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THE UNIVERSITY OF MICHIGAN
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AN EVALUATION OF WINTER COMFORT CONDITIONS IN THE MORTIMER E. COOLEY MEMORIAL LABORATORY

J. G. Lewis
F. N. Calhoon
C. T. Larson
H. A. Ohlgren

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PREFACE

This report is presented as a result of an investigation and evaluation of room temperature, relative humidity, and other conditions relating to personnel comfort in the Mortimer E. Cooley Memorial Laboratory, located on the North Campus of The University of Michigan, Ann Arbor, Michigan.

Presented here are some of the measurements taken during the period from September, 1955, to April, 1956. A previous report, 461:1110-1-T dealt with the period from May, 1955, to September, 1955.

The work upon which this report is based was undertaken at the request of R. G. Folsom, Director, Engineering Research Institute, The University of Michigan, and of G. G. Brown, Dean of the College of Engineering, The University of Michigan.

The authors wish to acknowledge gratefully the advice and suggestions of E. W. Hewson, Professor of Meteorology, Department of Civil Engineering, The University of Michigan; G. C. Gill, Meteorological Laboratory, The University of Michigan, who kindly arranged the loan of certain measuring equipment used in the study; the cooperation of the U. S. Weather Bureau, Willow Run Station; and the assistance of the Department of Mechanical and Industrial Engineering, The University of Michigan, in lending certain measuring equipment for use on this project.

The installation of equipment, observation of many of the measurements, and preliminary organization of the data are due to the following engineering students of The University of Michigan: G. A. Aktay, R. J. Annesser, S. B. Koehler, and R. B. Oswald.

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ABSTRACT

A summary is presented of the results of measurements of temperature, humidity, and other physical variables related to comfort conditions in the Mortimer E. Cooley Laboratory, The University of Michigan, for the period September, 1955, through April, 1956.

Most of the data presented describe the temperatures which prevailed in several selected rooms on the second story of the Cooley Laboratory. Records were kept of the temperatures inside copper balls painted black on the exterior, located approximately in the center of each room. The temperatures of the air at a location 6 to 12 inches away from the black ball were also recorded. A measure of the thermal radiation to or from a room is given by consideration of both the temperature within a black ball and the dry bulb temperature of the air. During the period September, 1955, through early March, 1956, black ball and air temperatures were compared in three rooms. These three rooms comprised two rooms on the south side of the building, one with shade screens and one without shade screens, and one unshaded room on the north side of the building. Results are also reported for a fourth room for which data were obtained during the latter part of March and during April, 1956. This room was located on the north side of the laboratory and provided with shade screens.

Emphasis in this report is given to reporting of temperatures which prevailed in the rooms selected for study. Secondary emphasis was given to the recording of comfort sensations and to the measurement and reporting of relative humidity, wind velocity, and lighting conditions within some of the rooms. It is believed that the comfort results reported are less reliable than the temperature results because of the difficulties of providing a fully representative statistical sampling of comfort sensations by trained observers.

It is concluded that the use of shade screens on the south side of the building has greatly reduced the effect of direct radiant solar heating within the shaded rooms. Even during the winter time the unshaded room displayed a significant portion of days in which high radiant temperatures were noted in unshaded rooms. The temperature variations in the shaded room on the south side of the building are much less marked than those in the unshaded room. Relatively secondary effects of the shade screens were noted upon the temperature and comfort conditions in the rooms located on the north side of the building.

OBJECTIVES

The objectives of this study are primarily to extend the objectives of the study for the summer season previously reported to the fall, winter, and spring seasons to provide an estimate of the comfort conditions within the Cooley Laboratory during an entire year, particularly as influenced by the shade screens installed on the south side of the building.

Some specific objectives are:

1. to evaluate the effect of aluminum shade screens placed outside large windows of southern exposure in the Mortimer E. Cooley Memorial Laboratory in reducing personnel discomfort caused by radiant solar heating of work areas;

2. to examine the results of the measurements taken in the Mortimer E. Cooley Memorial Laboratory to see whether additional information on conditions required for human comfort in interior work areas could be derived from the results of the study. Of particular interest was the relating of the simultaneous effects of radiant solar heating, humidity, and effective temperature.

INTRODUCTION

The Mortimer E. Cooley Laboratory is located on the North Campus of The University of Michigan. Employed in this building is a type of construction in which nearly all the north and south walls of certain portions of the building are constructed of glass. Windows extend from ceiling to floor and nearly from wall to wall on north and south walls.

Some of the laboratories and offices on the south side of the building were uncomfortably hot on sunny days prior to the installation of shade screens in June, 1955. The shade screens were installed to reduce radiant heating of the working areas by direct sunlight and secondary radiation heating by the hot window glass. The results of this study affirm the desirability of the installation of shade screens on the south side of the building and show that the radiant temperatures on the south side of the building have been greatly reduced during sunny weather by the installation of the shade screens.

This report deals in particular with the extension of the observation of physical conditions related to comfort to the fall, winter, and spring seasons, as supplementary to the previous report covering the conditions during the summer seasons. The influence of shade screens upon general comfort conditions during the winter was studied to determine whether the screen might have some adverse or undesirable effects during the winter. It was desired to determine whether the shade screens would reduce the loss of heat from the building thus helping to keep the working personnel warm during the periods of cold weather. The performance of shade screens was therefore evaluated during the fall, winter, and spring of 1955-1956. During the winter of 1954-1955, it was observed that large quantities of moisture condensed on the interiors of the windows of the Cooley Laboratory and either dripped on the window sills or froze on the windows and thawed and dripped when the weather warmed. It was believed that the installation of the shade screens might reduce this tendency toward condensation of moisture on the windows through reduction of radiant heat loss to the exterior.

EXPERIMENTAL PROGRAM

A. GENERAL

The experimental program developed for this study was intended to gather data necessary to evaluation of comfort conditions of workers in the Mortimer E. Cooley Memorial Laboratory. Records were kept of physical measurements together with some reactions of personnel within the building. The pertinent experimental data required and the manner in which they were obtained are listed below.

B. EXTERIOR MEASUREMENTS

The exterior weather data were obtained from the United States Weather Bureau at Willow Run Airport, located less than ten miles from the Cooley Laboratory and in a similar environment. Values for the following measurements were recorded:

1. Outside air temperature
2. Wind velocity and direction
3. Sky coverage by clouds

C. INTERIOR MEASUREMENTS

During certain portions of this study wet and dry bulb temperatures were taken daily in the test rooms, using a sling psychrometer. Sensations of comfort of some of the workers in the test rooms were recorded at the same time. A rather small sample of workers was taken. Often only the observer alone recorded his comfort sensations. The work done in the Cooley Laboratory generally consisted of office and electronics-laboratory work.

A recording hygro-thermograph was located in the north side unshaded room and another hygro-thermograph was located in the north side shaded room. Both of the hygro-thermographs were used to measure air temperatures and to indicate changes in the relative humidities in these respective rooms. Temperatures of the black globe, the glass window pane, the shade screen, and the room air for the south side rooms were recorded at intervals of 24 minutes by means of an electronic temperature recorder. A plan of the second floor of the Cooley Laboratory is shown in Fig. 1, and an elevation of the test rooms is shown in Fig. 2. These figures illustrate the locations of the thermocouples in the test areas. The position of the black globes was fixed at the same level as the upper portion of the bodies of human beings occupying the test areas. The dry bulb air temperatures were measured at points 6 inches removed from the black

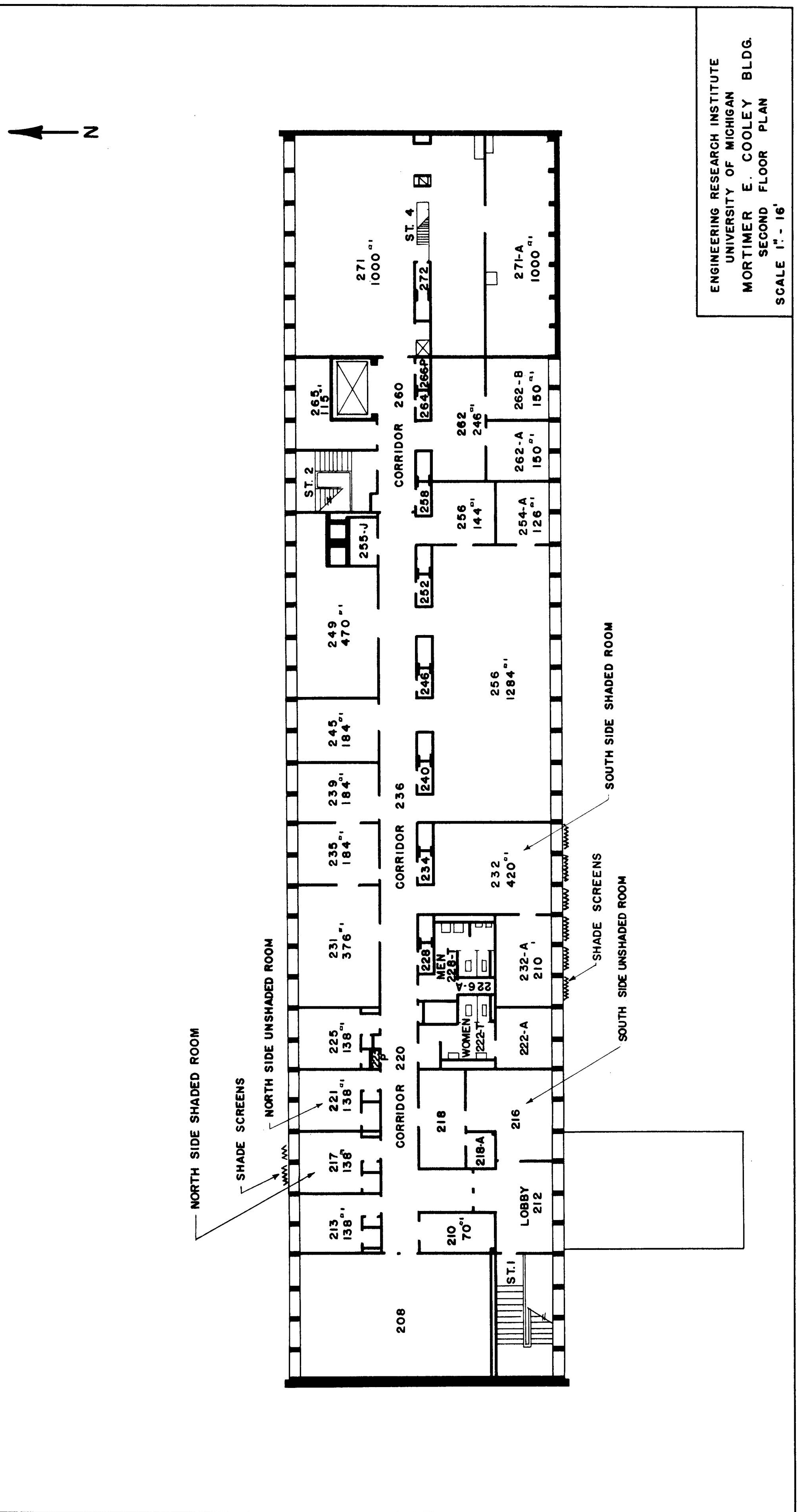


FIG. I - PLAN OF THE SECOND FLOOR OF THE COOLEY LABORATORY

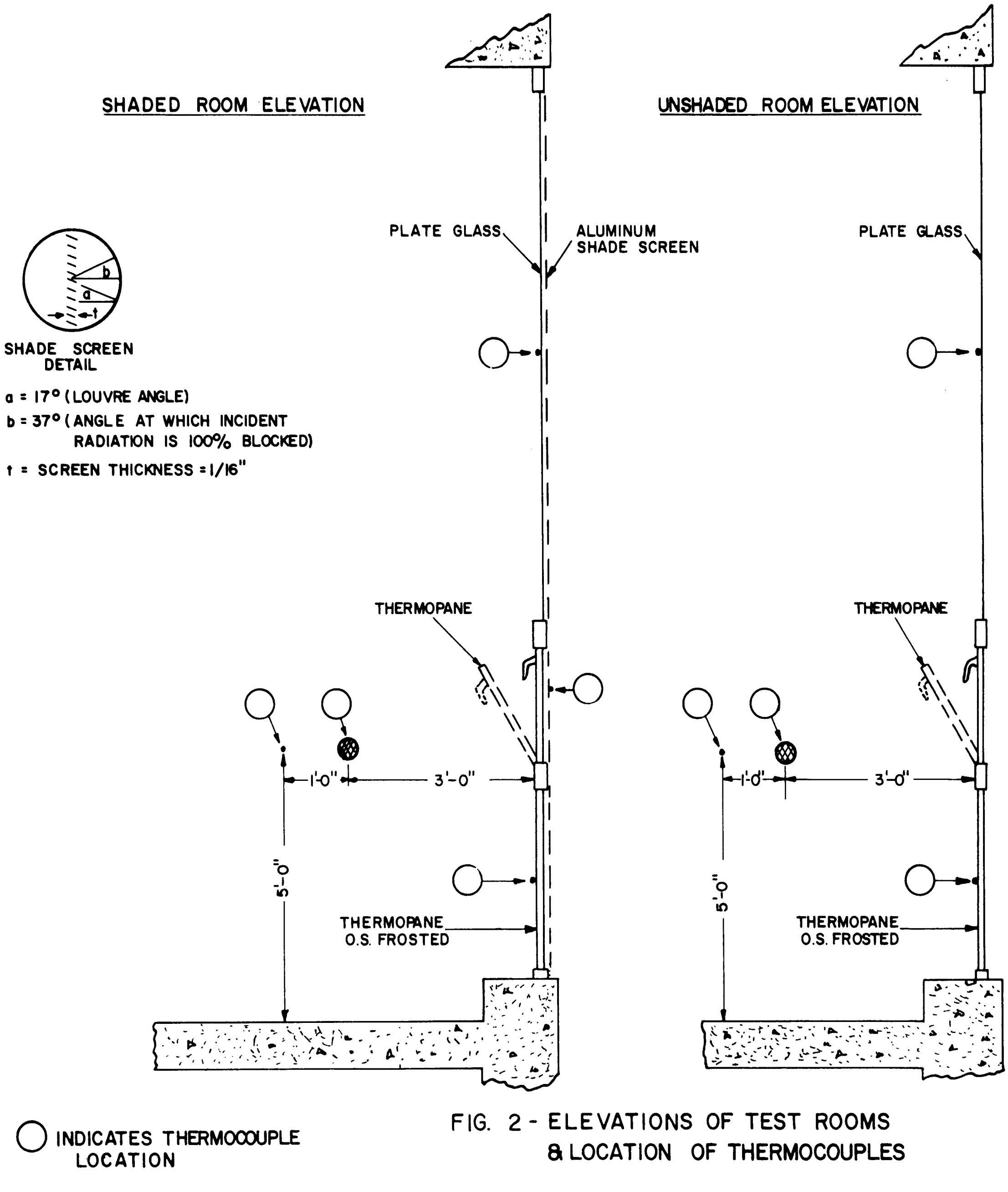


FIG. 2 - ELEVATIONS OF TEST ROOMS & LOCATION OF THERMOCOUPLES

globes. The temperatures of the glass panes were recorded by thermocouples cemented to the interior surfaces of the glass at the geometric centers of the panes. The temperatures of the shade screens were measured by thermocouples cemented to the screens. The data recorded were as follows:

1. South Side Shaded Room
   a. Screen temperature
   b. Inside glass temperature
   c. Globe temperature
   d. Air temperature
   e. Window position, inside shade position and thermostat setting
   f. Relative humidity

2. South Side Unshaded Room
   a. Inside glass temperature
   b. Globe temperature
   c. Air temperature
   d. Relative humidity
   e. Window position, inside shade position, and thermostat setting

3. North Side Shaded Room
   a. Screen temperature
   b. Inside glass temperature
   c. Globe temperature
   d. Air temperature
   e. Window position, inside shade position, and thermostat setting
   f. Relative humidity

4. North Side Unshaded Room
   a. Inside glass temperature
   b. Globe temperature
   c. Air temperature
   d. Relative humidity
   e. Window position, inside shade position, and thermostat setting

DESCRIPTION OF BUILDING

A. DESCRIPTION OF THE ROOMS SELECTED FOR EXPERIMENTATION

The Cooley Laboratory has two exterior walls consisting essentially of glass. These walls face either north or south. The four rooms studied are noted in Fig. 1 and will be referred to as the north side shaded room, north side unshaded room, south side shaded room, and the south side unshaded room.

B. DESCRIPTION OF WINDOWS IN THE COOLEY LABORATORY

Figure 2 shows typical elevations of the windows in the Cooley Laboratory. The entire wall consists of three sections of windows. "AKlo" glass is used in all three sections. In the upper two sections the "AKlo" glass is clear and in the lower section it is frosted. In the lower two sections the "AKlo" glass is used in combination with clear plate glass to form two thermopane panels. In the lower two sections the "AKlo" glass is mounted on the outside. The "AKlo" glass is 1/4 inch thick, tinted blue, and is described more fully as "Blue Ridge AKlo Heat Absorbing Clear" glass.[1] The "thermopane" panels consist of two sheets of 1/4-inch-thick plate glass mounted in the same frame and separated by an air space.

DESCRIPTION OF EQUIPMENT

A. THE GLOBE THERMOMETER

A discussion of the theoretical background involving the use of the globe thermometer is given in a previous report, 461:1110-1-T. The globe thermometer consists of a thermocouple located in a 6-inch-diameter copper ball coated on the outside with black matte paint. This device is intended to give an indication of the thermal radiation conditions within the room in which it is located. The globe reaches equilibrium with its surroundings in about 15 minutes, after which the heat gained by radiation is balanced by the heat lost by convection to the surroundings. The rate of convective heat loss is governed by local air velocity among other things. The air velocity is measured by a hot-wire anemometer.

B. TEMPERATURE RECORDER

An electronic null-balance temperature recorder was employed with 12 records printed on a strip chart at the rate of one point every two minutes. The thermocouples used were copper constantan, 38 calibration.

The temperature recorder was calibrated against a standard mercury thermometer, employing a water bath at different temperatures. The recorded temperatures were within 0.5°F of the standard thermometer readings. The error of the standard thermometer which was used was ± 0.2°F. The standard thermometer was NBS No. 52, a Princo No. 271726, range -3°C to +60°C.

C. OUTSIDE AIR TEMPERATURE RECORDER

The outside temperature was continuously recorded by means of a bimetallic, helix, clockwind recorder located in a shaded area on the roof of the Cooley Laboratory. This instrument deviated less than ± 1°F from the standard thermometer.

D. HUMIDITY MEASUREMENT INSTRUMENTS

A sling psychrometer was used to obtain wet and dry bulb temperature data in the test rooms. Calibration of the thermometers mounted on the sling psychrometer was conducted against the standard mercury thermometer referred to above. A maximum deviation of ± 0.2°F was found for the psychrometer thermometers.

A recording hygro-thermograph was located in a north unshaded room to record variations of relative humidity. Another hygro-thermograph was used in the north shaded room to record air temperature and relative humidity.

E. THERMOCOUPLE INFORMATION

The electronic null-balance temperature recorder received primary signals from copper-constantan thermocouples. The glass surface temperatures were measured by fixing the thermocouples to the glass surface with Canada balsam. The screen temperatures were measured by sealing the thermocouple bead with Canada balsam between two fins of the screen. Globe temperatures were measured by means of a thermocouple located at the geometric center of each globe. Room-air temperatures were measured by thermocouples located each at the same levels as the respective globe, but removed from the globe a sufficient distance to be outside the influence of the thermal convection currents of the globe.

F. AIR-VELOCITY MEASUREMENTS

The air-velocity measurements are taken with a hot-wire anemometer. This anemometer was checked against pitot-tube readings in a wind tunnel and the agreement between these two instruments was close.

EVALUATION OF RESULTS

The results of this study are summarized and evaluated from three points of view. Firstly, temperature data are reported in the form of plots of maximum daily temperatures at designated locations in the Mortimer E. Cooley Laboratory. Secondly, the variation throughout the day for a number of selected temperatures is analyzed in more detail in a second series of charts. Thirdly, impressions of comfort are reported as they relate to the variables of temperature and humidity for a small, arbitrarily selected group of observers.

The authors believe that primary emphasis in this report should be focused upon the reporting of the physical data of temperatures, because it is believed that these data are the most reliable resulting from the study. The comfort data are presented for what they are worth but are not claimed to be definitive.

In Figs. 3-14 the maximum daily temperatures at designated locations have been plotted against the date on which these temperatures occurred. The objective in presenting Figs. 3-14 has been to provide a concise abstract of the large number of temperature data points which were available. Probably but little fundamental significance can be attached to this method of reporting data, but it is regarded as one means of providing a concise picture of the daily and seasonal temperatures experienced with and without shade screens on the north and south sides of the building.

For the months of September, October, and November, 1955, the daily maxima for selected temperatures are presented. These were the black globe in the south shaded and unshaded room and the air in the south shaded and unshaded room. Inspection of Fig. 3 for September, 1955, indicates that the black globe in the south unshaded room showed temperatures almost uniformly higher than the air in the south unshaded room by values in the neighborhood of 10°F. Both the black globe and the air in the south shaded room remained lower in nearly all cases than the air in the south unshaded room. Unfortunately, the temperature recorder was out of order for approximately the last 2-1/2 weeks of September, and the temperature record is incomplete in this regard.

In Fig. 4 daily maximum temperatures during October, 1955, for the same points as mentioned for September, show trends similar to those of the September plot. The recorder was out of order for about the first 2 weeks of October also. The maximum radiant temperatures in the south unshaded room reached values almost as high in October as they did in September. However, the temperatures during October fluctuated over considerably wider limits than during September. Possibly this wide fluctuation of temperature was one variable causing noticeable discomfort during this period. That is, if people came to work dressed for cold weather, radiant temperatures approaching 100°F would result in discomfort much more noticeable than if the people had come in dressed for warm weather. It has been noted in a previous report (461:1110-1-T) that black ball temperatures reached maxima somewhat higher during the summer than they did during October.

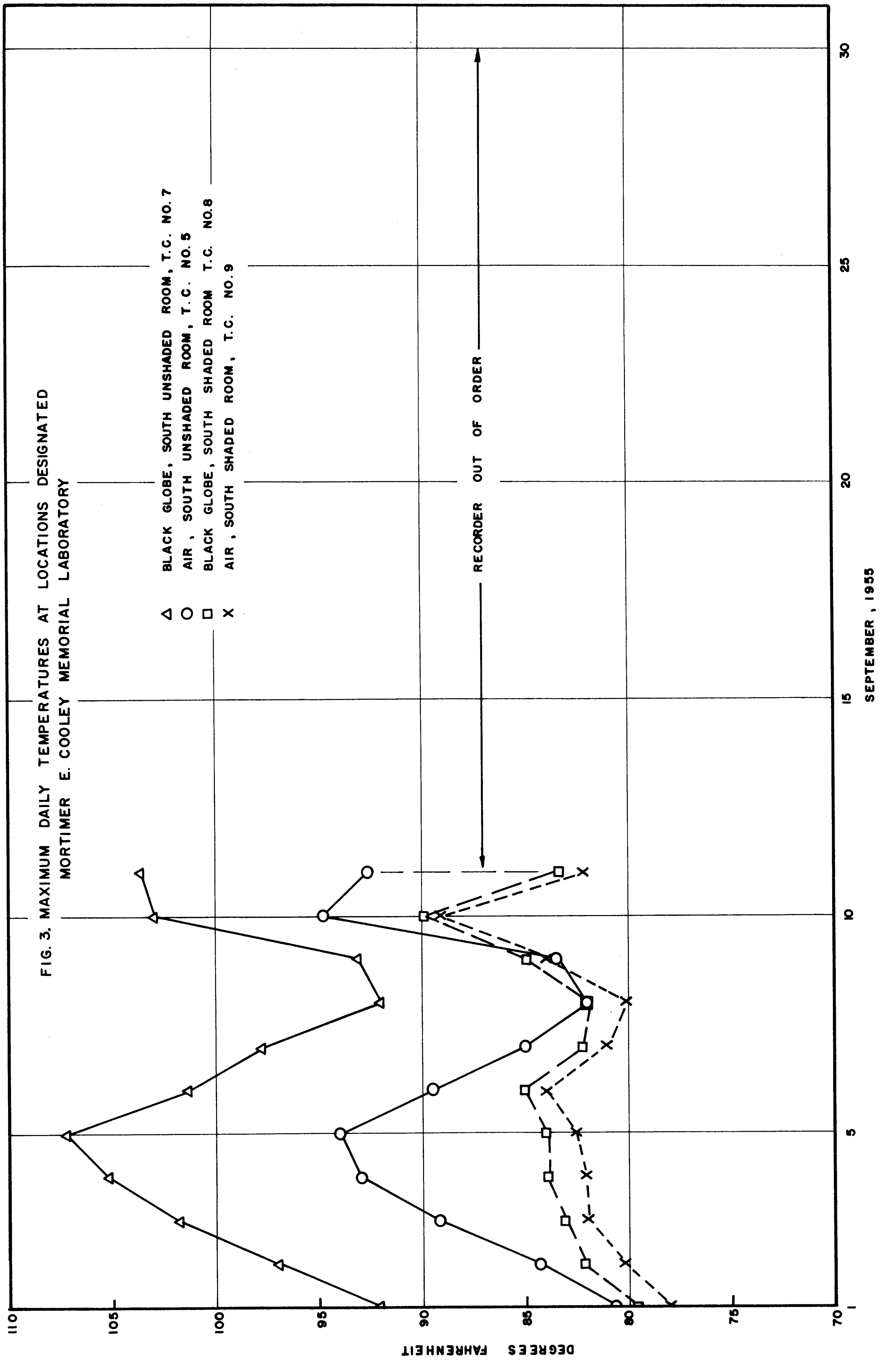


FIG. 3. MAXIMUM DAILY TEMPERATURES AT LOCATIONS DESIGNATED MORTIMER E. COOLEY MEMORIAL LABORATORY

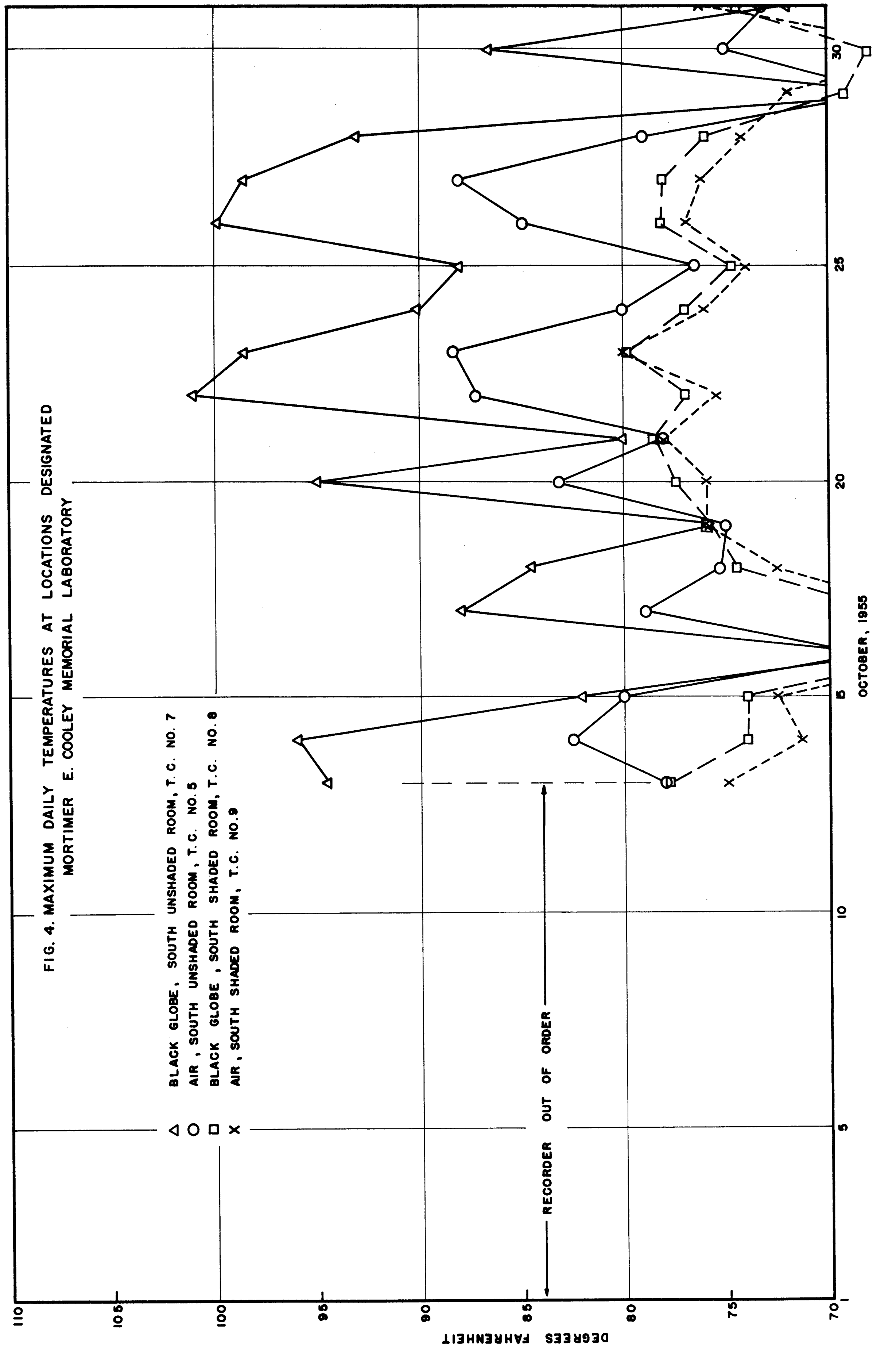


FIG. 4. MAXIMUM DAILY TEMPERATURES AT LOCATIONS DESIGNATED MORTIMER E. COOLEY MEMORIAL LABORATORY

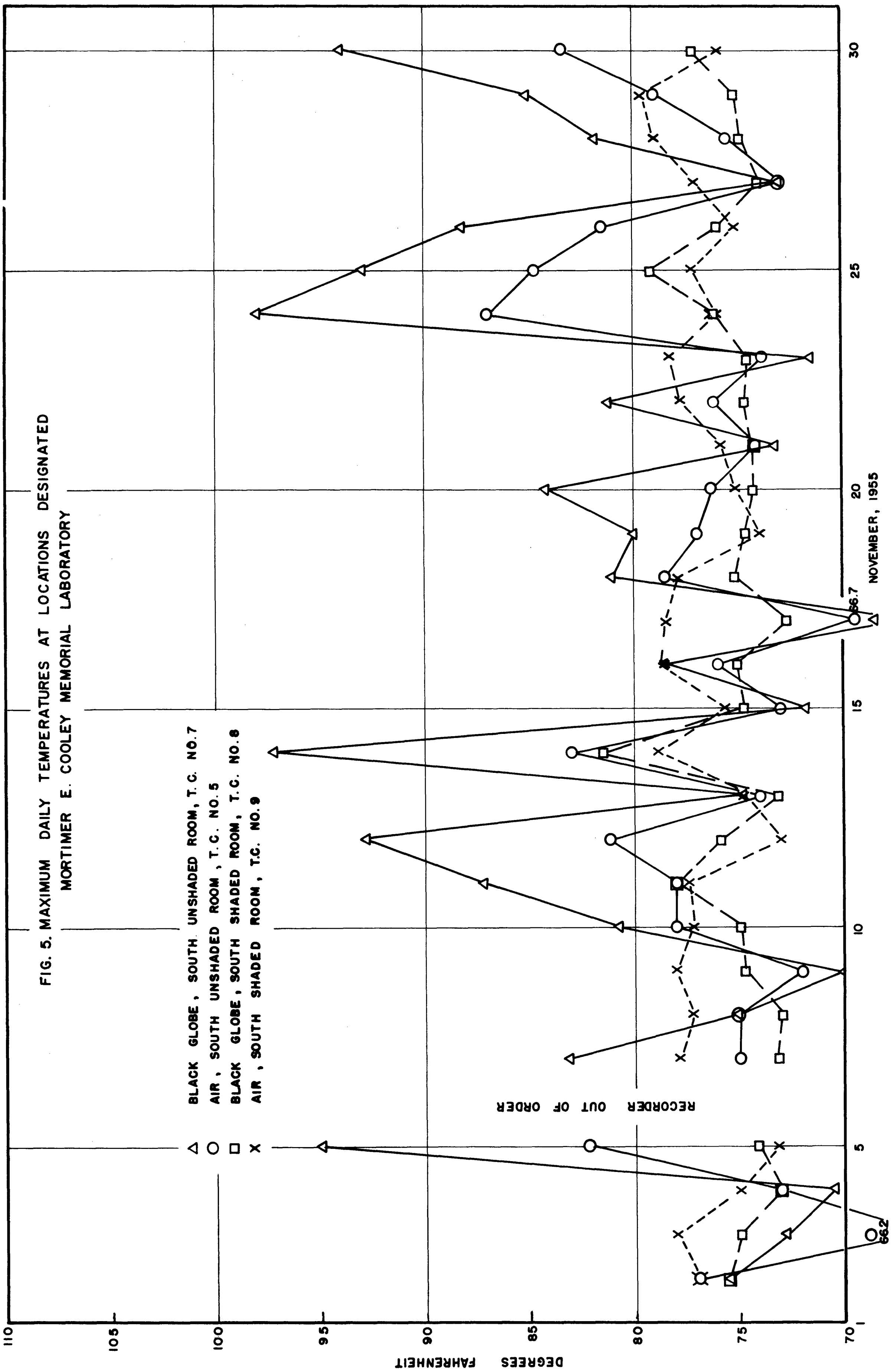


FIG. 5. MAXIMUM DAILY TEMPERATURES AT LOCATIONS DESIGNATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

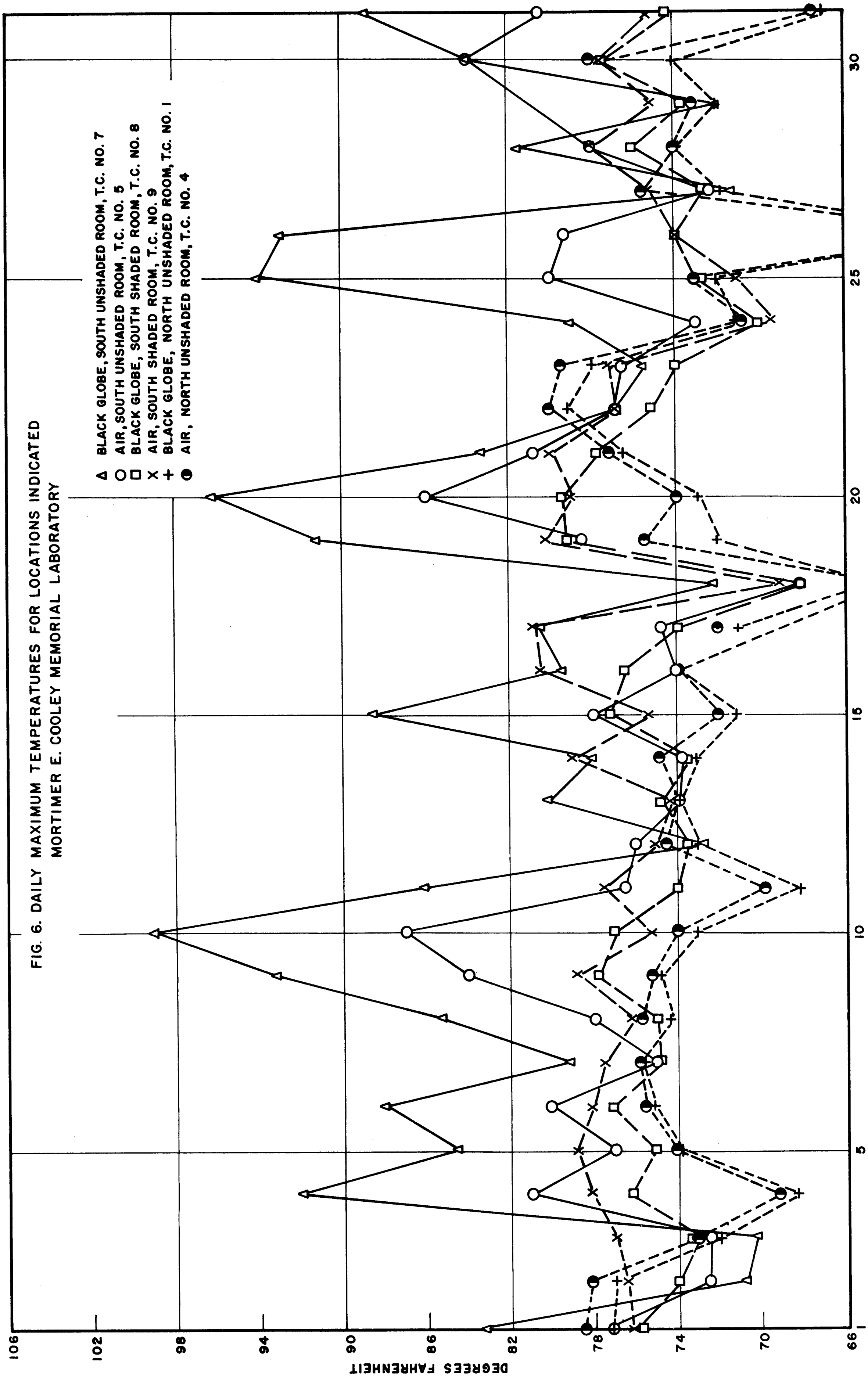


FIG. 6. DAILY MAXIMUM TEMPERATURES FOR LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

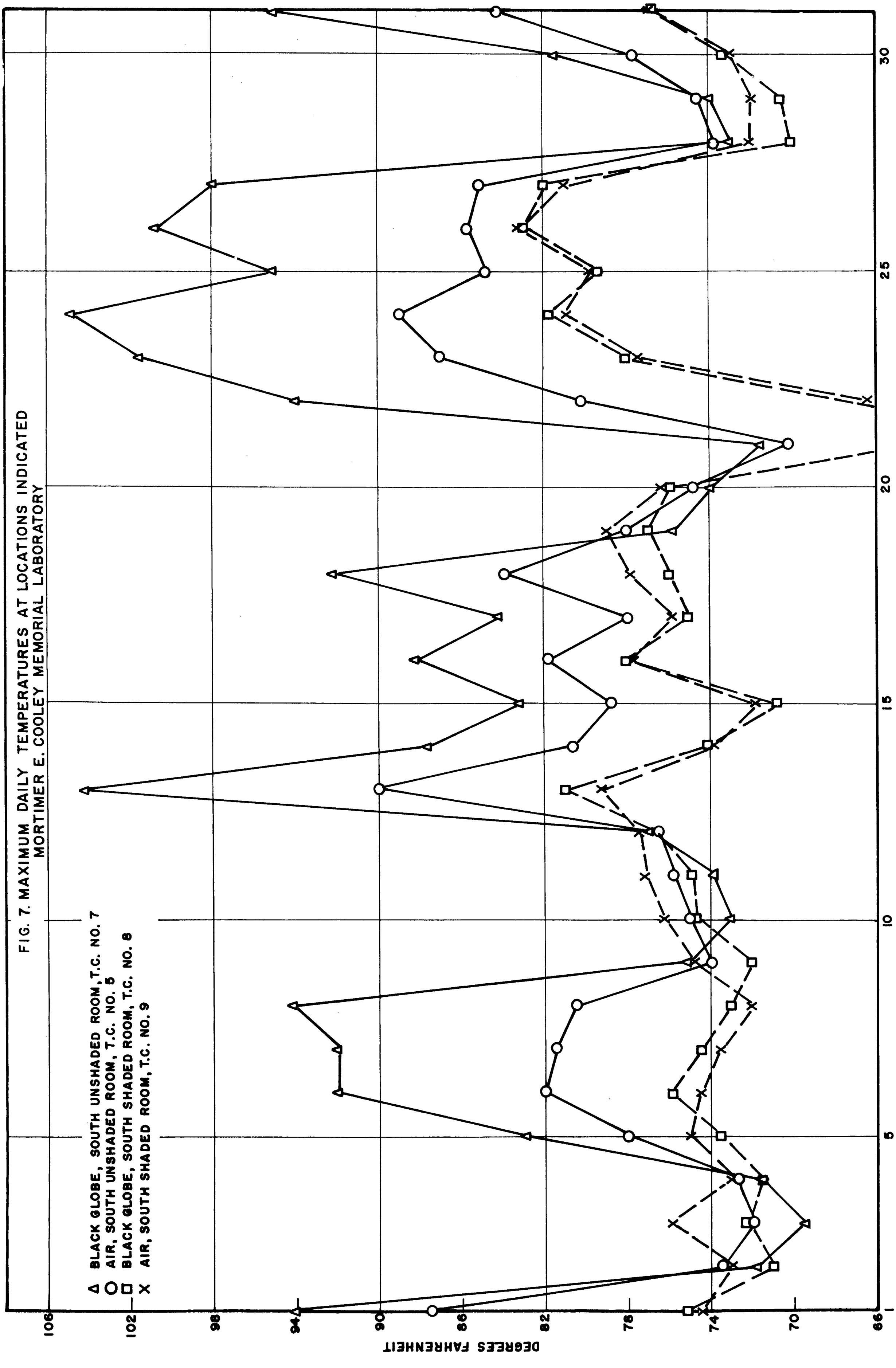


FIG. 7. MAXIMUM DAILY TEMPERATURES AT LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

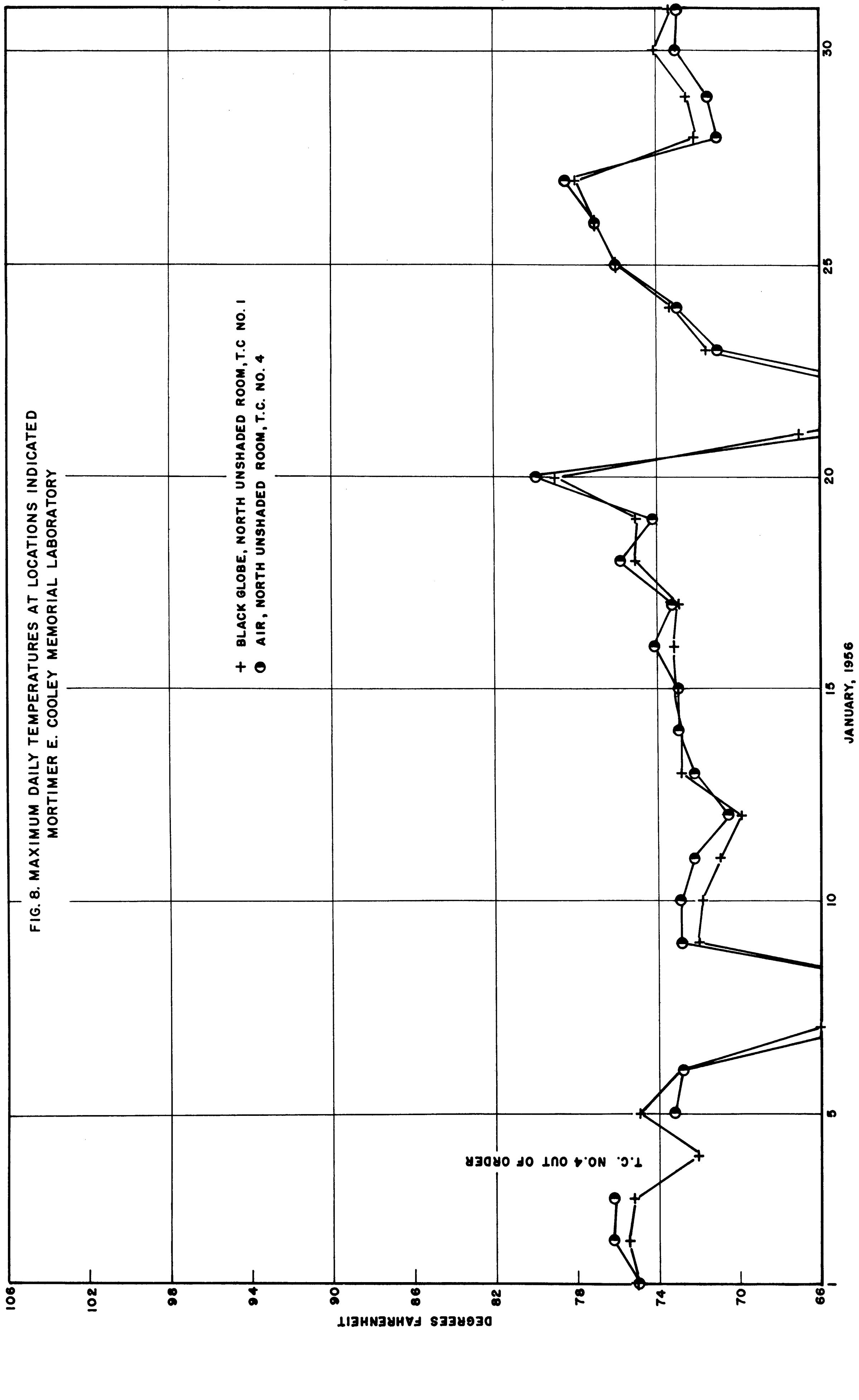


FIG. 8. MAXIMUM DAILY TEMPERATURES AT LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

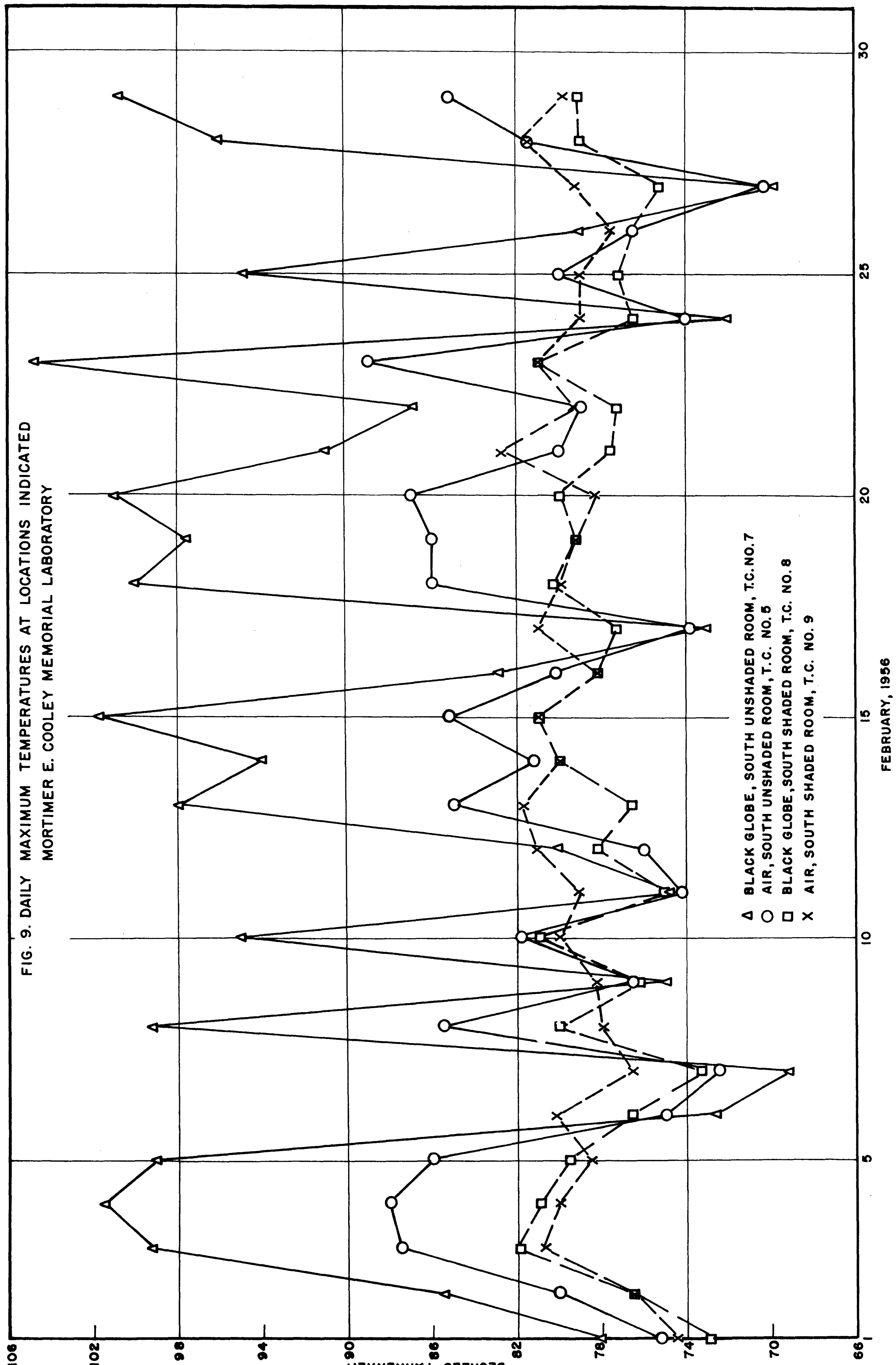


FIG. 9. DAILY MAXIMUM TEMPERATURES AT LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

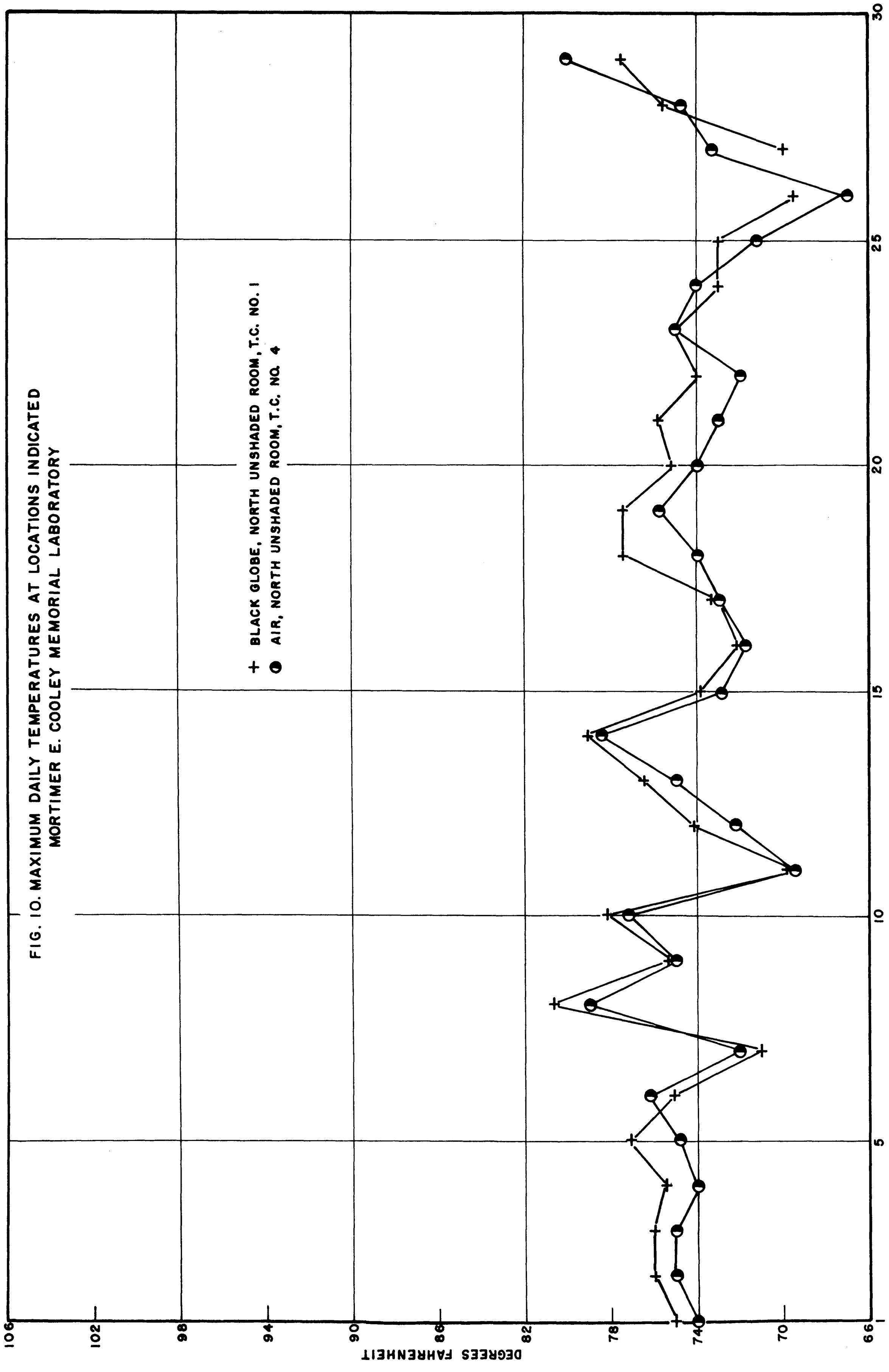


FIG. 10. MAXIMUM DAILY TEMPERATURES AT LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

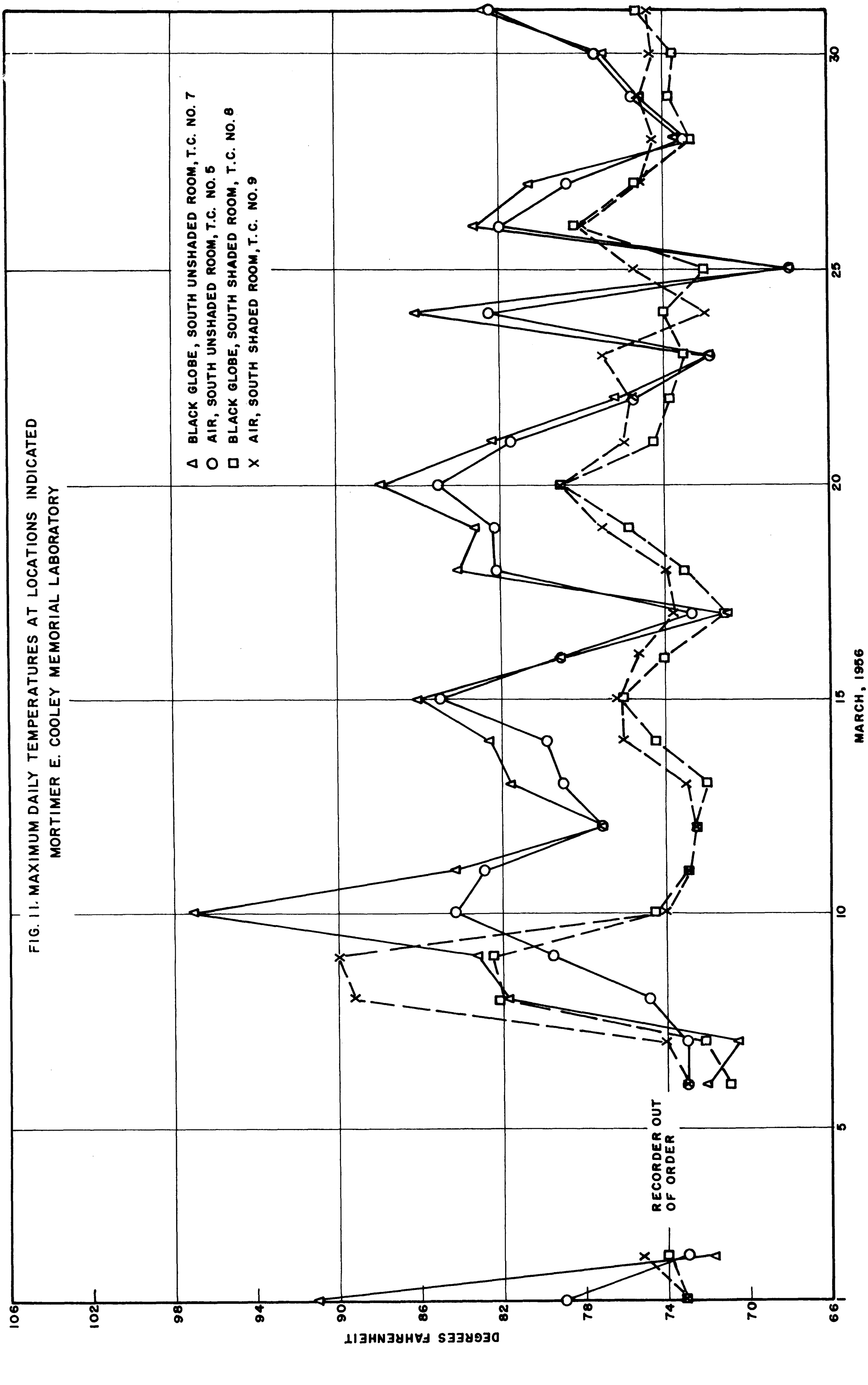


FIG. 11. MAXIMUM DAILY TEMPERATURES AT LOCATIONS INDICATED MORTIMER E. COOLEY MEMORIAL LABORATORY

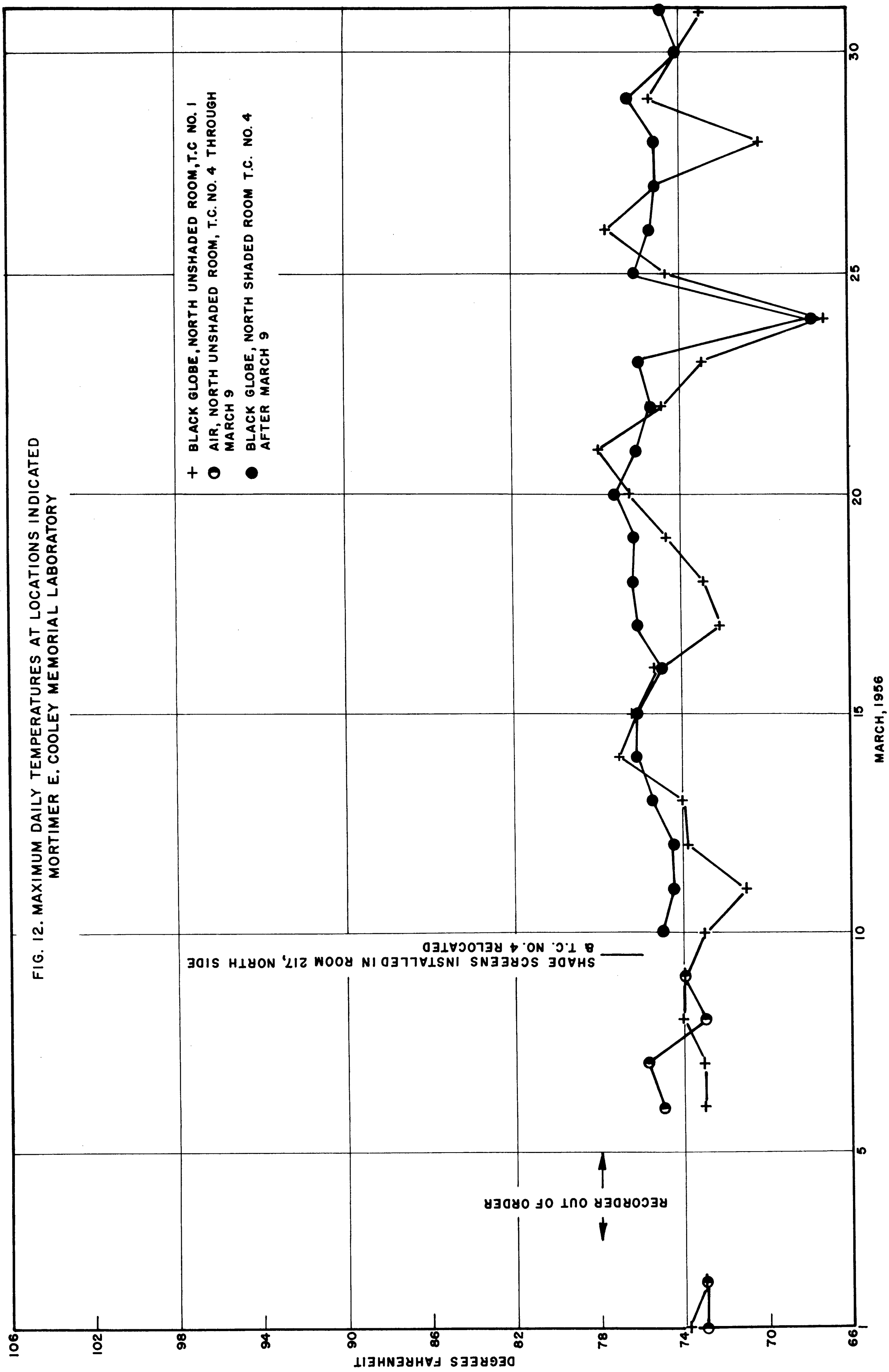


FIG. 12. MAXIMUM DAILY TEMPERATURES AT LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

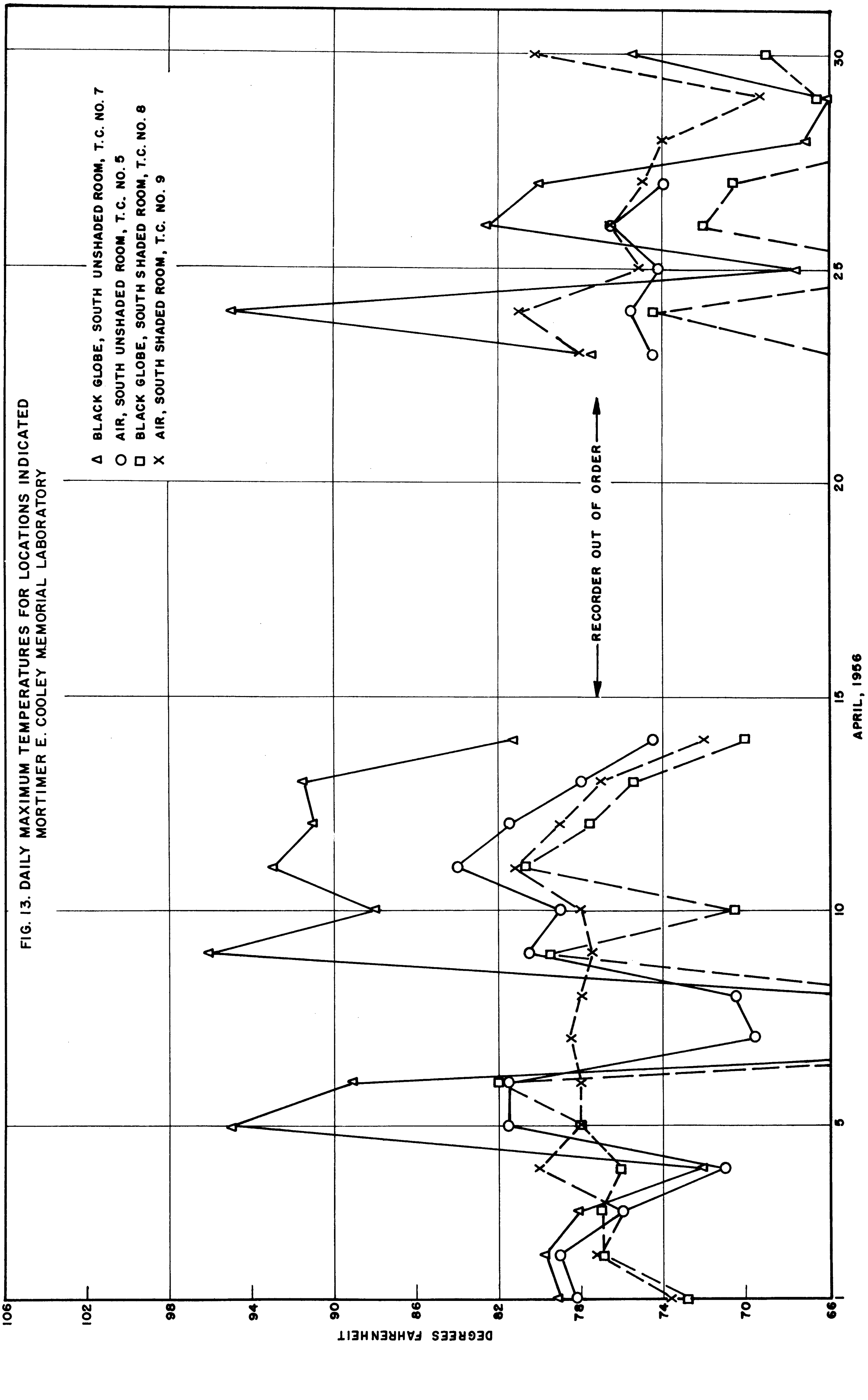


FIG. 13. DAILY MAXIMUM TEMPERATURES FOR LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

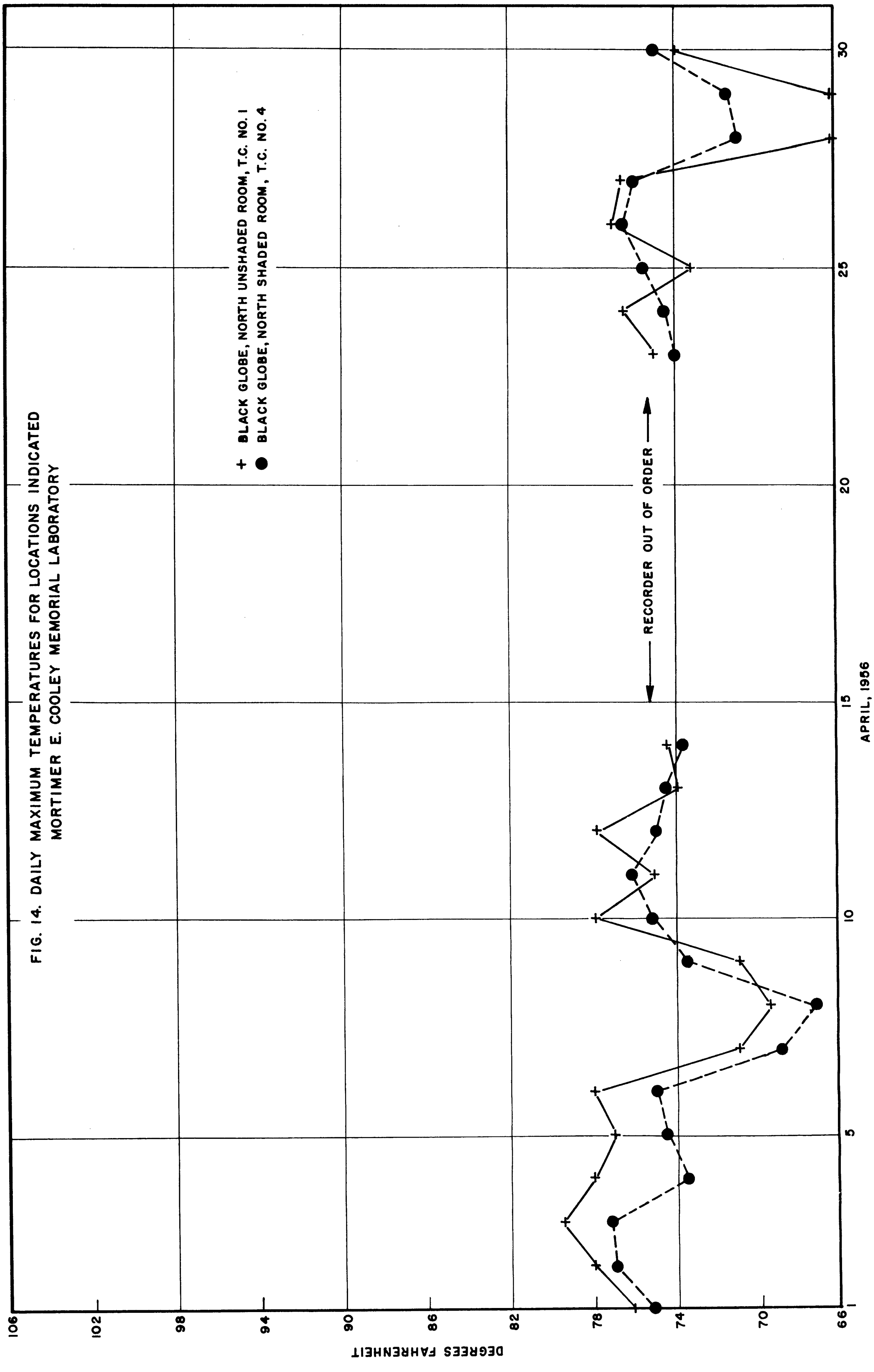


FIG. 14. DAILY MAXIMUM TEMPERATURES FOR LOCATIONS INDICATED
MORTIMER E. COOLEY MEMORIAL LABORATORY

In Fig. 5 the same temperatures are plotted for November, 1955, as were mentioned above for September and October, 1955. For November, temperatures follow much the same trend as for September and October except that generally in the shaded room both the black ball and air temperatures remained relatively stable. The air temperature in the unshaded room was somewhat lower than for the previous months, but again there were noticeable large fluctuations in the black ball temperature in the unshaded room. This situation could again cause the kind of discomfort mentioned in the paragraph above.

In Fig. 6 daily maximum temperatures for December, 1955, are plotted by days. For the month of December it was decided to include in the same plot the black ball and air temperatures for the north unshaded room. This plotting of all 6 temperatures on the same chart results in a somewhat complex figure, but does serve to give a simultaneous comparison of comfort on both the north and south side of the building. It can be observed that both the black ball and air temperatures on the north side of the building were generally lower than corresponding temperatures on the south side of the building. It can also be observed that the black ball and air temperatures in the south unshaded room were again higher than they were in the south shaded room. It can be noted that even during the month of December quite high values of black ball temperature were observed in the south unshaded room, in one case approaching 100°F.

In Fig. 7 the data for the two south rooms are plotted for January, 1956. The pattern of temperatures here is similar to that for the fall months. It is surprising to note that the black ball temperatures in the south unshaded room reached quite large values and fluctuated between wide limits. Several black ball temperatures in the south unshaded room were observed in excess of 102°F.

In Fig. 8 daily maximum black globe and air temperatures for the north unshaded room are plotted for January, 1956. It was decided to plot these separately from the data for the south rooms to clarify the plots. The black globe and air temperatures follow each other rather closely for the north side room and remain mostly at moderate values. Some values below 66°F were observed.

In Fig. 9 for February, 1956, the black globe and air temperatures for the south shaded and unshaded rooms are plotted. In this plot the black globe and air temperatures for the south shaded room remained relatively stable, although fluctuating between about 74 and 82°F, somewhat higher than had been observed in some previous months. This situation may have been caused by operation of the building heating plant. One of the most interesting features of the February plot is the observance again of large variations in black ball temperature reaching a number of maximum temperatures in excess of 98°F. In this sense the February, 1956, plot for the south rooms is quite similar to that observed during portions of October. The maxima for black ball temperature in the south unshaded room were higher and more frequent during February than during October.

In Fig. 10 the black globe and air temperatures for the north unshaded room are plotted for February, 1956. These temperatures are relatively stable and close together, centering between 66 and 80°F.

In Fig. 11 the data for the two south rooms are plotted for March, 1956. March is the first month studied in which the black globe temperatures for the south unshaded room approach the other temperatures. Black globe temperatures for the south unshaded room are still higher than the other temperatures but only two maxima above 90°F were observed for the month.

In Fig. 12 the data for the north side rooms are plotted for March, 1956. On March 10, 1956, shade screens were installed in Room 217. Consequently, for the first 10 days of the month the black globe and air temperatures are presented for the north unshaded room, whereas for the latter 21 days of the month the black globe temperatures are presented for the north unshaded room and for the north shaded room. In either case the temperatures are relatively stable and center about 74°F, indicating relatively comfortable conditions.

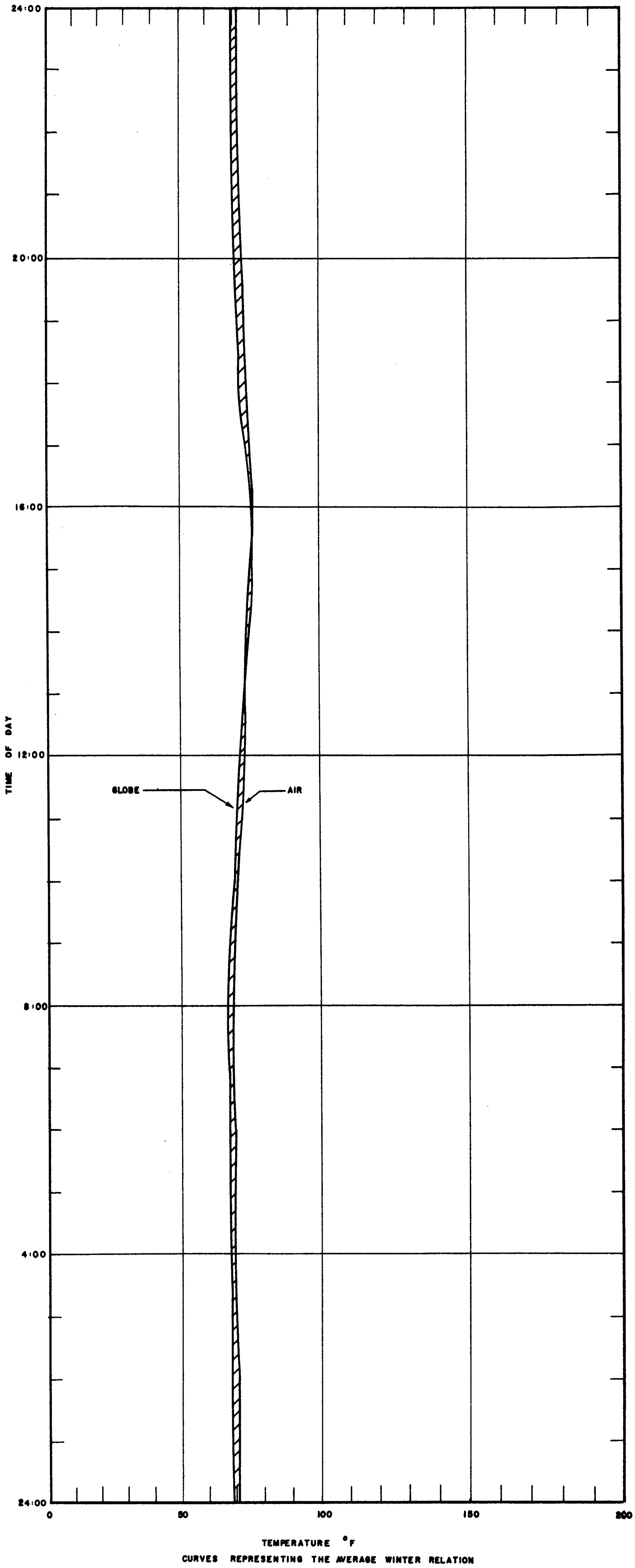
The black globe and air temperatures for the two south rooms for the month of April, 1956, are portrayed in Fig. 13. The recorder was out of order about one week during the middle of the month. Large maxima of black globe temperatures appeared for the south unshaded room as well as some low values for the black globe temperature. The other temperatures remained relatively stable, and the temperatures are rather close together. However, it appears that in a significant number of days the black globe in the unshaded room is higher than that in the shaded room.

A. VARIATIONS OF TEMPERATURES THROUGHOUT THE COURSE OF A SINGLE DAY

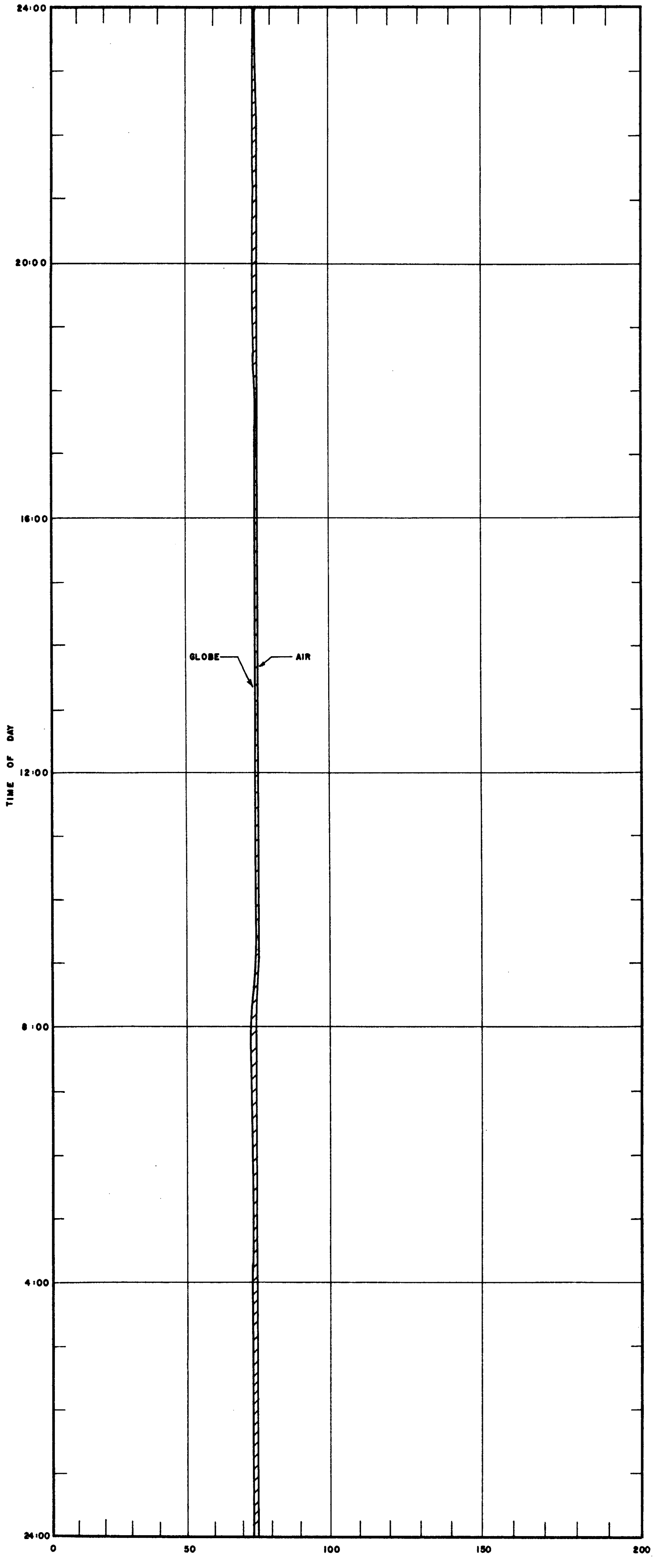
Figures 15 through 27 are presented to show the manner in which individual temperatures vary with the time of day. This information is supplementary to that provided in Figs. 3 through 14, the daily maxima for temperatures at selected locations.

The information in Figs. 15 through 27 was formulated by the following procedures, intended to provide a picture of representative conditions within the test rooms studied in the Cooley Laboratory. No fundamental significance is claimed for the method of formulating the data, and indications should be interpreted in the light of the procedures as described below.

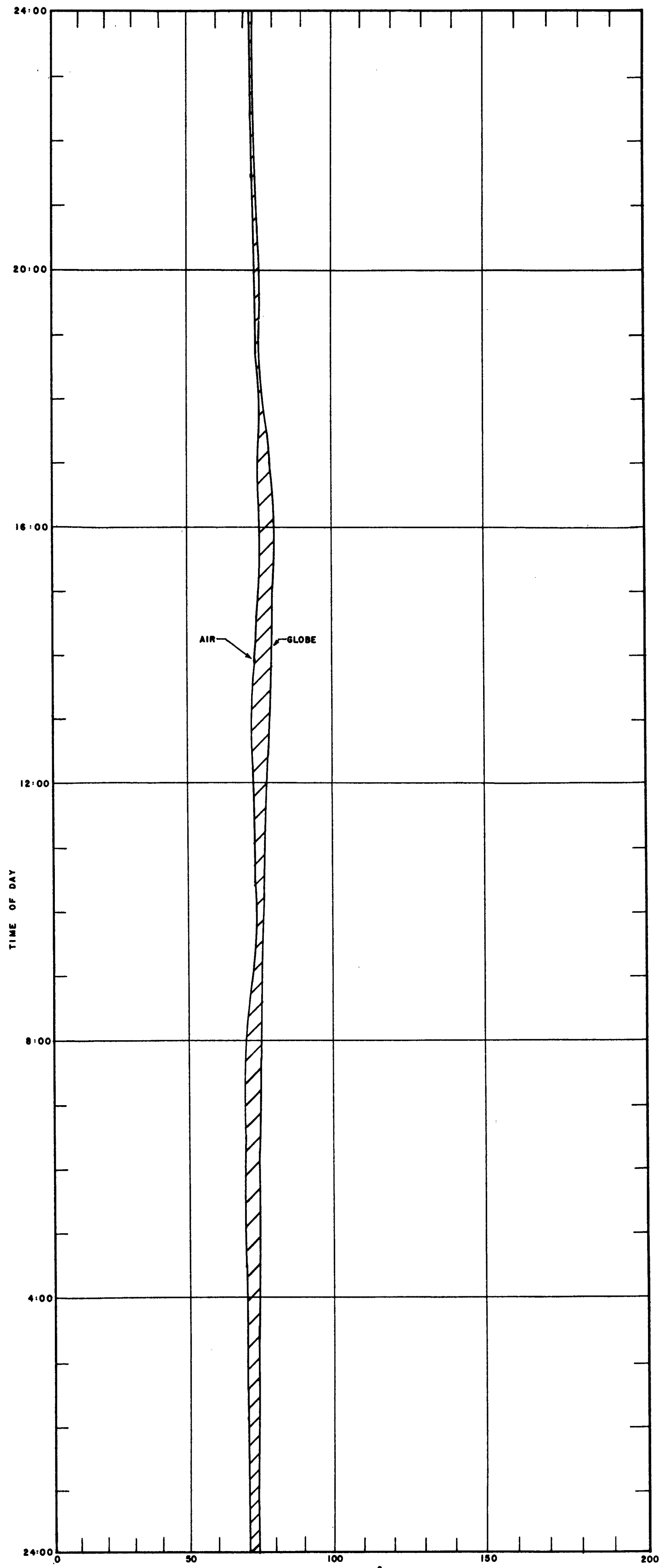
The average weather conditions for the months of January through March, 1956, were estimated from the data of the U. S. Weather Bureau at Willow Run. Average monthly conditions at the Weather Bureau Station mentioned for January, 1956, were: average monthly temperature, 25.3°F; average sky coverage from sunrise to sunset, 7.1; average wind velocity, 11.3 mph. For the month of February, 1956, at the same station: the average monthly temperature was



CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN AIR TEMPERATURE AND GLOBE TEMPERATURE
FOR THE NORTH SIDE UNSHADED ROOM
FIG. 15

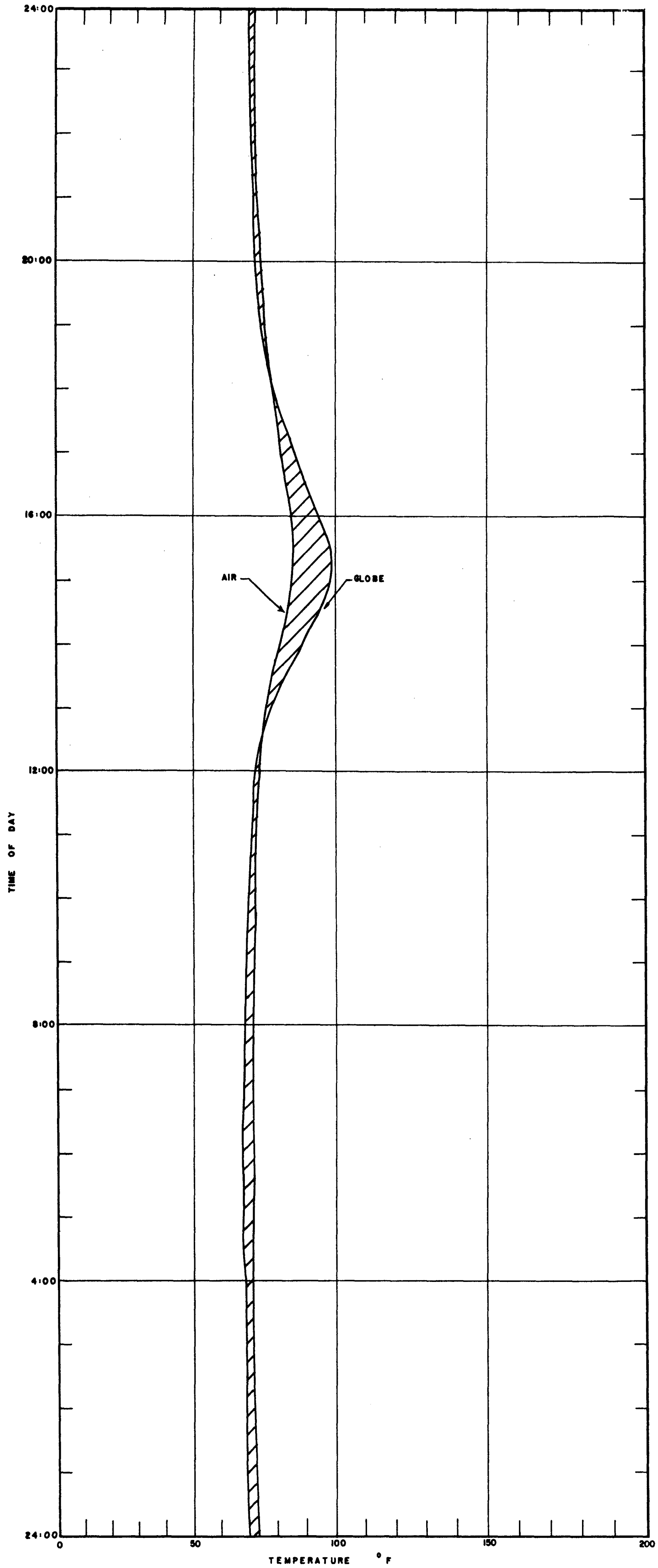


CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN AIR TEMPERATURE AND GLOBE TEMPERATURE
FOR THE NORTH SIDE SHADED ROOM
FIG. 16

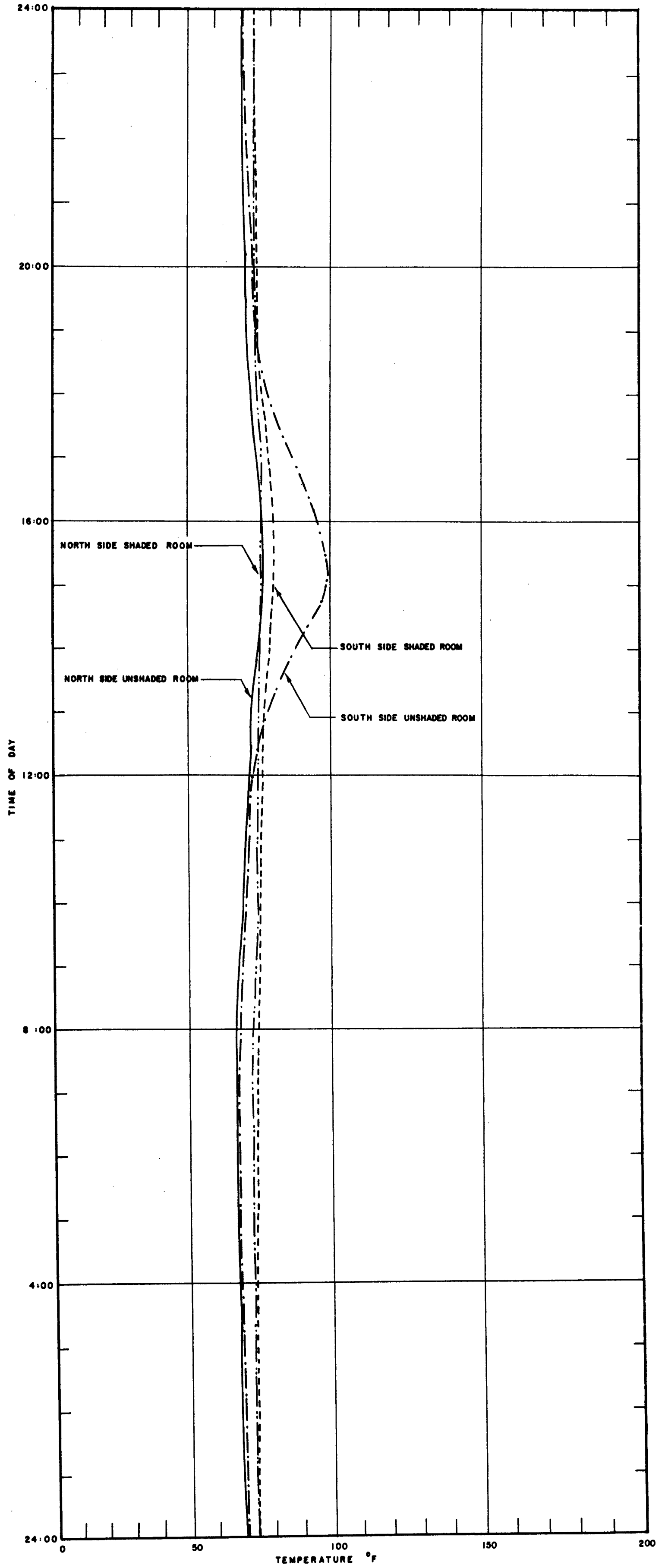


CURVES REPRESENTING THE AVERAGE WINTER RELATION BETWEEN AIR TEMPERATURE AND GLOBE TEMPERATURE FOR THE SOUTH SIDE SHADED ROOM

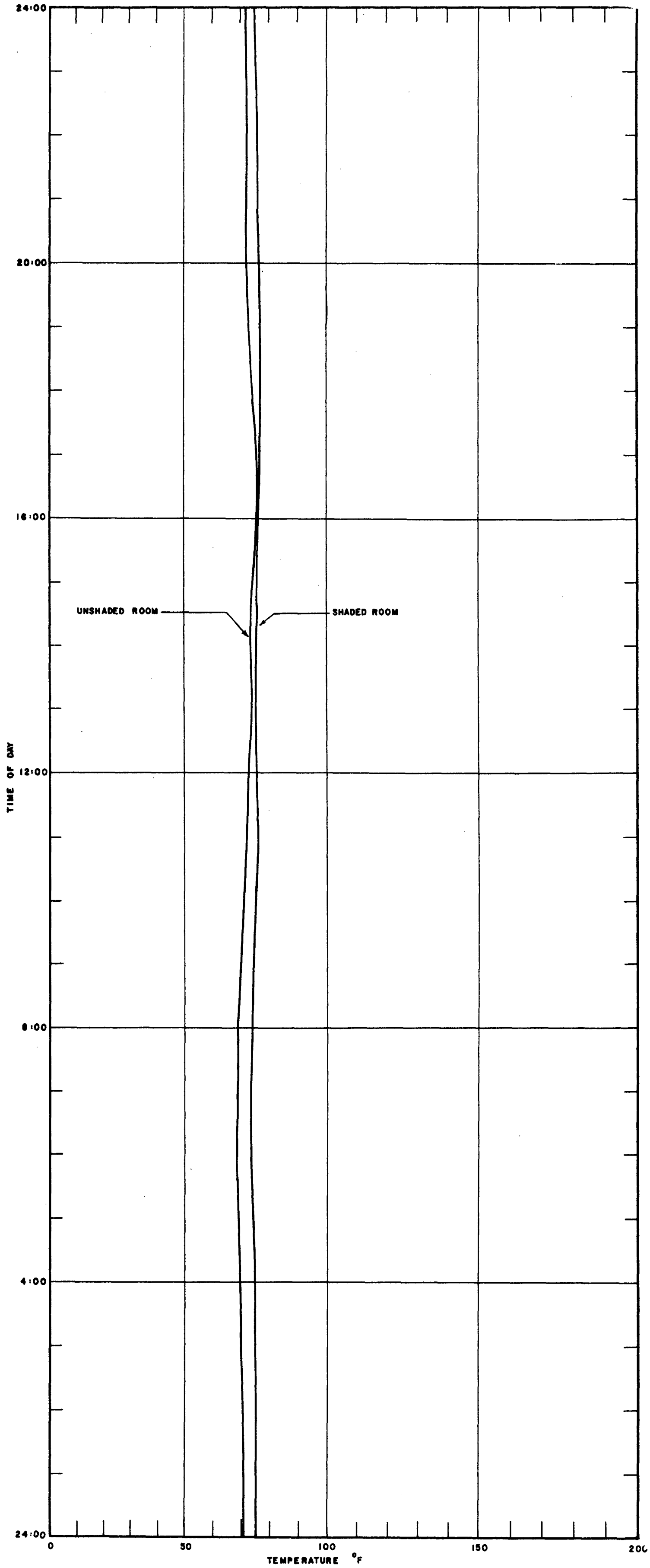
FIG. 17



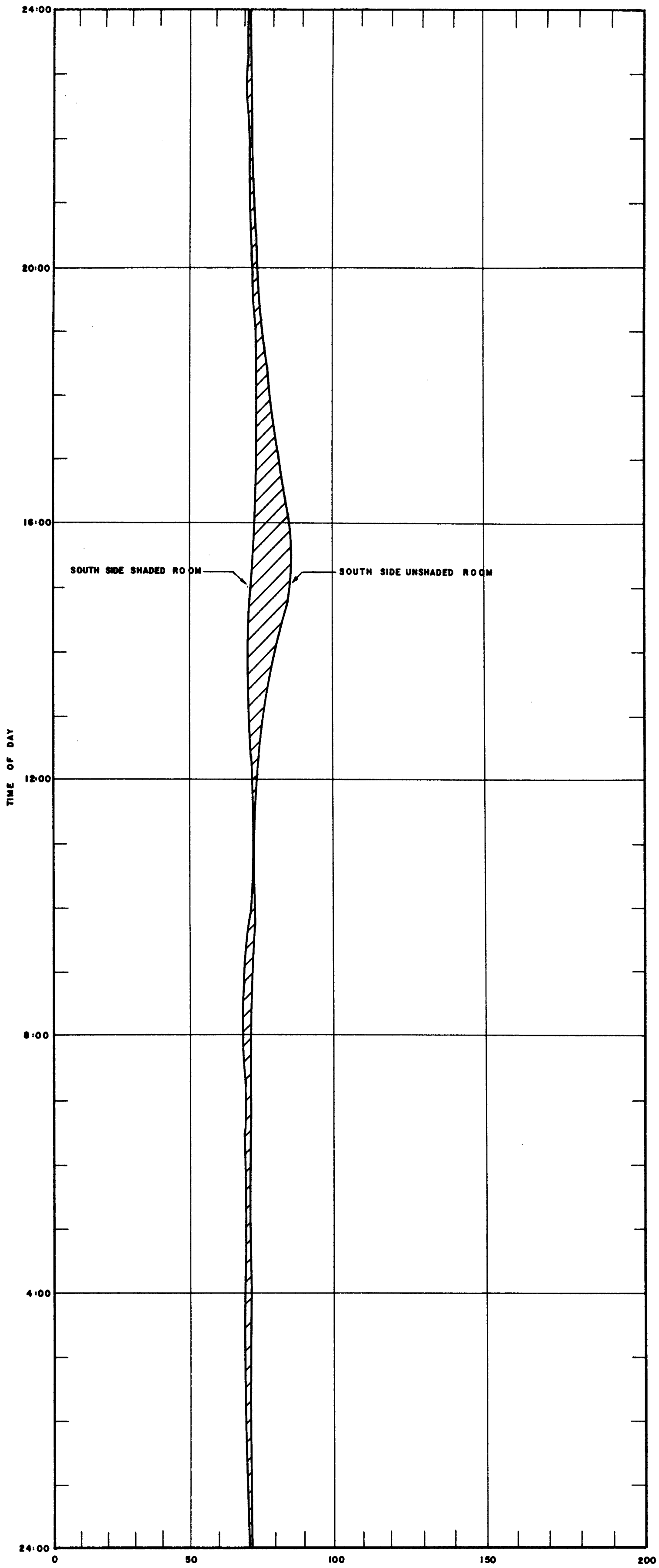
CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN AIR TEMPERATURE AND GLOBE TEMPERATURE
FOR THE SOUTH SIDE UNSHADED ROOM
FIG. 18



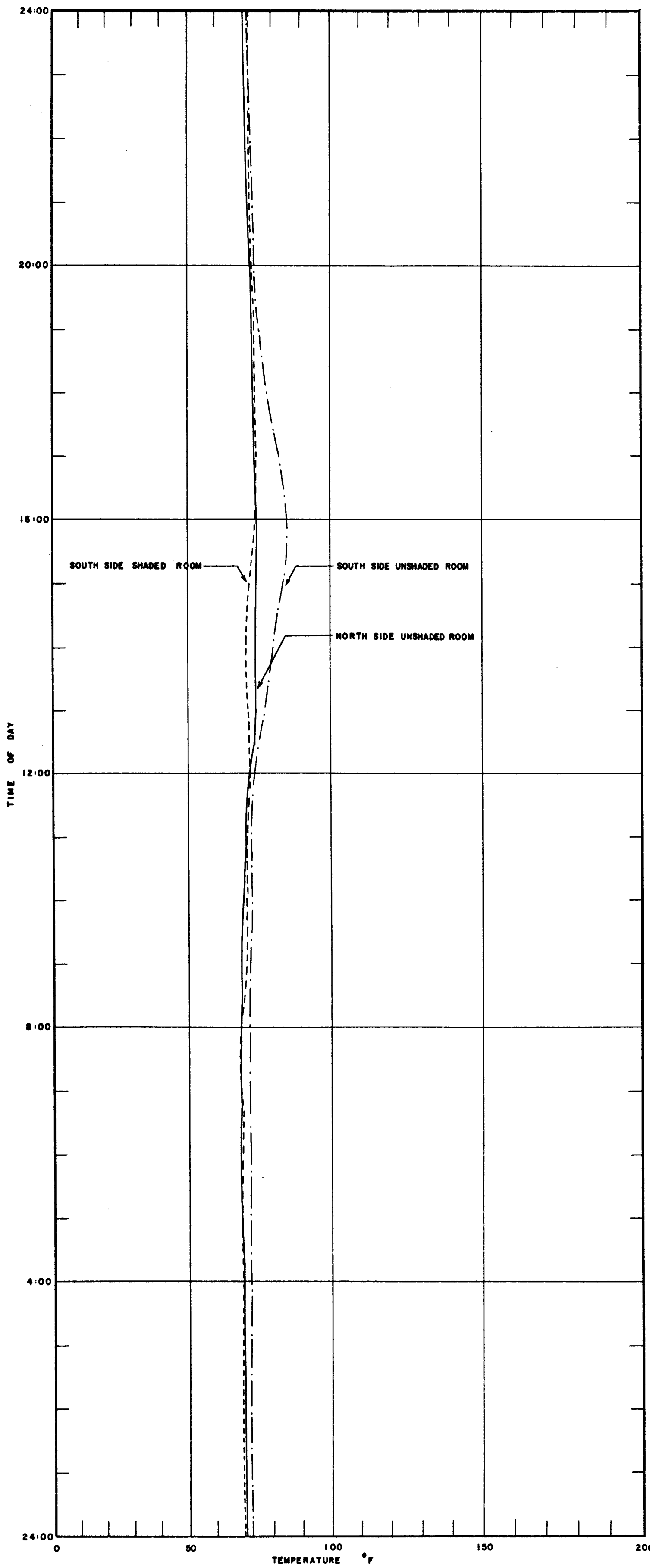
CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN GLOBE TEMPERATURES
FOR THE NORTH, SOUTH SIDE SHADED AND UNSHADED ROOMS
FIG. 19



CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN AIR TEMPERATURES
FOR THE NORTH SIDE SHADED AND UNSHADED ROOMS
FIG. 20

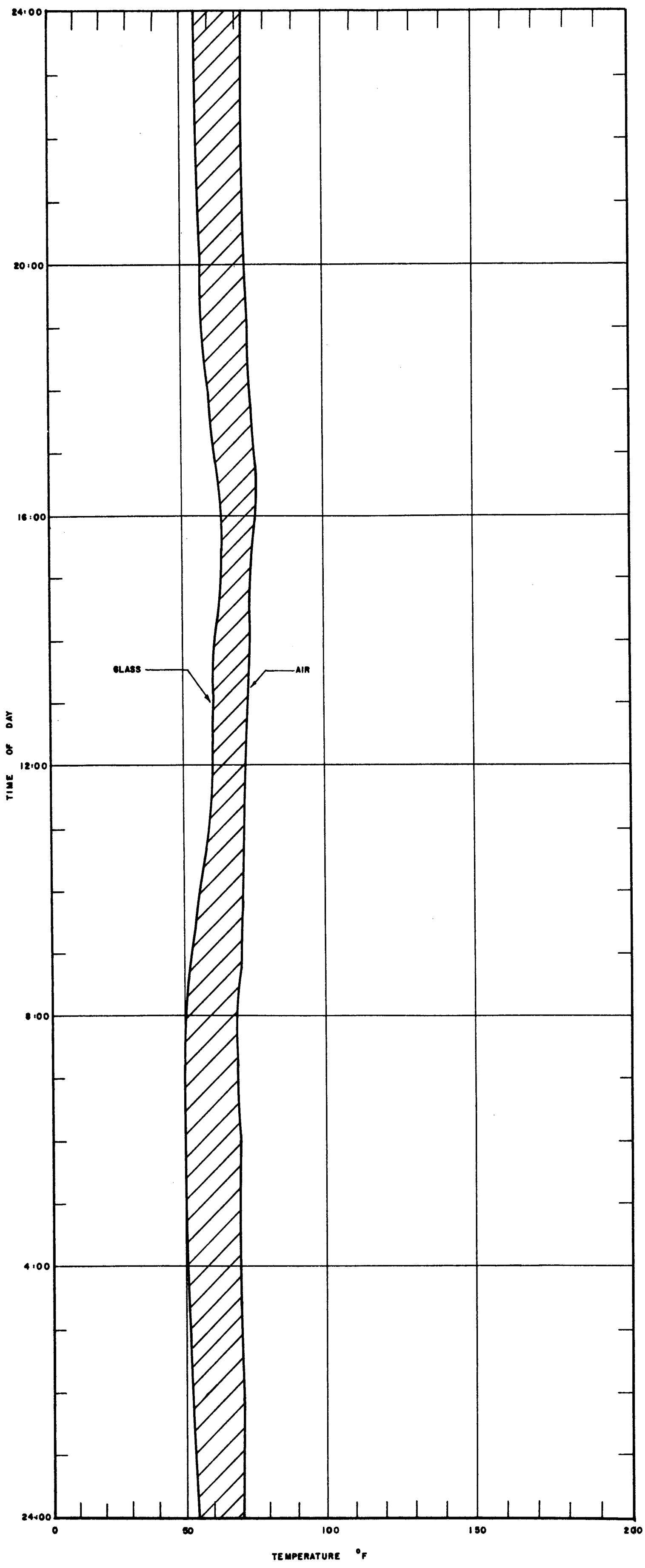


CURVES REPRESENTING THE AVERAGE WINTER RELATION BETWEEN AIR TEMPERATURES FOR THE SOUTH SIDE SHADED AND UNSHADED ROOMS
FIG. 21

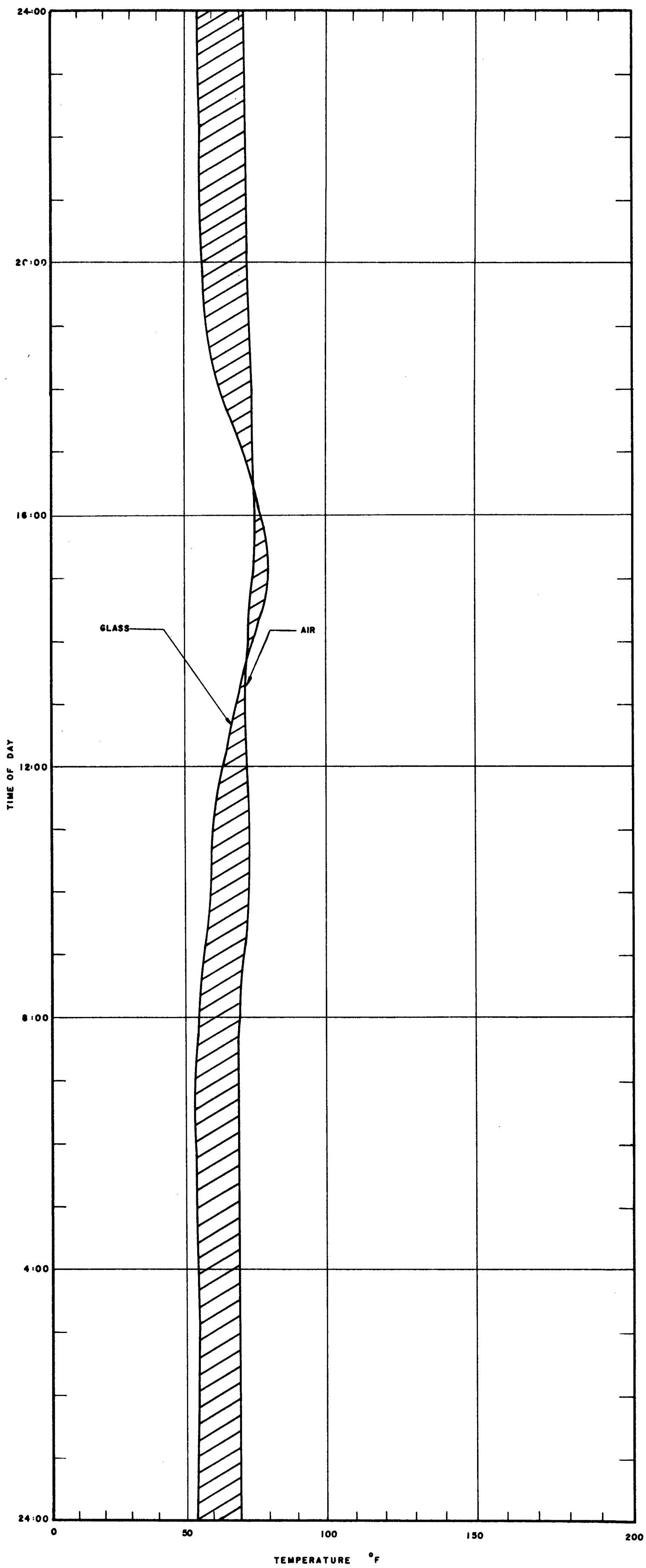


CURVES REPRESENTING THE AVERAGE WINTER RELATION BETWEEN AIR TEMPERATURES FOR THE NORTH, SOUTH SIDE UNSHADED ROOMS AND SOUTH SIDE SHADED ROOM

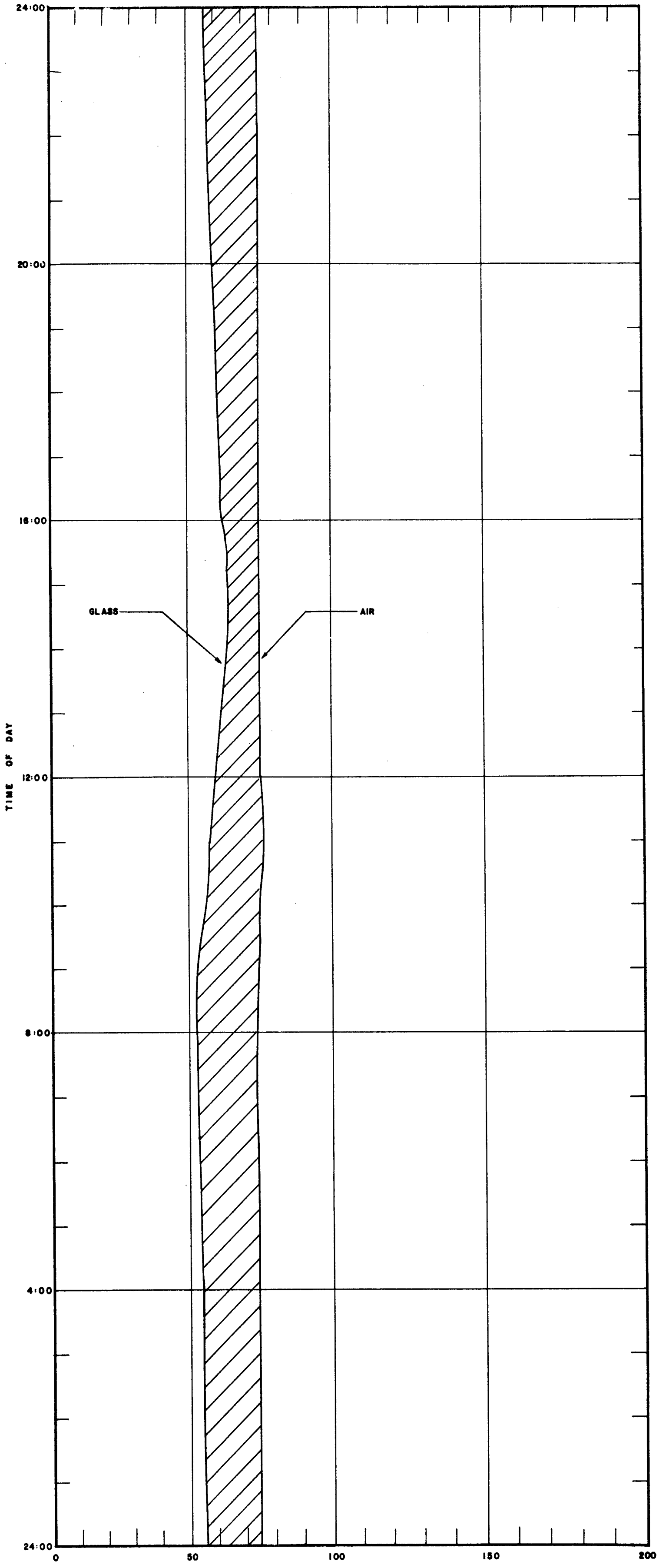
FIG. 22



CURVES REPRESENTING THE AVERAGE WINTER RELATION BETWEEN AIR TEMPERATURE AND GLASS TEMPERATURE FOR THE NORTH SIDE UNSHADED ROOM
FIG. 23

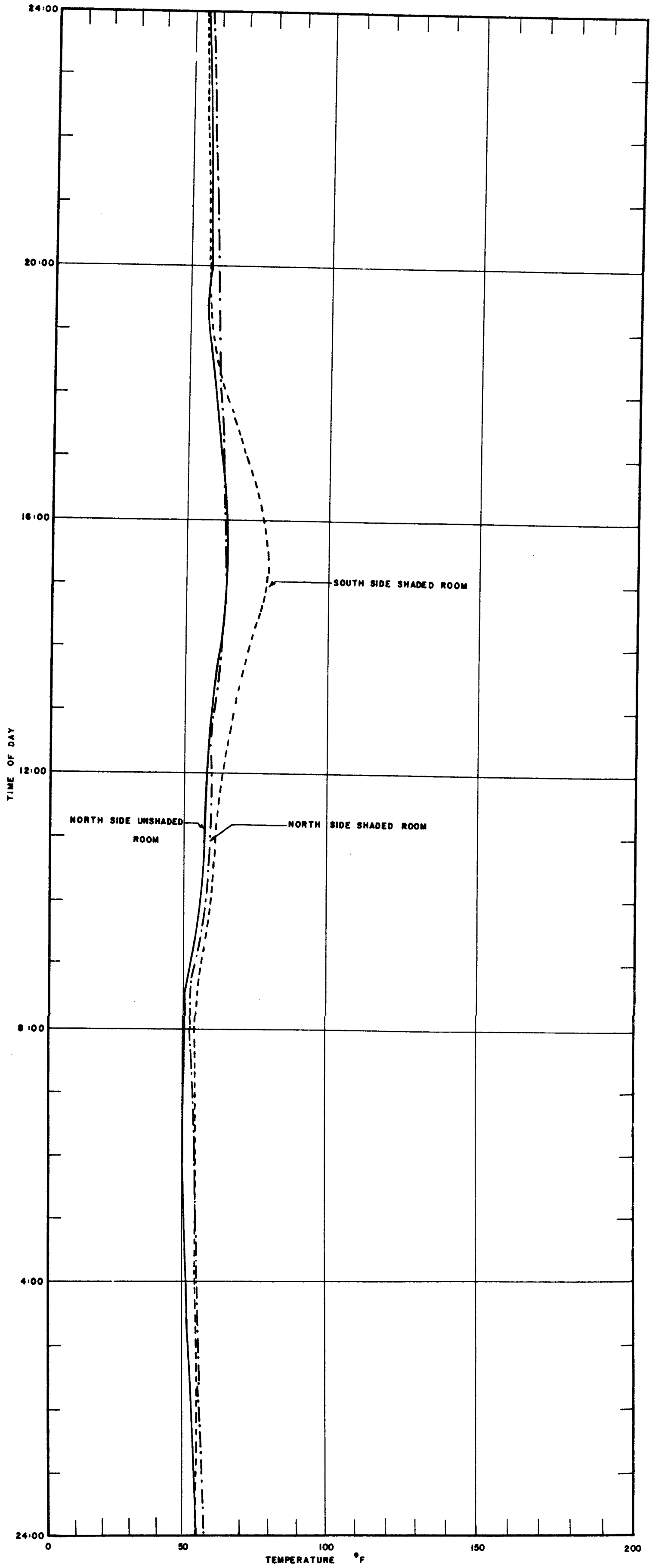


CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN AIR TEMPERATURE AND GLASS TEMPERATURE
FOR THE SOUTH SIDE SHADED ROOM
FIG. 24

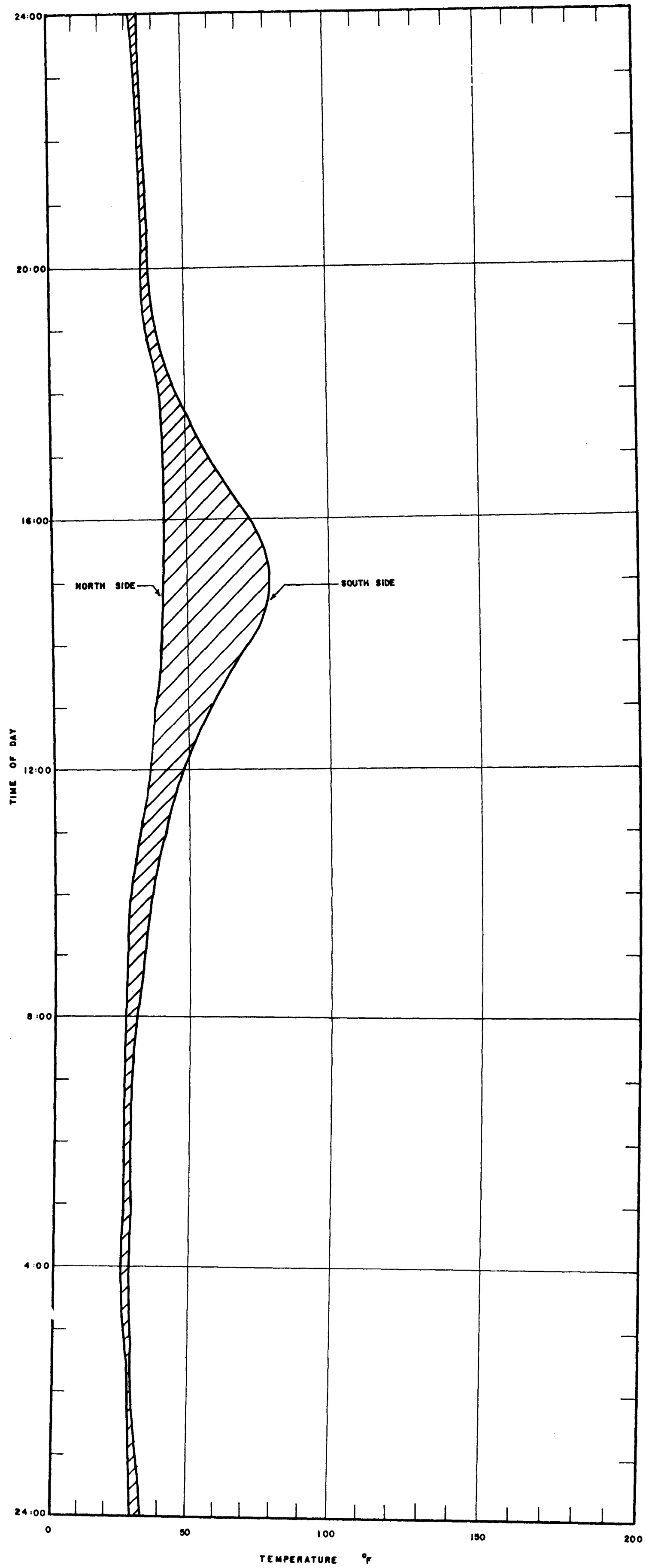


CURVES REPRESENTING THE AVERAGE WINTER RELATION BETWEEN AIR TEMPERATURE AND GLASS TEMPERATURE FOR THE NORTH SIDE SHADED ROOM

FIG. 25



CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN GLASS TEMPERATURES
FOR THE NORTH, SOUTH SIDE SHADED ROOMS AND
NORTH SIDE UNSHADED ROOM
FIG. 26



CURVES REPRESENTING THE AVERAGE WINTER RELATION
BETWEEN SCREEN TEMPERATURES
FOR THE NORTH AND SOUTH SIDE SHADED ROOMS
FIG. 27

28.0°F; the average sky coverage from sunrise to sunset was 6.9; and the average wind velocity was 11.6 mph. For the month of March, 1956, at the weather station mentioned, the average monthly temperature was 32.9°F; the average sky coverage from sunrise to sunset was 7.3; and the average wind velocity was 13.8 mph.

Averages for the three-month period were obtained from the average conditions for January, February, and March, 1956. Three-month averages were: temperature, 28.7°F, sky coverage, 7.1, and wind velocity, 12.2 mph. Once these were established from the weather bureau data, the weather records were searched for individual days which most closely approximated the average conditions during this period. Two days meeting these requirements were February 5, 1956, and March 15, 1956. For February 5, 1956, the average temperature was 29°F, the average sky coverage was 7.0, and the average wind velocity, 7.6 mph. For March 15, 1956, the average temperature was 29°F, the average sky coverage, 6.0, and the average wind velocity, 11.3 mph.

The data for February 5, 1956, formed the basis for all the temperature records presented in Figs. 15 through 27 with the exception of the data for the north side shaded room. Since the shade screens were installed in the north side room on March 10, 1956, the data for February 5 could not be used. Consequently, the data for the north side shaded room were taken from data recorded March 15, 1956, a day which also nearly met the average conditions as described above.

February 5, 1956, is representative of weather conditions as mentioned previously and also represents the day on which the solar angle and duration are at approximately average values for the three-month period of January, February, and March, 1956. The data for March 15, 1956, for the north side shaded room were adjusted for the duration of solar exposure to give the same time-dependent relationship of temperatures as that observed on February 5. That is, the temperatures recorded March 15, 1956, were not changed in plotting. However, the time scale was compressed to match the shorter length of day observed on February 5.

It is believed that the presentation of both the daily maximum temperatures, Figs. 3 through 14, and the average manner in which these temperatures varied throughout typical days, as presented in Figs. 15 through 27, provides a representative picture of temperature conditions in the Cooley Laboratory during the period under study.

B. SOME OBSERVATIONS OF COMFORT CONDITIONS

Data which were related to the comfort of personnel are presented in this section. Comfort data were obtained during regular working hours, 8 a.m. to 5 p.m. The observers whose impressions are reported comprise two or three people working on the study and doing office work, drafting, and electronics-laboratory work. Consequently, a small population is represented and the results must be viewed with some reservations. The data have been obtained by imposing the minimum restrictions of inconvenience on the personnel.

Figure 28 displays a plot of effective temperature against humidity, showing those conditions in which the evaluating personnel were comfortable at conditions not usually considered to lie within the winter comfort zone of the comfort chart. No data are available to explain why the relatively large number of points lie outside the comfort zone, although this observation may result from radiant heating, heavy clothing, individuals who do not meet the norm, or possibly other reasons.

In Fig. 29 points which were uncomfortable are plotted on the comfort chart. The plot shows that almost all the conditions of discomfort fall outside the winter comfort zone. Points as indicated are differentiated as to whether the subject felt too cool or too warm.

In Fig. 30 the mean radiant temperature minus the dry bulb temperature has been plotted against effective temperature over a range of relative humidities from 20% to 40%. A straight line has been drawn separating the comfortable from the uncomfortable points when radiant heating was being received by the subject. This straight line represents the upper limiting values of comfort. Any point lying on the upper side of this line would be uncomfortably warm; any point lying below the line but above the zero values of mean radiant temperature less dry bulb temperature would be comfortable. No attempt has been made to interpret the data for which mean radiant temperature was less than the dry bulb temperature.

On the basis of Fig. 30, it can be estimated that a 3-1/2°F rise in mean radiant temperature is equivalent to a decrease of 1°F in effective temperature when radiant heat is being received by the subject. Houghten, Gunst, and Suciu[2] made a similar study for winter conditions and found that for a 70°F effective temperature and 30% relative humidity a 2 Fahrenheit-degree change in mean radiant temperature was equivalent to a 1 Fahrenheit-degree change in the effective temperature in approaching the limits of the comfort zone. The work done by Houghten, Gunst, and Suciu was done in the winter but without appreciable sky glare.

The above results are summarized in Fig. 31. The use of the modified ASHVE comfort chart can be illustrated by an example. For instance, assume that the data are as follows:

Effective temperature: 68°F
Relative humidity: 50%
Mean radiant temperature minus dry bulb temperature: 5°F

Point A is located in the plane of the figure by values of the relative humidity and the effective temperature. This point could also be located

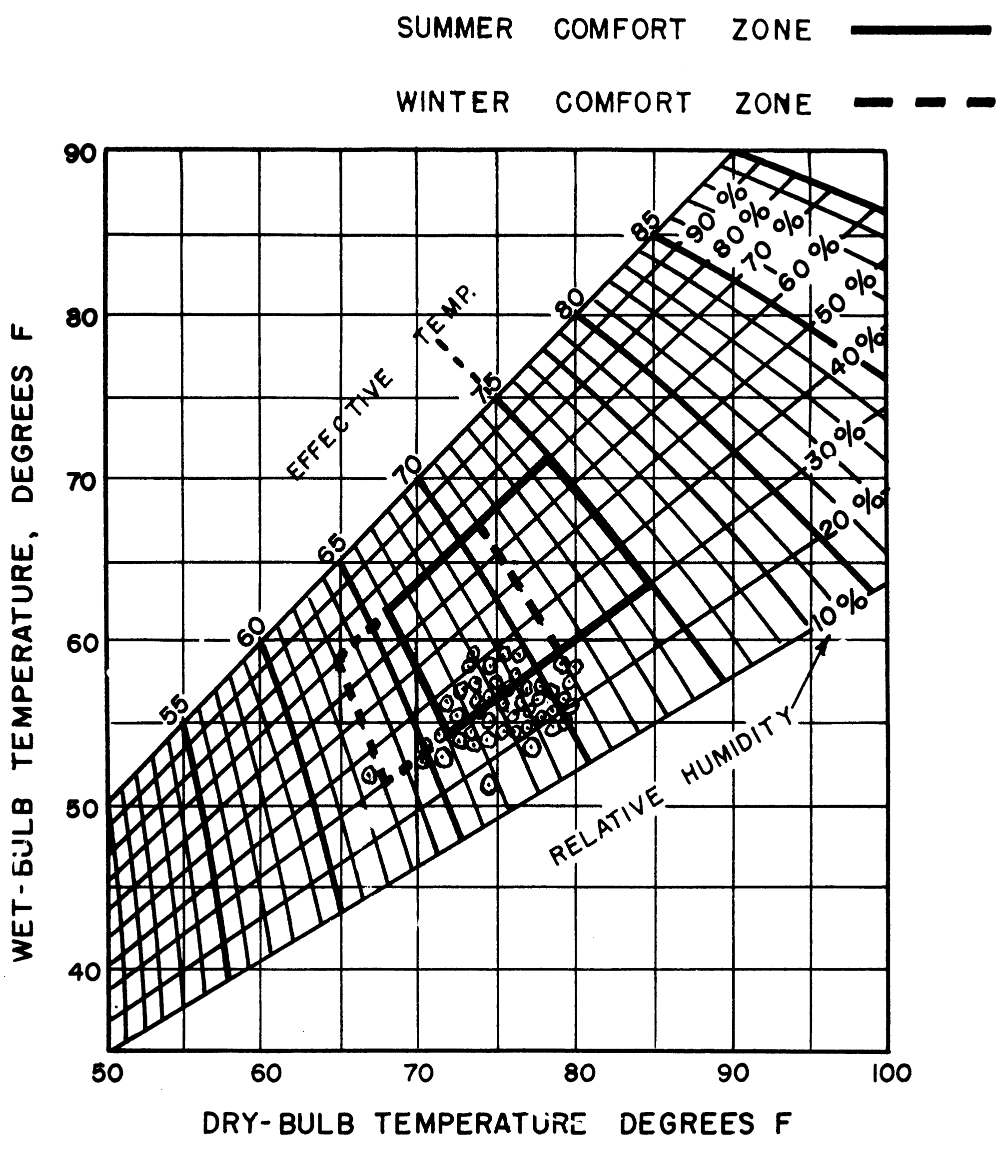


FIG. 28 - COMFORT CONDITIONS IN THE TEST ROOMS

KEY :
⊙ COMFORT

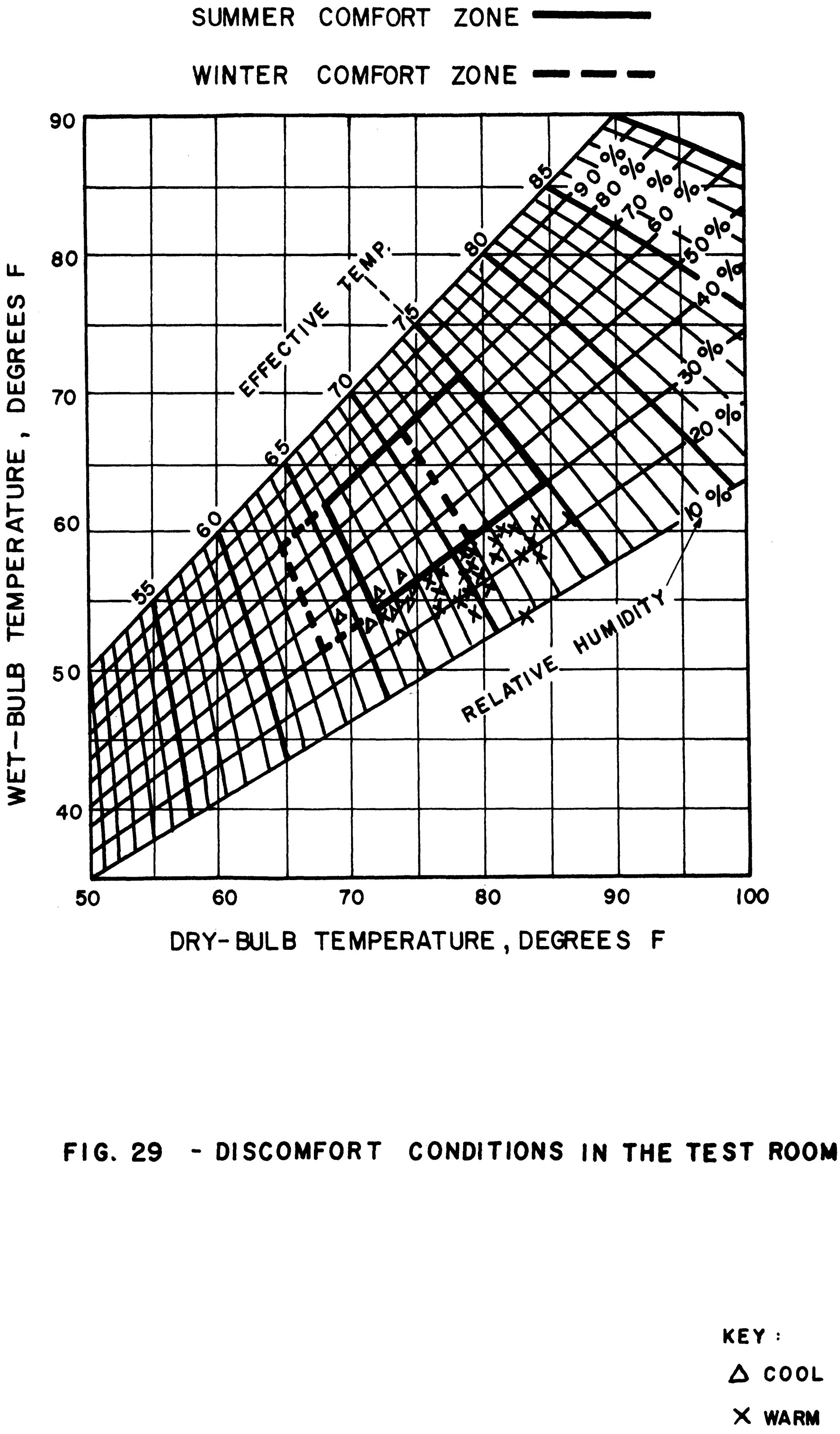
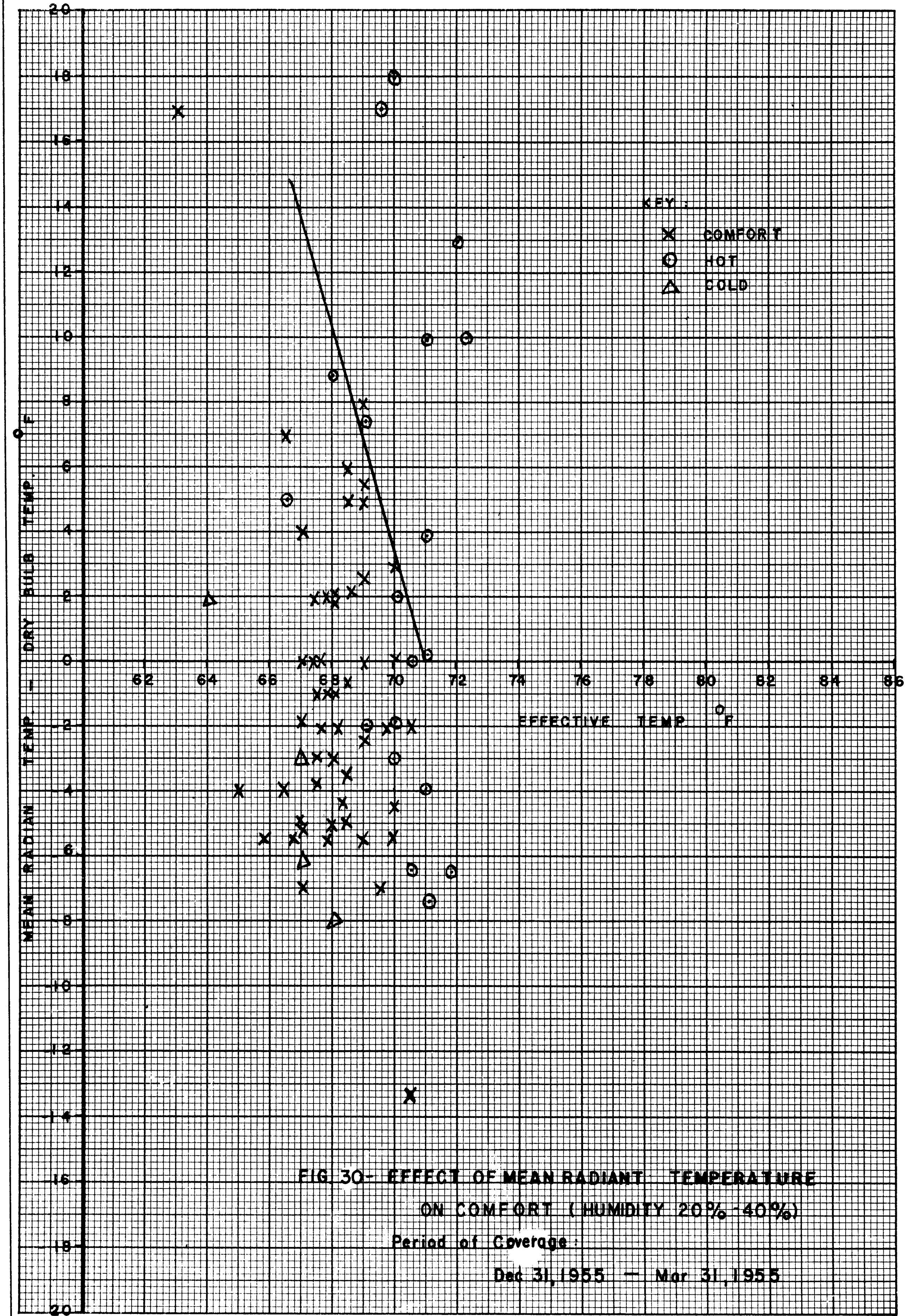


FIG. 29 - DISCOMFORT CONDITIONS IN THE TEST ROOMS


MEAN RADIAN TEMP. – DRY BULB TEMP. °F
EFFECTIVE TEMP °F
KEY :
COMFORT
HOT
COLD
FIG. 30 - EFFECT OF MEAN RADIANT TEMPERATURE ON COMFORT (HUMIDITY 20% - 40%)
Period of Coverage :
Dec 31, 1955 — Mar 31, 1955

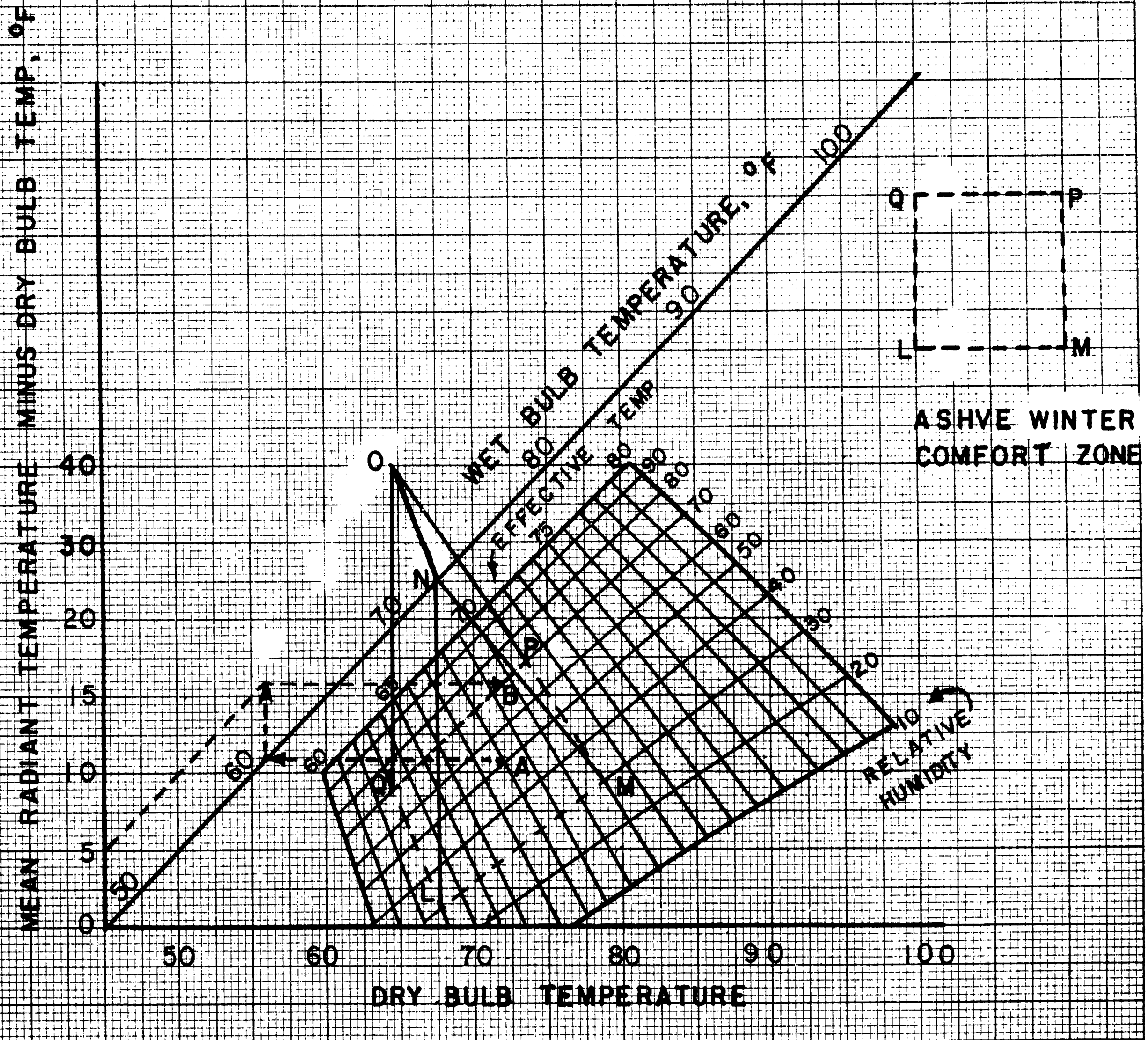


FIG. 31 - SCHEMATIC DIAGRAM SUMMARIZING THE EFFECT OF MEAN RADIANT TEMPERATURE ON WINTER COMFORT

from the wet and dry bulb temperatures at constant low air velocity. Point B in space is located by first moving horizontally to the left to the 45° line (which corresponds to mean radiant temperature minus dry bulb temperature equals 0°F line), then vertically to mean radiant temperature minus dry bulb temperature equals 5°F line and then horizontally to the right to point B directly above point A. It is seen that point B is inside the surface of the comfort volume (solid zone). Hence this air condition would probably be comfortable. If, however, for the same point A, the mean radiant temperature minus dry bulb temperature were 12°F, the corresponding point would lie outside the boundaries of the comfort zone defined by the planes LMPQ, LMN, MNOP, and OPQ.

The applicability of this above correlation is doubtful since there are many factors which tend to eliminate its use as a means of predicting human comfort from these results. The most important of these factors is the lack of data at the limiting conditions of comfort, since the conditions of the rooms were regulated by the personnel to give comfortable conditions. The observers were neither numerous, nor trained to evaluate comfort objectively, nor limited to the type of clothing worn, nor required to remain in the test area for the prescribed period for thermal equilibrium, nor were the subjects checked to determine their physical conditions, metabolic rates, body temperatures, or pulse rates as compared to the norm or deviation from the norm. The small range of relative humidity covered by this study also contributes to the limitation of any conclusions which may be drawn from any of the above results.

C. THE EFFECT OF THE SHADE SCREENS ON LIGHT CONDITIONS IN THE COOLEY LABORATORY

Tests were made on four consecutive days in the Cooley Laboratory to determine the lighting conditions in the rooms under observation. The results are shown in Table I. The results were obtained at about 12:00 noon on each of the days indicated, of which two of the days were rainy and the other two were sunny.

Shades on the north side shaded room decreased the light in the room. Artificial lighting was required continuously in the shaded room during the test period. Even with continuous artificial light, the room still seemed dismal to workers in the room. The unshaded room was bright most of the time, but not to the extent of causing glare. Artificial lighting was required in the unshaded room only on very dull days.

In the south side shaded room, which was exposed directly to the sun, the average decrease in natural light due to shades was 83% for the days tested. This effect was desirable, since the unshaded room was usually very bright. The shaded room did not have the characteristics of a disturbing glare on bright days but did require artificial lighting all the time.

TABLE I

EFFECT OF SHADE SCREENS UPON LIGHTING
IN THE COOLEY MEMORIAL LABORATORY

Date	Unshaded Room Light-Meter Readings in Foot-Candles	Shaded Room Light-Meter Readings in Foot-Candles
	North Side Rooms	
March 3	120	58
March 4	310	32
March 5	180	59
March 6	300	80
	South Side Rooms	
March 3	68	16
March 4	118	39
March 5	340	90
March 6	7600	112

CONCLUSIONS

The shade screen installation on the south side of the Cooley Laboratory is of value in decreasing the radiant solar heat gain and glare during the fall and winter seasons as well as during the summer. It is concluded that the installation of shade screens on the north side of the building is undesirable. It is not possible to draw firm conclusions regarding the effect of shade screens upon heat loss in the building during the winter season. The shade screens cause a rather gloomy appearance within the shaded rooms on the north side of the building by decreasing natural light received from the outside.

No condensation occurred on the windows within the building during the cold weather during this study. It is possible that heavy condensation noticed during previous winters was caused by unusually humid conditions within the building or possibly by the drying of the concrete materials used in the construction of the building during the first few seasons of use.

BIBLIOGRAPHY

1. "Blue Ridge AKlo Glass," Libbey-Owens-Ford Glass Company Bulletin.

2. Houghten, F. C., Gunst, S. B., and Suciu, J., A.S.H.V.E. Trans., 47 (1941), 93.