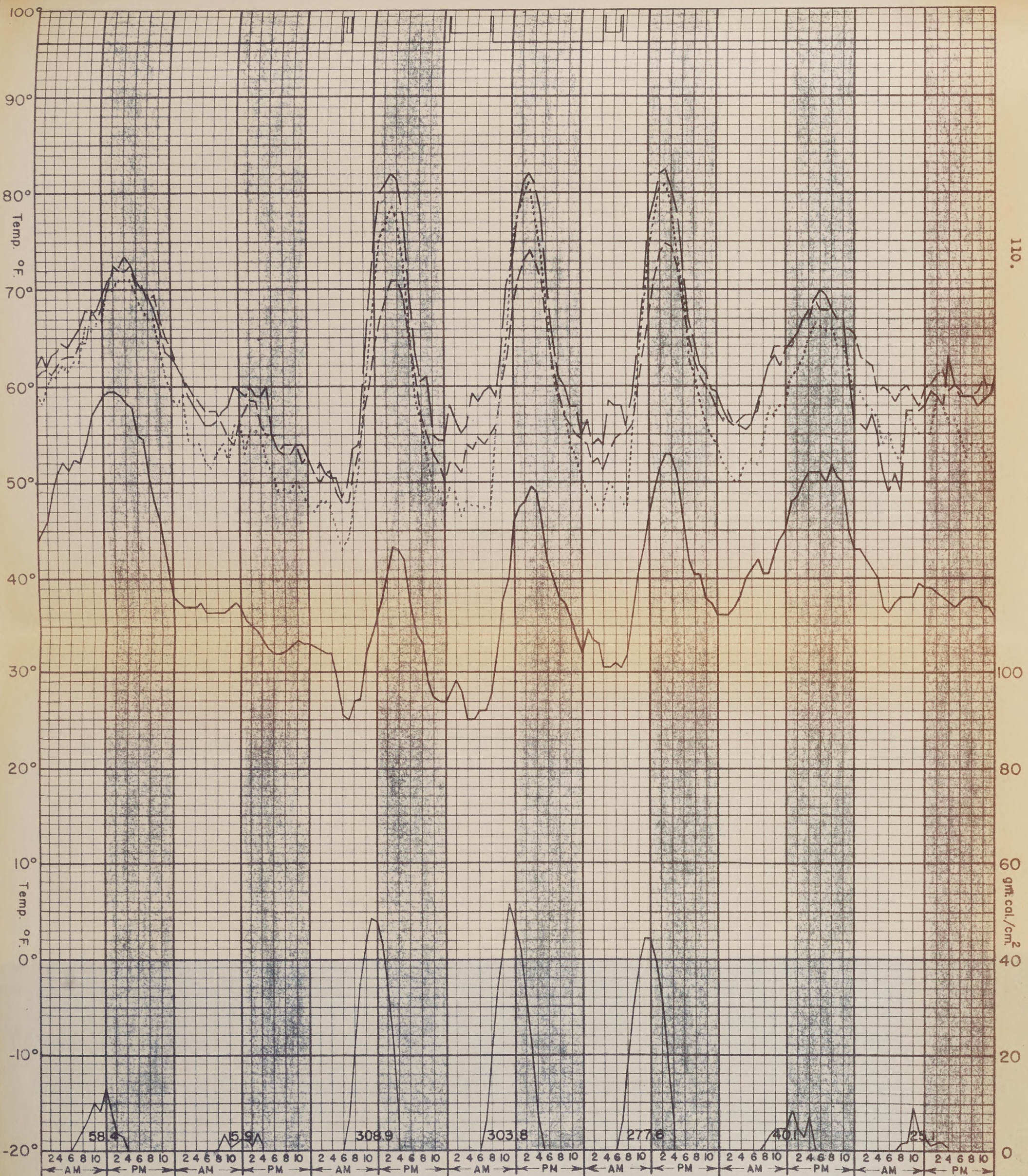
WEEK OF FEB. (1-7)

TEMPERATURES AND SOLAR RADIATION



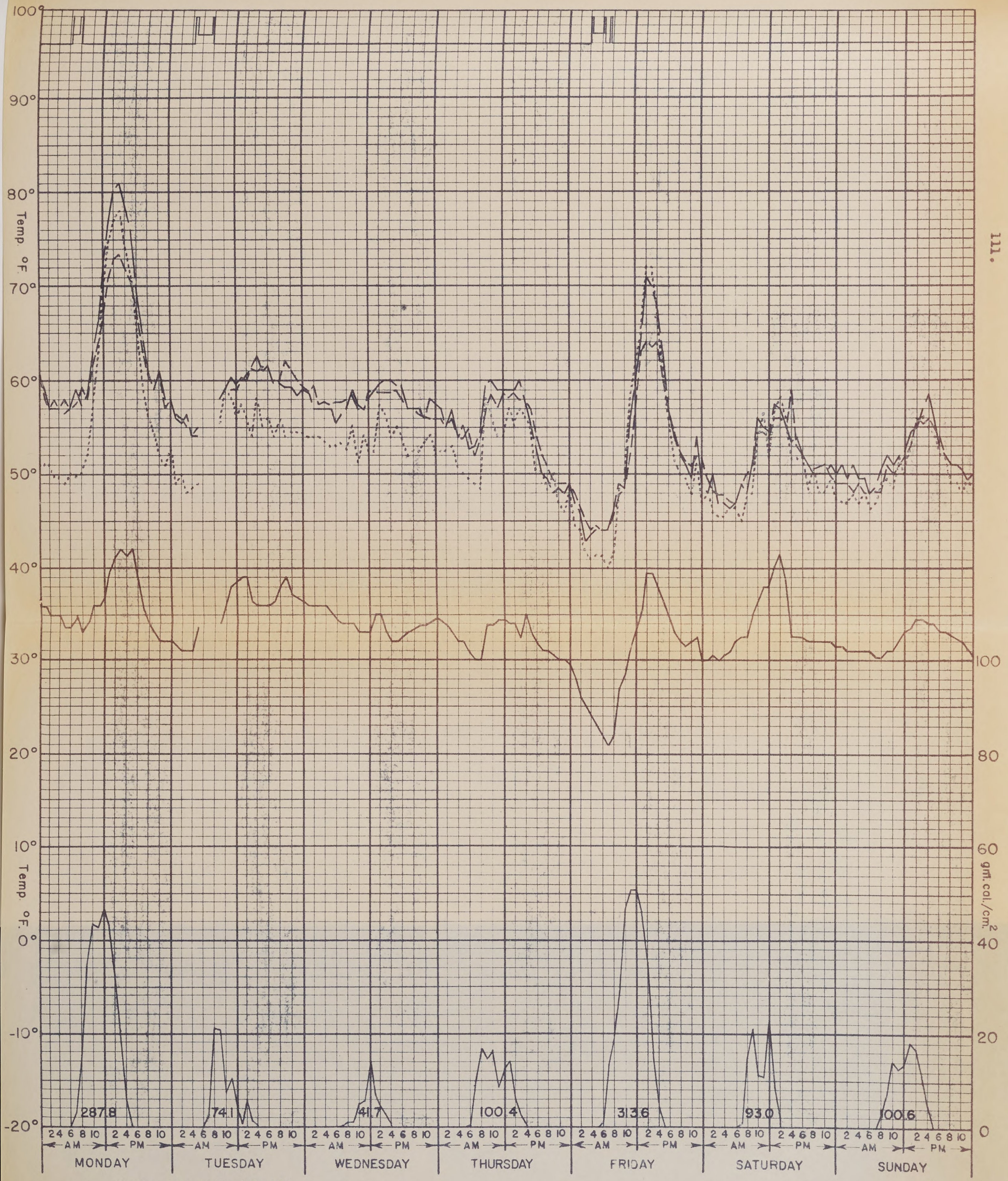
WEEK OF FEB. (8-14)

TEMPERATURES AND SOLAR RADIATION



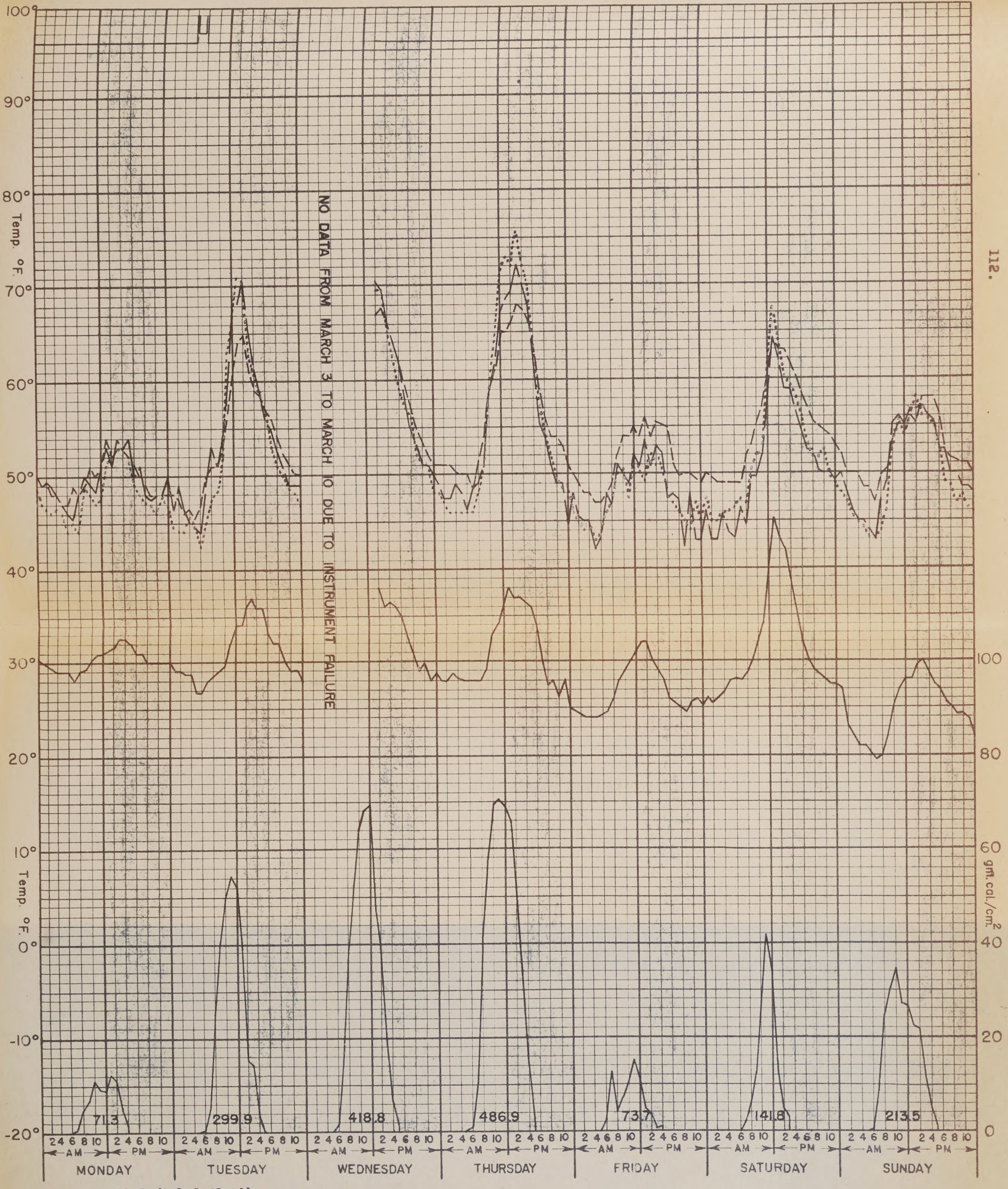
WEEK OF FEB (15-21)

TEMPERATURES AND SOLAR RADIATION



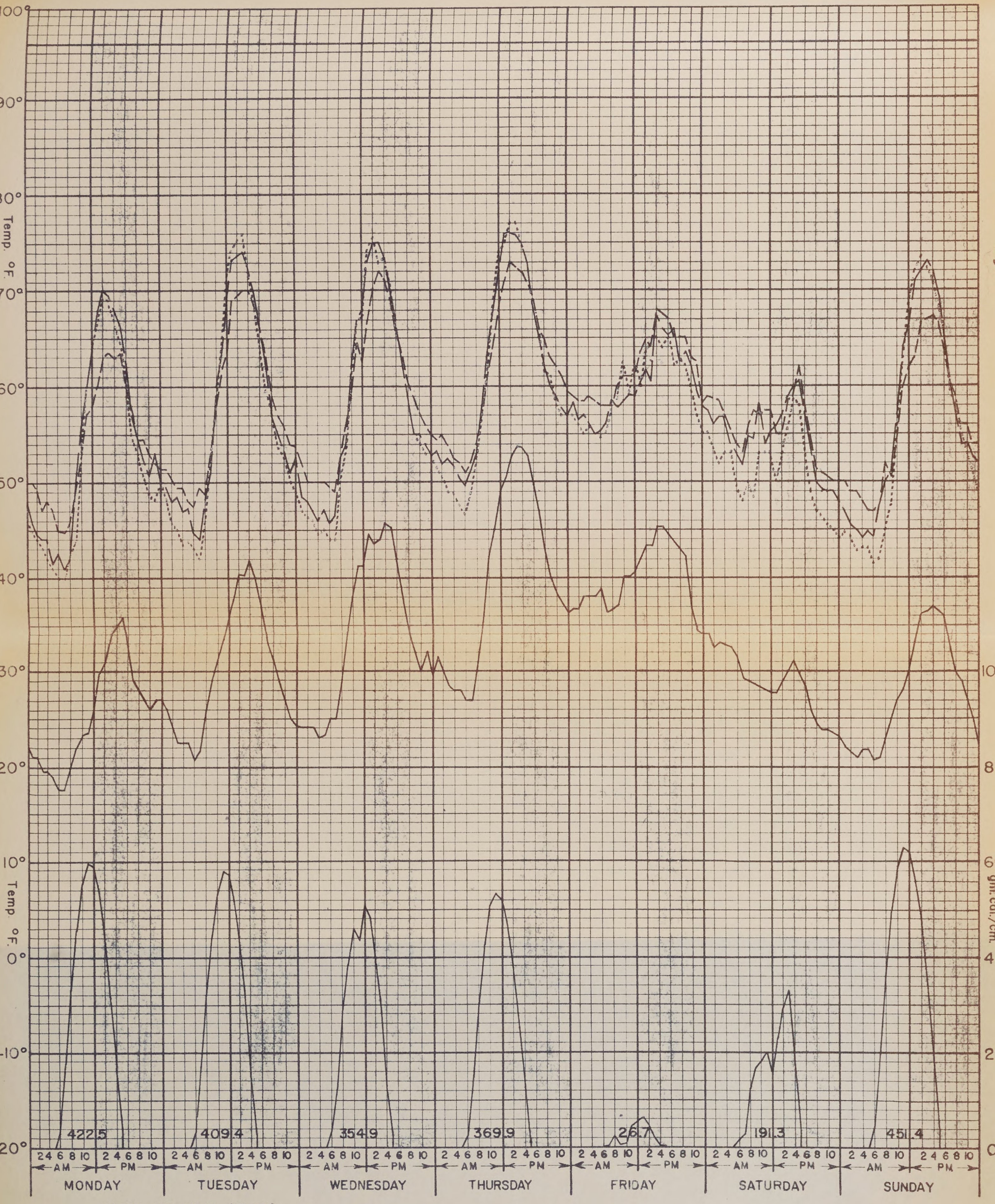
WEEK OF FEB. (22-28)

TEMPERATURES AND SOLAR RADIATION



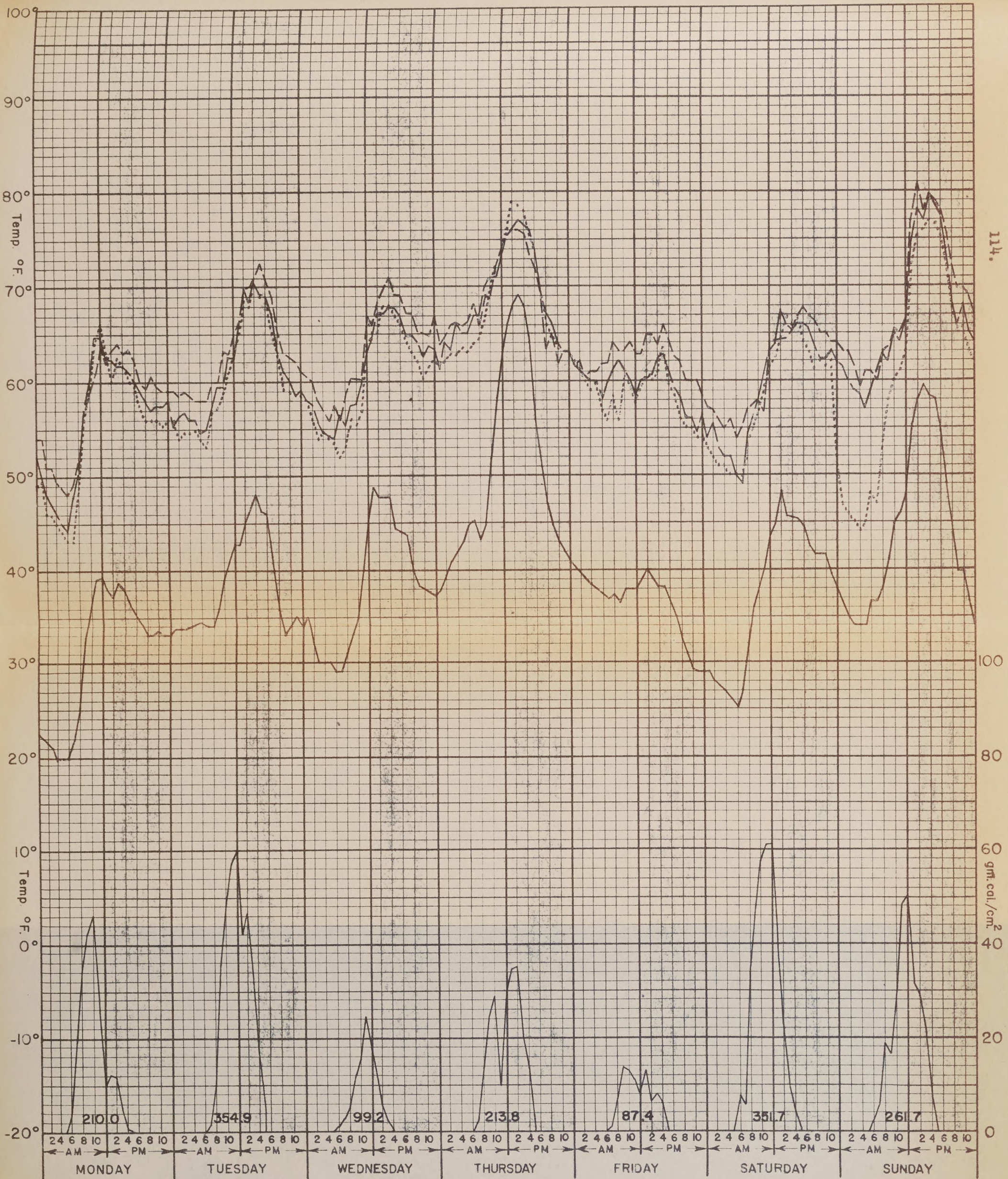
MAR. (1-2 & 10-14)

TEMPERATURES AND SOLAR RADIATION



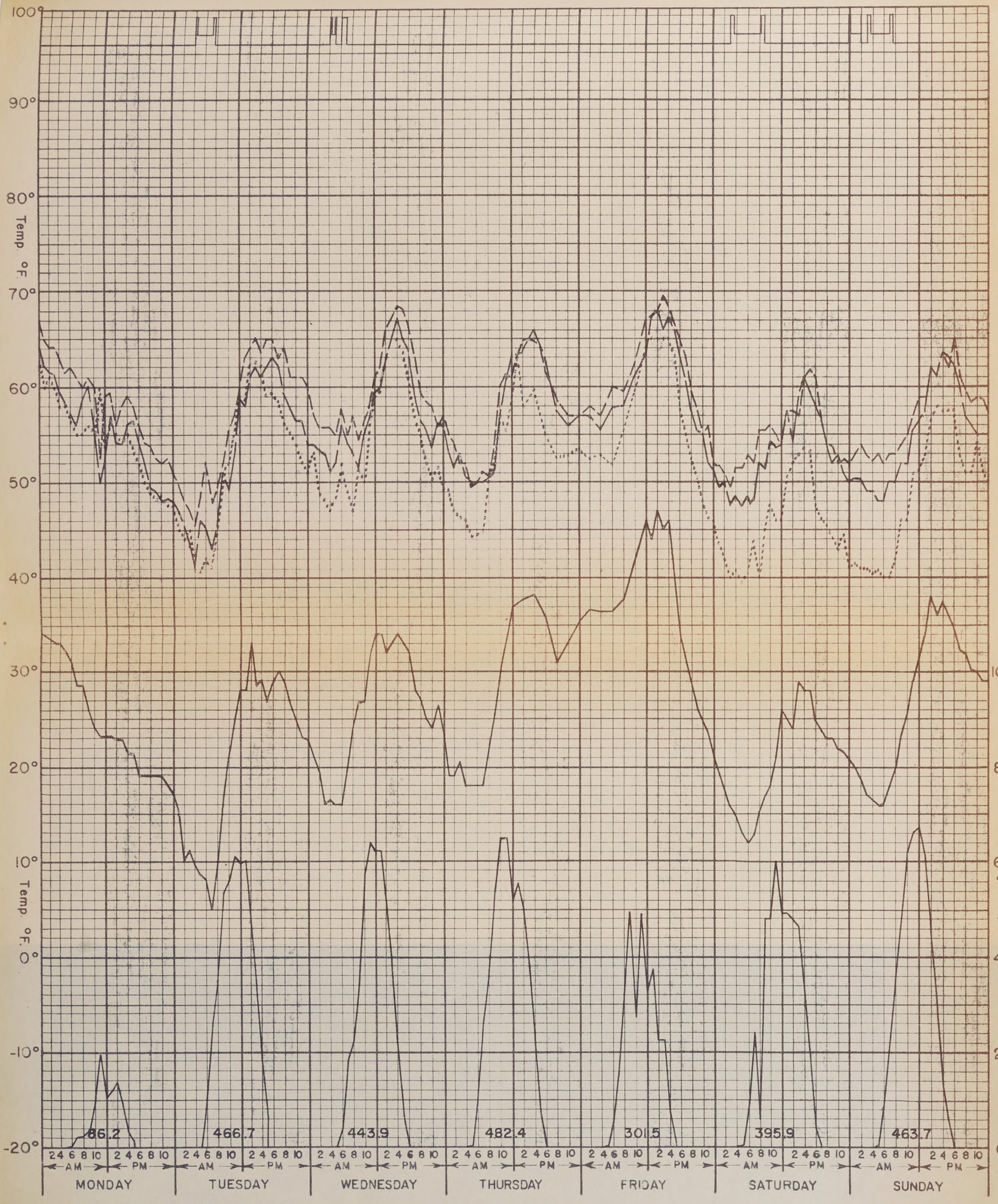
WEEK OF MAR. (15-21)

TEMPERATURES AND SOLAR RADIATION



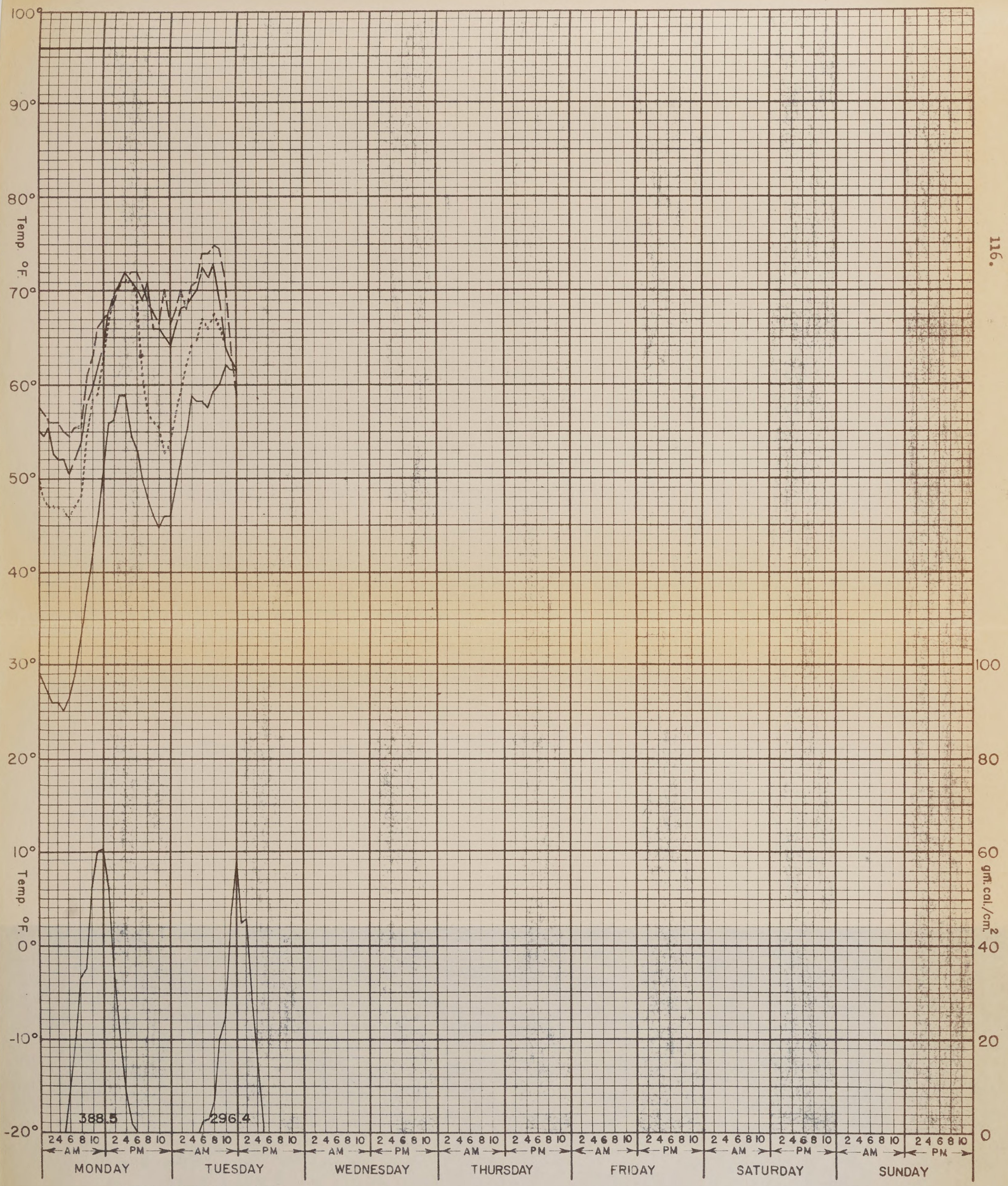
WEEK OF MAR. (22-28)

TEMPERATURES AND SOLAR RADIATION



WEEK OF MAR. 29 - APRIL 4

TEMPERATURES AND SOLAR RADIATION



WEEK OF APRIL (5-11)

TEMPERATURES AND SOLAR RADIATION

GLOSSARY

Angle of Incidence - The angle between the direction of the rays of the sun and a perpendicular to the surface under consideration.

Atmospheric Absorption - The absorption of solar radiation by the components of the atmosphere such as oxygen, ozone, carbon dioxide and water vapor.

Direct Solar Radiation - The radiant energy received directly from the sun.

Double-pane Windows - Two panes of glass separated by an air space and fastened together around the outer edges with a strip of lead which forms an air tight metal to glass bond.

Gram-calorie - The amount of heat energy required to raise the temperature of one gram of water at 15° C. one degree centigrade.

Indirect, Diffuse, or Sky Radiation - The scattered solar radiation received by the earth from the atmosphere.

Mean Solar Distance - The mean distance of the earth from the sun. It is an arithmetical mean distance between the greatest and least distances between the earth and the sun.

Nocturnal Radiation - Radiation exchange between the earth and the atmosphere at night.

Normal Incident Radiation - The impingement of solar radiation on a flat surface at right angles to the sun's rays.

Photosphere of the Sun - The layer from which most of the sun's light is emitted which reaches us directly without absorption and reemission before leaving the sun. The photosphere may be regarded as the layer which is the limit to which we can see into the interior of the sun.

Solar Altitude - The angular elevation of the sun above the true horizon.

Solar Constant - The rate at which solar radiation is received outside the atmosphere on a surface that is normal to the incident radiation, at the earth's mean solar distance from the sun. The value of 1.94 gram-calories per square centimeter per minute is the common one used.

Total Incident Solar Radiation - The total direct plus diffuse solar radiation measured perpendicular to the surface under consideration.

Transmitted Solar Radiation - The portion of the total incident radiation which passes directly through the glass.

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