THE EFFECT OF SOLAR RADIATION ON TEMPERATURE MEASUREMENTS

By

SHERRELL T. MYRICK

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Approval Sheet

GENERAL SURVEY OF FIELD

It is strange indeed, in view of our complete dependence on the sun for our existence, that it was not until the beginning of the present century that any measurements of the solar radiation approaching exactness were made. It is even more strange that, considering the fundamental nature of researches on the source of our life and warmth, the astrophysical observatory of the Smithsonian Institution is the only agency in the world today making a general study of the sun and earth rays. It is a sign of awakening public interest that the National Geographic Society in the year 1925 made a grant to Doctor Abbot to enable him to select the best site in the Eastern Hemisphere, equip it for these important researches, and maintain there for several years a new observatory under the title "The National Geographic Society Solar Radiation Expedition" cooperating with the Smithsonian Institution. The new observatory was installed on Mount Brukkaras in southwest Africa, in October, 1926.

Dr. S. P. Langley came to the Smithsonian in 1887. He had already won fame as an astronomer and physicist whose prime interest was the study of the sun, and in accepting the position of secretary of the institution, it was understood that an observatory was to be provided to enable him to continue his research. In 1891 private means provided funds for a frame building which was erected back of the main Smithsonian building. Instruments which Langley had already brought or constructed were installed and

the work begun. The frame building still stands, and is used today in the work of the Smithsonian Astrophysical Observatory. This very modest equipment initiated a research, the results of which may yet bring about a revolution in methods of forecasting the weather.

Langley's early work on the solar radiation was done with an instrument of his own invention - the holometer, a supersensitive electrical thermometer, which consists essentially of a metallic tape about one half an inch in length but narrower and much thinner than a human hair, through which an electric current continually passes. The slightest variation in the amount of heat falling on this wire will affect the flow of electric current through it, which change is registered by the motion of a beam of light from a tiny mirror across a moving photographic film. The mirror is about the size of the head of a pin, and is turned by the passage of varying electric currents near little magnets no larger than the point of a needle. By use of the bolometer the sun's spectrum map was extended by Langley to eight times the length that was known to Sir Isaac Newton. By means of these bolographic studies much knowledge was gained regarding the transmission of the sun's rays through the atmosphere, and beginning in 1902, determinations of the intensity of the sun's heat as it would be outside our atmosphere were made. It was noticed as early as 1903 that there appeared to be considerable variation in the amount of this solar radiation.

In 1895 Dr. G. Abbot, present secretary of the Smithsonian Institution, was added to the staff of the astrophysical observatory, and working under Langley's direction, he soon acquired a similar enthusiasm for the

study of the sun. Today Dr. Abbot has the satisfaction of seeing at least a partial fruition of Langley's dream, owing to his own years of skillful and painstaking research. The evidence of the direct dependence of our weather on the earth upon the variations in the sun's heat is becoming stronger and stronger. The Argentine Government has for several years actually used the Smithsonian daily valves of the solar radiation in issuing forecasts of the temperatures and rainfall for the region about Buenos Aires for a full week in advance.

In the early stages of the investigation, it was recognized that a standard instrument must be developed for exact measurements of the sun's heat. By 1910 there had been perfected what is termed the standard waterflow pyrheliometer, the principle of which rests upon the measuring of the intensity of the sun's heat in terms of the rise in temperature of a known weight of water caused by the complete absorption of solar rays over a known area in a given time. Known quantities of heat may be introduced electrically to check the accuracy of the instrument, which is generally recognized as the standard of the world. Another instrument, known as the "silver disk pyrheliometer", was developed by Dr. Abbot, which has proved to be highly satisfactory for the daily operations.

The immense importance to us of the knowledge of radiation is that it will enable us to forecast the harvests and in other ways look into the future. The heat received from the sun contains power which can be converted into work in some regions. For instance, in Cairo, Egypt, a 50-boiler horsepower plant was installed by Frank Shumann,

Manchester Association of Engineers, in March, 1914. This plant is run by solar heat. The actual maximum overall efficiency of the plant was found to be 4.32%, showing that about 75% of the boiler horse power theoretically possible was obtained.

It is not the purpose of this experiment to compete with the work that has been done, but merely to make a study of solar radiation and observe its effect upon temperature measurements. Some comparison can be made in the effects of atmospheric conditions on radiation.

VI PURPOSE

The object of this study was observation. It was impossible with such meager equipment really to measure the radiation of the sun. However, many interesting facts can be seen by observing the data taken.

The main purpose attempted was to show the impossibility of accurately measuring the temperature of the atmosphere with a dry bulb thermometer when it is exposed to the light rays of the sun. Next was to show as many effects of atmospheric condition on solar radiation as possible, and to show the reflecting or radiating effect of different colored materials.

VII GENERAL THEORY.

The center of attraction of our solar system, the sun, about which the planets, including our earth and moon, revolve, is an immense body, 865,000 miles in diameter and about 93,000,000 miles distant from the earth. It has a temperature of about 6,000° absolute. Such is the enormous size of the sun, that if it were hollowed out and our earth placed in the center of it, the moon could revolve about the earth in an orbit as great as its present one in the sky without approaching to the outside of the sun. Although dazzingly hot, so hot that an arc light would look brown against its surface, no burning fuel supplies the sun's heat, for even hydrogen and oxygen would fly apart at that tremendous temperature.

The sun, as well as other hot sources, like fires, stars, or lamps, sends out visible and invisible rays in every direction. These rays are vibrations which travel by wave motion, as do the rings upon still water when disturbed. If visible, we call these rays light; if invisible, then ultra violet or infra red rays. The moon, the planets, and all sorts of cool objects send out invisible rays, but they are reflected and originated from hot bodies like the sun or lamps. These rays, sent out by a cool body like the moon or earth, are so long of wave length as to be quite invisible to the eye, yet in their nature they are of the same sort as light.

Light given off by the sun is the most conspicuous form of radiation, and it was in connection with this form that the laws of radiation were

first studied.

Radiation is a form of energy, and, as such, can be produced from other forms of energy and converted into others. The most convenient form for the production of radiation is heat energy, and radiation, when destroyed by being intercepted by an opaque body, usually is converted into heat. If the hand is held close to a lamp, the radiation intercepted by the hand is destroyed, that is, converted into heat, and is felt as such. On the way from the lamp to the hand, however, the energy is not heat but radiation, and a body which is transparent to the radiation may be placed between the lamp and the hand and remains perfectly cold. A sufficiently sensitive heat-measuring instrument, such as a bolometer, shows the heat produced by the interception of the rays of a mercury lamp or the rays of the moon.

The theory stated above is the theory of the actions of the sun. It gives off light rays which, when intercepted by the proper body, are converted into heat energy, or if reflected by the body, do not affect its temperature. Our average temperature lies between the freezing and boiling points. That the climate of our earth remains within these limits is due to the fact that its temperature is in a balance, warmed by the incoming rays from the sun, and cooled off by the out going rays from the earth.

Temperature does not vary directly with radiation, as one might believe; for the earth's surface is so complex that its mountains, oceans, and other features, with the circulation of the atmosphere, modify extremely the effects of the solar heat. It is believed that as much as a quarter of the sun's heat is absorbed in the atmosphere itself, and as the atmos-

phere has but a small capacity for heat compared with the solid earth or the ocean, that its temperature must be almost immediately affected by solar variations, far more directly than the temperature of the ocean or the temperature of the land. But since the atmosphere is in some regions dry and transparent, the quantity of solar heat absorbed must vary greatly from place to place. So the change in the solar heat must produce very different temperature effects in the atmosphere in a cloudless desert region at high altitudes from those they would in a cloudy, humid, hazy region, where the air is contaminated, perhaps by the smoke of a great city.

The consequence is that air expansion due to the increased temperature accompanying increase of solar radiation, takes place in much larger proportion in the humid, hazy regions than it does in the cloudless, clear ones, and so the air must flow from the regions of the former condition to those of the latter. This produces changes in barometric pressure, which in turn produce the winds and cyclonic movements which are so familiar with the change of seasons and other variable conditions. The regions which are sources of these cyclonic disturbances move about from place to place. This alters the direction of the winds, and as is well known, the temperature depends intimately on the prevailing winds at every locality. This may explain why it is that we are not to expect at every locality and at every time of the year colder weather when the solar radiation is lower. There may be exactly the reverse, depending on these secondary effects. Thus when a thermometer is exposed to the sun, the light rays are intercepted by the bulb and converted into heat.

This will cause the thermometer to register a higher temperature than the actual temperature of the atmosphere.

There are many different ways of measuring radiant heat. One is with a bolometer and another is with a standard water-flow pyrheliometer. However, by the use of bulbs and thermometers alone, radiation can be proved, as this study attempts to show.

VIII METHOD USED AND DESCRIPTION OF APPARATUS

The apparatus used was selected because of its low cost, more could be shown with more expensive equipment, but this work was not intended to go into the study of the deep theories of solar radiation, and this apparatus was considered to be sufficient.

It consisted of three round brass bulbs, four thermometers, a sling psychrometer, and a stand (see Fig. 1). One bulb was painted an aluminum color, one was left plain, and one was painted black. Holes were cut in the ends of the blubs and corks inserted, through which thermometers were placed. These were mounted on the stand so that the bulbs were approximately five feet from the ground. At this same height a dry-bulb thermometer was exposed to the air. A wet-bulb psychrometer was used to make humidity readings.

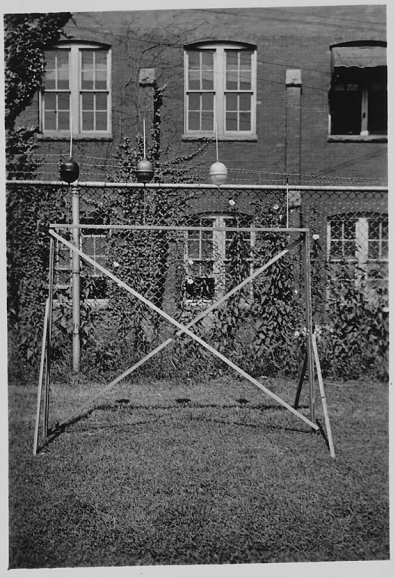


Fig. 1

The intention here was to show that radiation from the sun would affect the temperature of a body exposed to it. This fact would prove that a dry-bulb thermometer would also be affected to some extent. By the use of different colored bodies it could be shown which is the best absorber of the light rays, and also proved that a light ray is not heat until it strikes an opaque object. By taking relative humidity readings, a relation could be shown between relative humidity and atmospheric temperature; primarily that vapor pressure is a function of temperature, and that relative humidity is a function of vapor pressure. This equipment would also show that black bodies absorb light and light colored bodies reflect it.

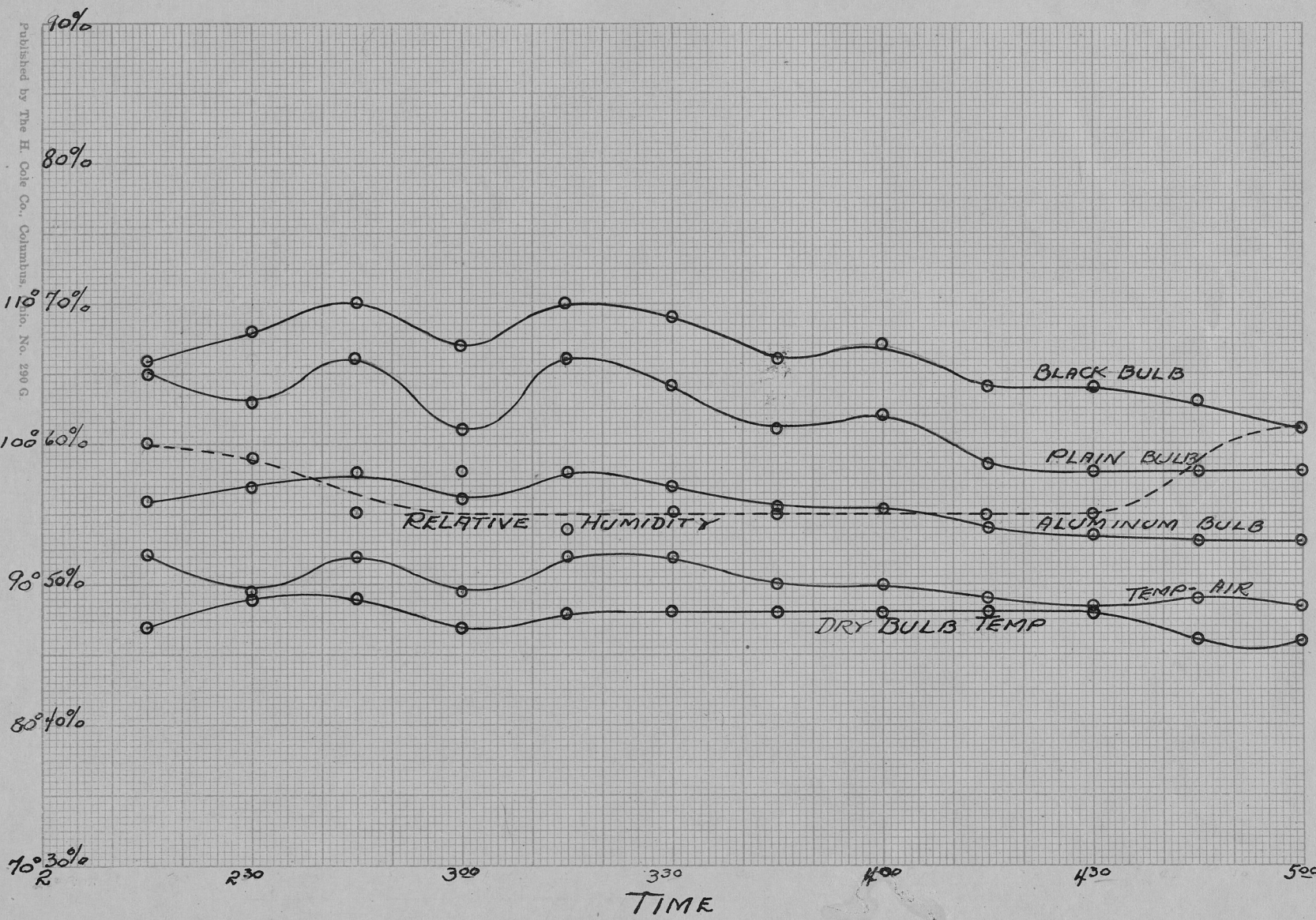
The apparatus was exposed to the sun, and readings taken at close intervals not exceeding fifteen minutes for approximately six hours a day through seven days. The relative humidity was taken at each reading of the thermometers. The atmospheric condition through which the sun was shining was noted at each reading.

From the data taken curves were plotted for each bulb with temperature as ordinates and time as the abscissae. Curves were also plotted showing relative humidity and dry-bulb reading of the psychrometer.

The main difficulty was in making correct readings with the psychrometer. The sun's rays would tend to make the dry-bulb thermometer read higher than it should. This would give the wrong humidity. To overcome this the psychrometer was whirled in the shadow of the operator, and the sun's rays were obstructed before they hit the thermometer bulb.

Even with this precaution, when the sun was behind a cloud the dry-bulb thermometer of the psychrometer would read a lower value.

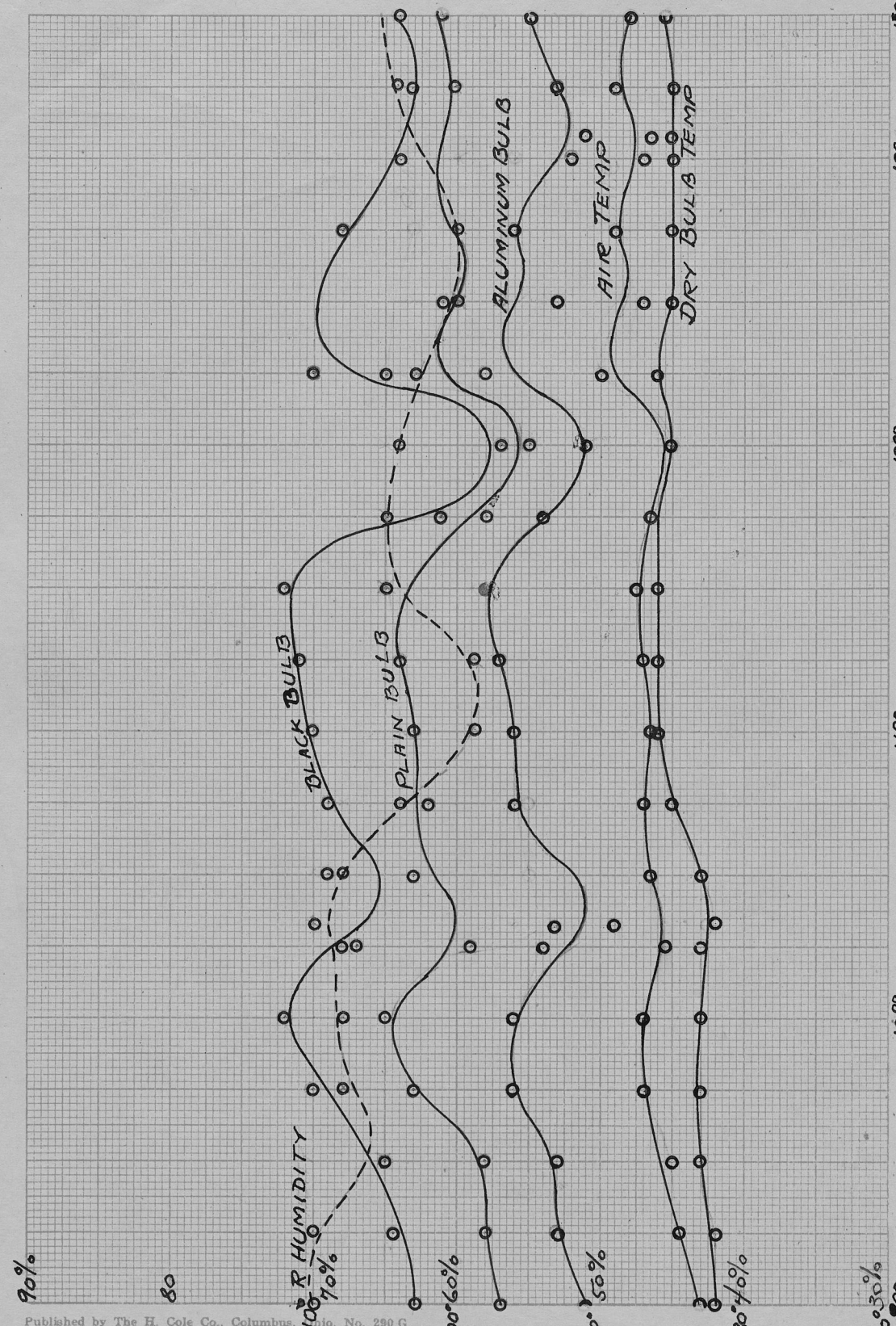
The main source of error was in taking the correct humidity readings, and in reading all of the thermometers at the same time. These were eliminated as much as possible, as described above.



CURVE SHEET 1
JUNE 7 AFTERNOON

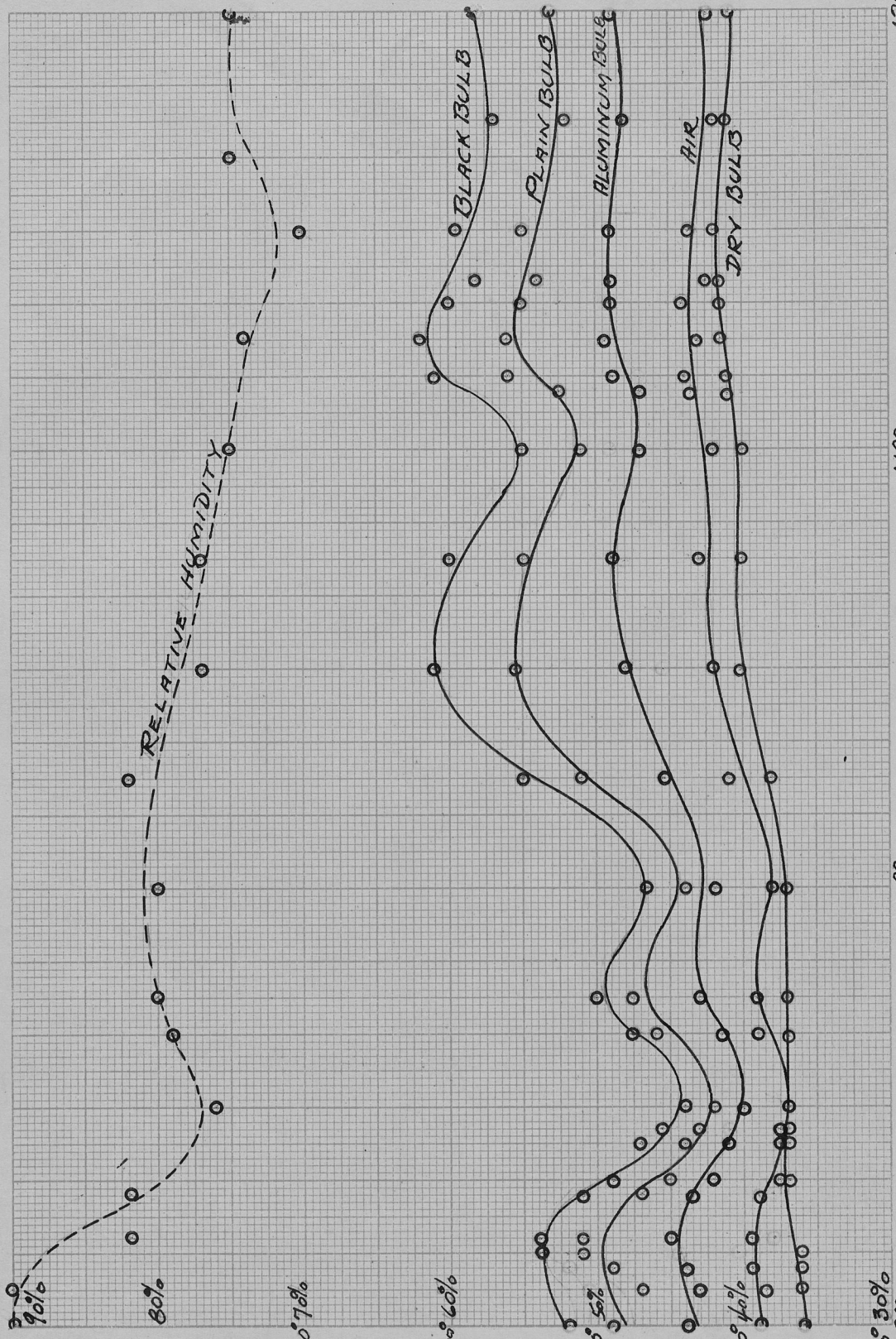
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CURVE SHEET 2
JUNE 8 MORNING



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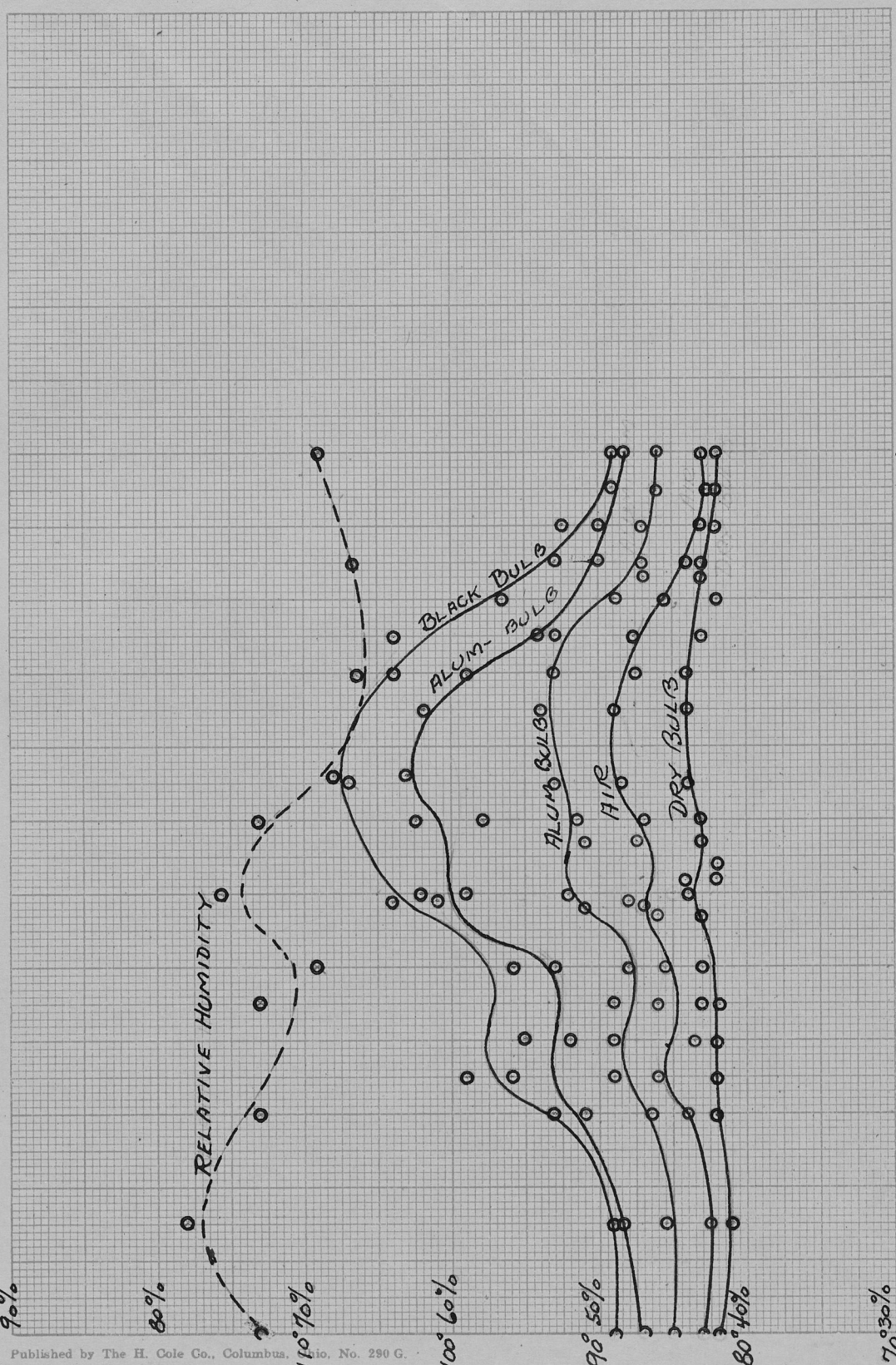
CURVE SHEET 3
JUNE 9 MORNING



RELATIVE HUMIDITY % TEMPERATURE DEG-FAHR-

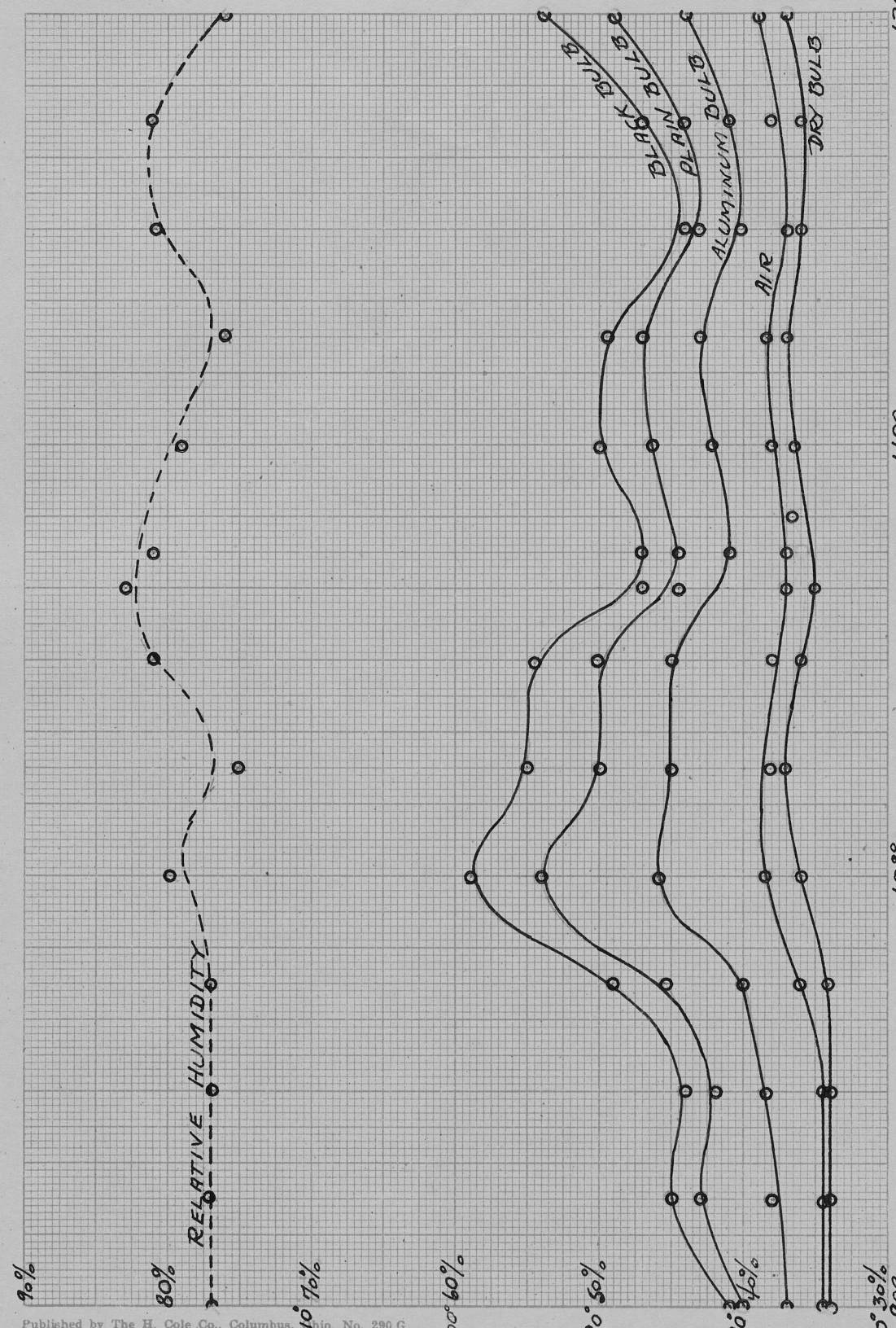
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CURVE SHEET 4
JUNE 9 AFTERNOON

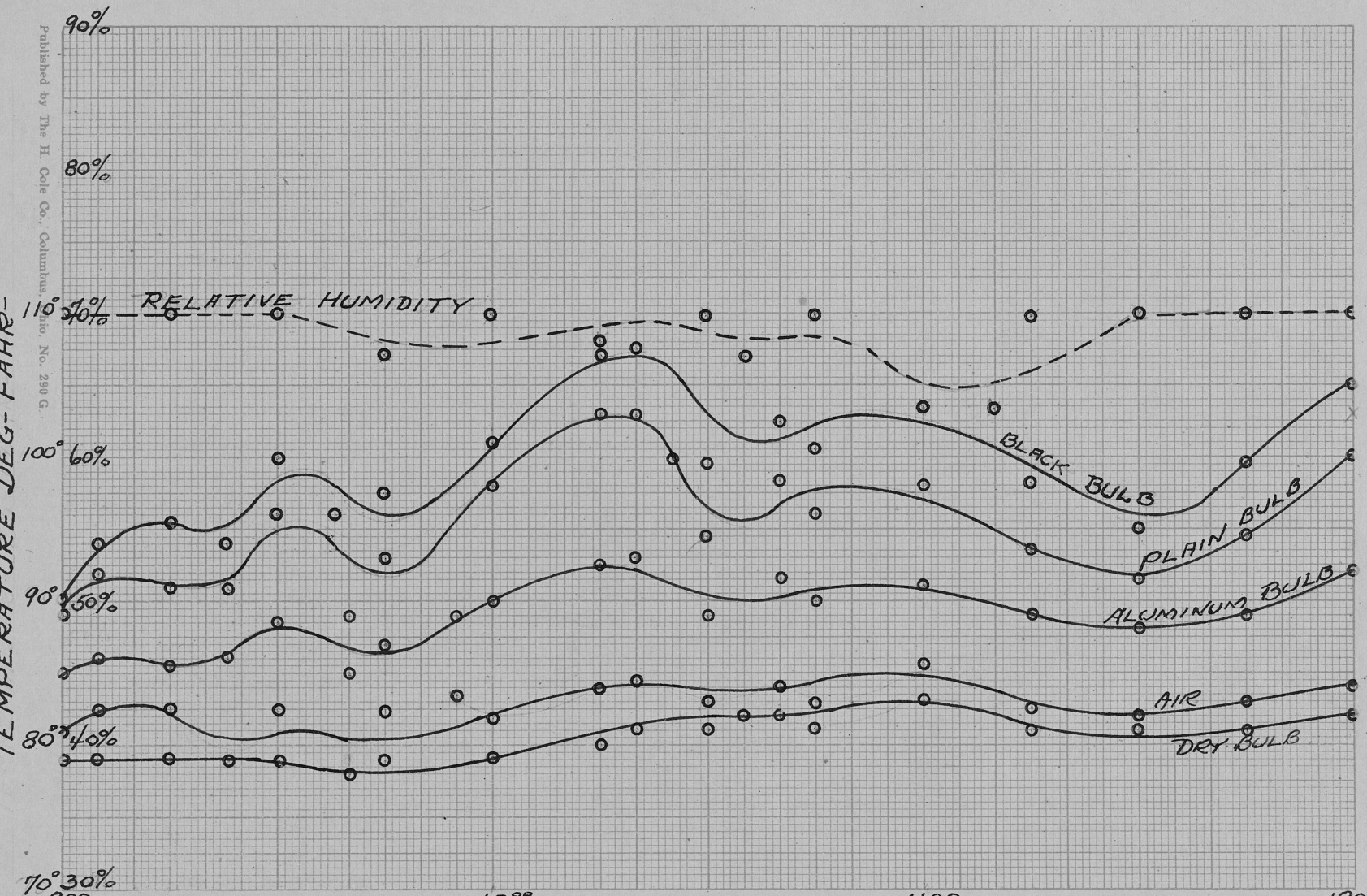


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CURVE SHEET 5
JUNE 10 MORNING

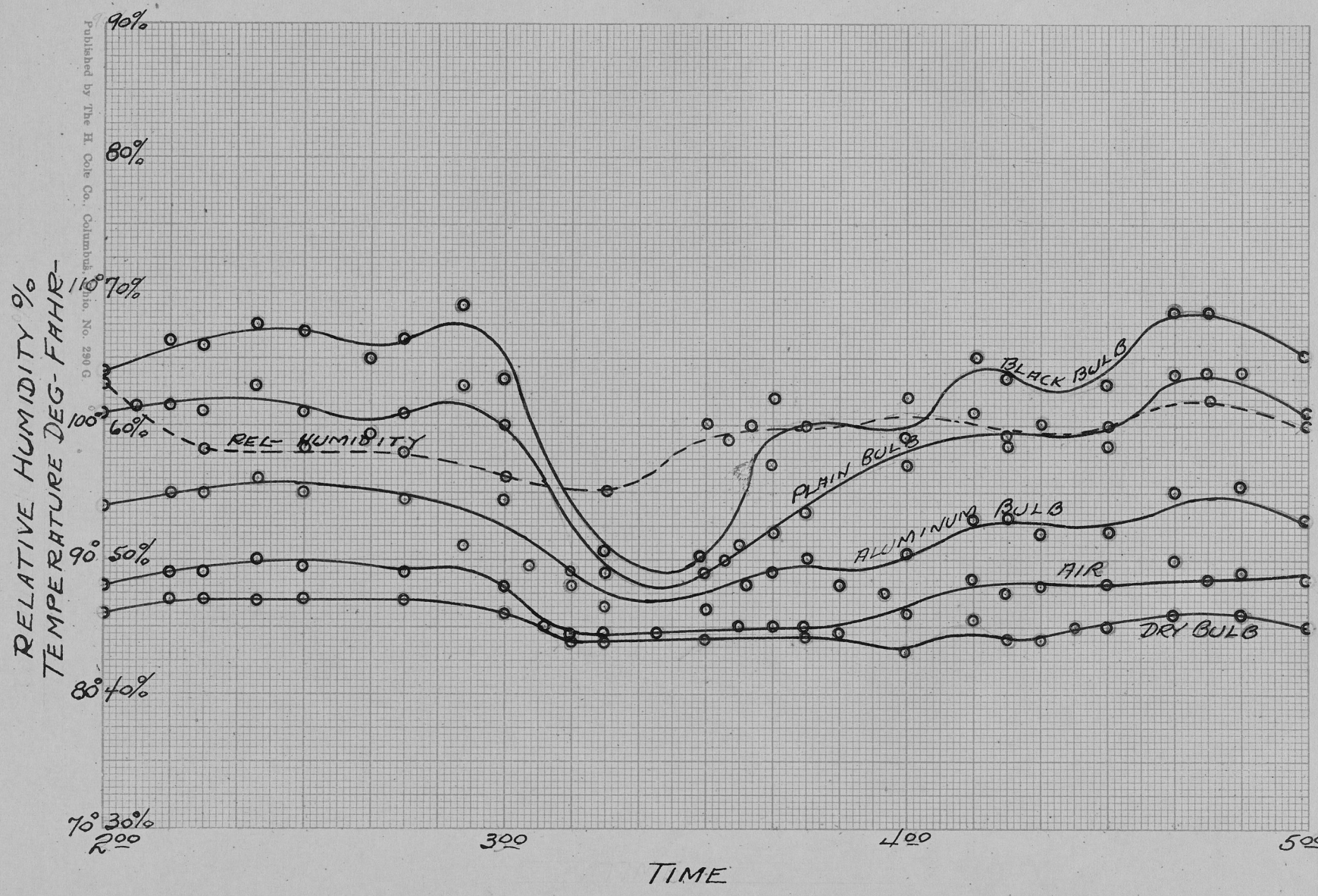


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CURVE SHEET 6.
JUNE 11 MORNING.

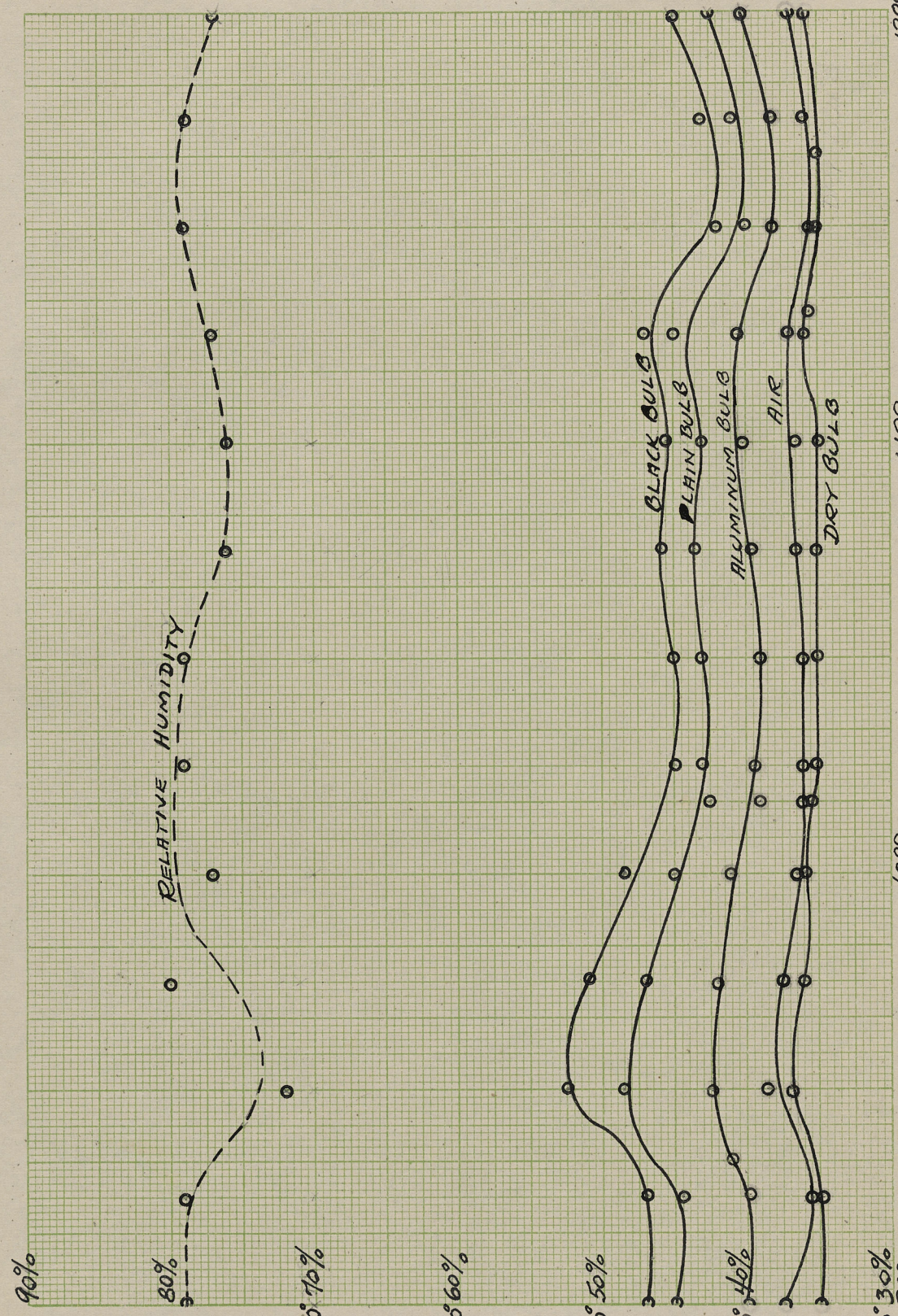
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CURVE SHEET 7
JUNE 11 AFTERNOON

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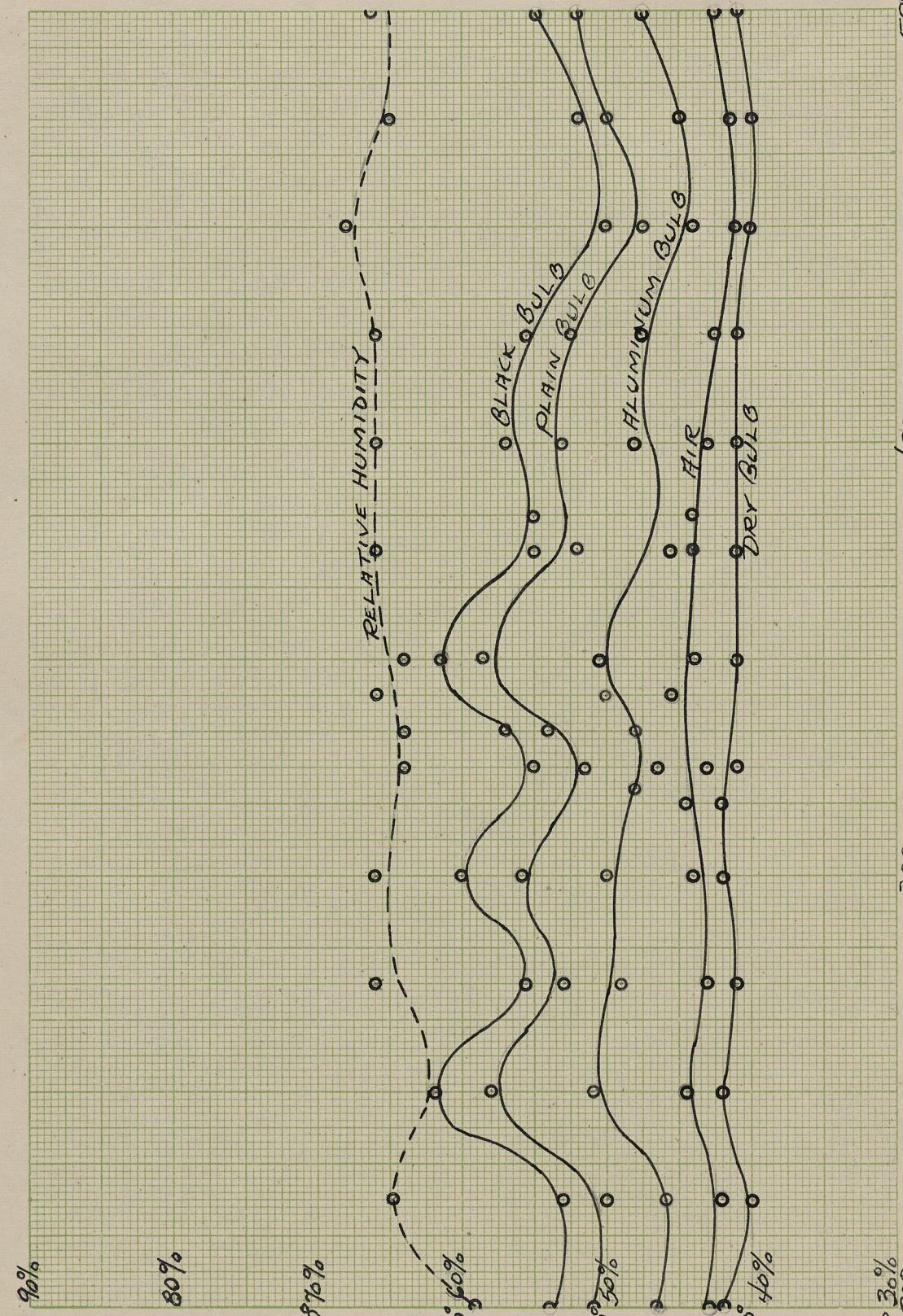
CURVE SHEET 8
JUNE 12 MORNING



RELATIVE HUMIDITY % TEMPERATURE DEG - FAHR -

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CURVE SHEET 9
JUNE 12 AFTERNOON



RELATIVE HUMIDITY % TEMPERATURE DEG FAHR-

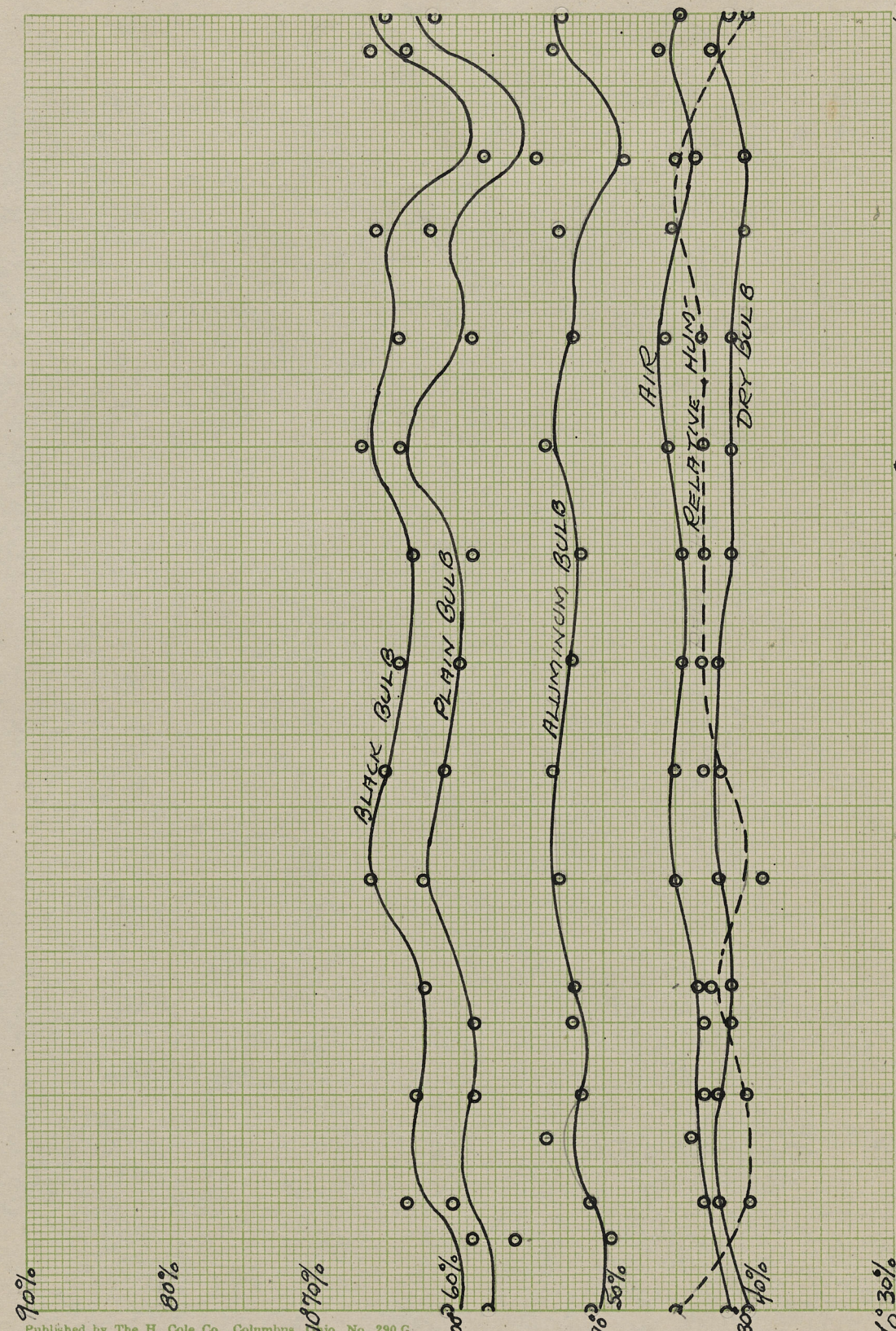
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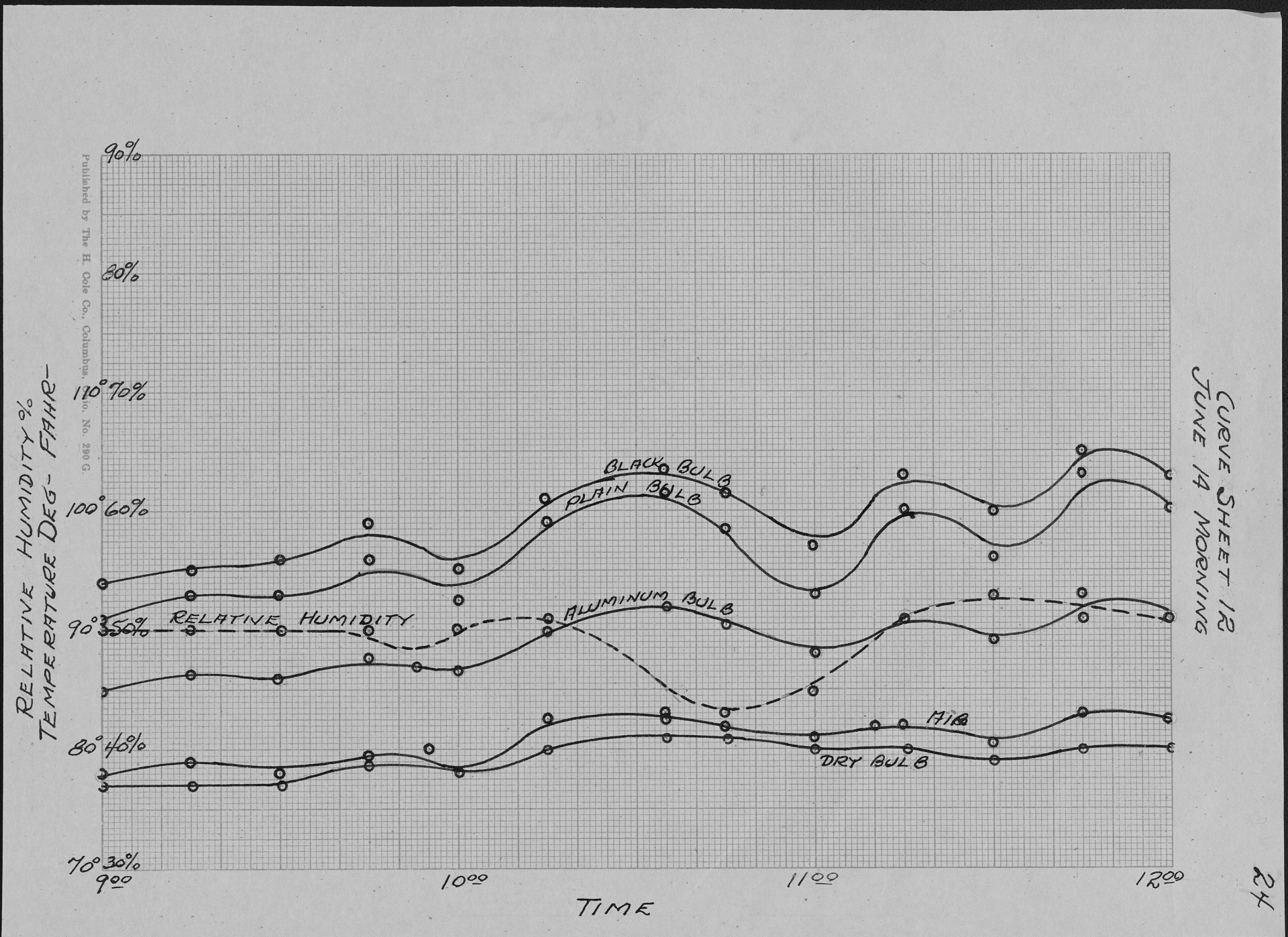
CURVE SHEET 10
JUNE 13 MORNING

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CURVE SHEET 11
JUNE 13 AFTERNOON



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Curve Sheet 12
June 14 Morning
Relative Humidity %
Temperature Deg- Fahr-
90%
80%
70%
60%
50%
40%
30%
110°
100°
90°
80°
70°
Black Bulb
Plain Bulb
Relative Humidity
Aluminum Bulb
Air
Dry Bulb
9^00
10^00
11^00
12^00
Time
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24

DISCUSSION OF RESULTS

The curves show a difference in temperature of the dry-bulb thermometer on the psychrometer, and the temperature shown by the plain thermometer exposed to the rays of the sun. The difference shows that a thermometer exposed to the sun's rays will not give the correct temperature of the atmosphere. This difference in reading is not constant, and that fact is attributed to the variations in the intensity of solar radiation, and to the inaccuracy in taking humidity readings.

By reference to curve sheet 1, it is apparent that there is very nearly a constant difference in the heat absorbed by the bulbs, yet it was impossible to measure the heat absorbed by the bulbs, since a thermometer measures only the quality of heat. However, it seems logical that a higher temperature for the thermometer in the black bulb would indicate that more heat was being absorbed by the bulb than was lost by connection currents of air at the dry-bulb temperature; accordingly the temperature of the inside of the bulb rose until it was sufficiently high for a balance between: -

(1) Radiant heat absorbed (T^4sun - T^4black body) according to the Stefun-Boltzman law, and

(2) Connection currents, (temp body) - (dry bulb) which dissipate the heat. This is essentially a heat balance between the sun's rays and the circulating air currents. With the same reasoning, the uncovered bulb would reach a higher temperature owing to the reception of radiant

energy from the sun. Likewise, it seems that its temperature would be a matter of equilibrium between the (1) radiant heat and (2) connection currents. A thermometer must essentially reach an equilibrium temperature in cases where heat is changing form.

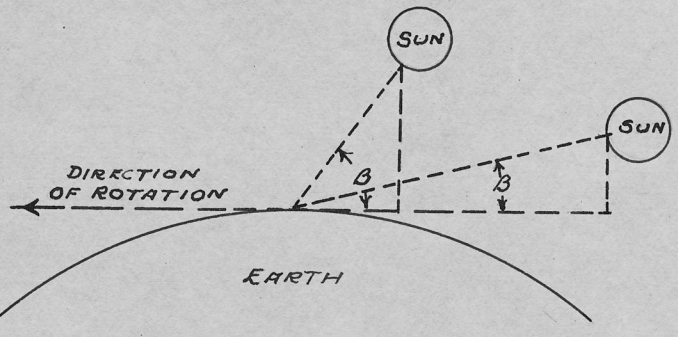
Referring to curve 1, between 3:30 and 4:30 P.M., the dry-bulb is constant. Note 1 -

(1) The uncovered bulb falls steadily.

(2) Aluminum covered bulb falls steadily.

(3) Black Bulb)
(4) Brass Bulb) rise and fall.

Now as the dry-bulb is constant, it appears that the uncovered bulb shows less radiant heat is being emitted between the sun and the glass of the bulb. Likewise for the aluminum covered. This is easily explained by the revolving of the earth away from the sun, and consequently as the angle decreases (B) (see sketch)



More atmospheric air and water vapor are between the radiating body and receiving body and hence less radiant heat is received by the thermometer bulbs. The curves verify these facts, and the same can be shown on other occasions. This, however, is a representative case.

There was radiation effect shown even when the sky was heavily covered with clouds and it was raining. This is shown on curve sheet 3 at nine o'clock. Note the high humidity, and how it decreased as the temperature increased. When the sun was covered by a heavy cloud, there was a drop in all three of the bulb curves, and also a small drop in the air curve. The bulb curves approached the air curve, and the constant difference of all three was very small; yet they never came entirely together. The higher the temperature the greater the difference between all of the curves. This difference was more nearly constant at high temperatures than when the radiation was varying.

The bulbs of different colors held true to theory. The aluminum bulb was supposed to reflect approximately 90% of the sun's rays and absorb about 10%. It gave temperatures which were closer to the air than the other two bulbs. The plain brass bulb was between the aluminum and the black bulb, and it was due to absorb approximately half of the rays. The black bulb gave the highest readings, and it was due to absorb nearly all of the rays. There was always a greater difference between the aluminum and plain brass bulbs than between the black and plain brass bulbs. When touched with the hand the aluminum bulb seemed cool on the bottom and warmer on the top. The plain brass bulb was much warmer on top, and slightly warm on the bottom. The black bulb was too hot on top for comfort to the hand. This indicated that the earth was giving off cool rays and the bulbs were being warmed by the sun only. The lower temperature of the aluminum bulb showed that it was reflecting the majority of the light rays and they were not being converted into heat.

The other two bulbs did not reflect as many of the light rays, and more of them were converted into heat.

The action of the wind proved to have a major effect on temperature. Curve sheets 10 and 11 show its effect. The sky was clear and the sun was never covered with clouds, yet a low temperature prevailed even though the humidity was low. Temperature varied as usual, but this time the wind caused its fluctuation instead of the clouds. The wind,, however, did not cause it to vary as much as the clouds.

Humidity, which, as we said before, is a function of vapor pressure, seemed, with one exception, to vary inversely with temperature: when the wind was blowing. As a whole all the humidity curves drop when the temperature rises and rise when the temperature drops. On curve sheet 3 a high humidity prevails and a low temperature results. As the temperature increases the humidity decreases.

The intensity of solar radiation varies considerably with the time of day. It increases gradually from morning up into the afternoon. It is greatest from twelve A.M. to one P.M., constant from one P.M. to four P.M., and then begins gradually to decrease.

C O N C L U S I O N S

It is impossible to measure accurately the temperature of the atmosphere with a dry-bulb thermometer when exposed to the light rays of the sun.

Different colored bodies are affected differently by solar radiation.

(a) Black bodies absorb as much as 98% of light rays. (Kent)

(b) Highly polished bodies or light painted bodies reflect the majority of light rays.

(c) The amount of heat absorbed is dependent on the type and color of the body exposed to the sun and its area.

Our climate is in a balance warmed by the incoming rays from the sun and cooled by the out going rays from the earth.

Glass is strongly transparent for light rays, yet it is not transparent to the cool rays given off by cold bodies.

Atmospheric water vapor, like glass, also transmits nearly 90% of sun rays freely, but is highly absorbing of most rays emitted by the earth. Of those remaining earth rays which water vapor transmits freely, ozone, existing only very high up in the atmosphere, is an active absorber. Hence our atmosphere toward the earth's surface acts much as does the glass of a hot bed, and helps devidedly to keep the earth warm. (Smithsonian Institute)

The average degree of cloudiness, and the average purity of the atmosphere play the outstanding part in determining the amount and quantity of solar radiation.

The upper surface of a cloud reflects 78% of the incident solar radiation, so that the quantity of heat available to warm the earth is

greatly decreased by an increase in total cloud surface (Physiological Effects of Radiant Energy, by Laurens).

On a clear but humid day the absorption of solar radiation by water vapor would be very near 15%. In contrast, water vapor absorbs terrestrial radiation almost completely. (Laurens)

Scattering and reflection from dust particles produce the opposite effect. Dust particles, being materially larger than air molecules, affect the long waves of terrestrial radiation in much the same way as air molecules act upon the shorter waves of solar radiation. That is, they merely scatter terrestrial radiation and reflect little Solar radiation, however, is both scattered and reflected in large measure by dust particles. Humphreys computes that the total effect of dust in preventing the transmission of solar radiation is 30 times as great as it is with terrestrial radiation. This he calls an "inverse greenhouse effect", which produces an eventual lowering of the surface temperatures. (Laurens)

Great variations in daylight take place when small clouds pass over the sun on a clear day. In such cases, the light may fall from 9,000 or more foot candles to 3,000 or less in one minute's time and return to the original amount during the succeeding minute. (Laurens)

Smoke affects the amount of solar radiation.

The amount of solar radiation which reaches the earth's surface is dependent upon every momentary change in atmospheric transparency, cloudiness, dustiness, and humidity.

The drier the atmosphere the greater the solar radiation.

Humidity varies inversely with temperature.

Variations on the earth's solar distance will affect solar radiation.

Dustiness or haziness of the atmosphere causes variations.

Solar radiation will affect the comfort zone. A person's comfort in the sun will be dependent on the color of the clothing worn, and the way it is woven.

Wind will affect radiation, and if solar radiation is at its peak, a cool wind may make a great difference in the temperature.

Altitude will affect solar radiation.

The energy radiated by a black body is proportional to the fourth power of the absolute temperature W $E = K (T^4 - To^4)$ where E = total energy radiated by the body at T to the body at To and K is a constant. The total radiation from other than black bodies increases more rapidly than the fourth power of the absolute temperature, so that as the temperature is raised the radiation of all bodies approaches that of the black body. (Kent)

B I B L I O G R A P H Y

Smithsonian Institute

Volumes 1 and 11

Physiological Effects of Radiant Energy,

by Laurens.

Radiation Light and Illuminati on,

Steinmetz.

Refrigeration, February issue.

Kents, Hand Book for Mechanical Engineers

Marks, Hand Book for Mechanical Engineers

A P P E N D I X

JUNE 7 — AFTERNOON

TIME		TEMPERATURES DEG. FAHR.				AIR CONDITION			
Time of Day	Duration of run	Air	Alum. bulb	plain bulb	Black bulb	pyschrometer read. dry bulb	wet bulb	relative humidity	cond. of sky
2:15 P.M.	---	92.2	96°	105	106	87	75	60%	clear
2:30 "	15 min.	89.5	97	103	108	89	77	59%	"
2:45 "	15 "	92	98	106	110	89	76	55%	"
3:00 "	15 "	89.5	96	101	107	87	74	58%	"
3:15 "	15 "	92	98	106	110	88	74	54%	"
3:30 "	15 "	92	97	104	109	88	75	55%	"
3:45 "	15 "	90	96	101	106	88	75	55%	"
4:00 "	15 "	90	96	102	107	88	75	55%	"
4:15 "	15 "	89	94	98.5	104	88	75	55%	"
4:30 "	15 "	88.5	93.5	98	108	88	75	55%	"
4:45 "	15 "	89	93	98	103	86	75	61%	"
5:00 "	15 "	88.5	93	98	102	86	75	61%	"

JUNE 8 — MORNING

9:00 A.M.	---	83	91	97	103	82	74	70%	Clear
9:15 "	15 min.	84.5	93	98	104.5	82	74	70%	"
9:30 "	15 "	85	93	98	105	83	74	65%	"
9:45 "	15 "	87	96	103	110	83	75	68%	"
10:00 "	15 "	87	96	105	112	83	75	68%	"
10:15 "	15 "	85.5	94	99	107	83	75	68%	"
10:20 "	5 "	82.5	89	93	96	82	74	70%	Cloudy
10:30 "	10 "	86.5	95	103	109	83	75	68%	Clear
10:45 "	15 "	87	96	102	109	85	75	64%	"
11:00 "	15 "	86.5	96	103	110	86	74	59%	"
11:15 "	15 "	87	97	104	111	86	74	59%	"
11:30 "	15 "	87.5	98	105	112	86	76	65%	"
11:45 "	15 "	86.5	94	98	102	86	76	65%	"
12:00 "	15 "	85	91	95	97	85	75	64%	Cloudy
12:15 "	15 "	90	98	105	110	86	75	63%	Clear
12:30 "	15 "	87	93	97	101	85	74	60%	Cloudy
12:45 "	15 "	89	96	103	108	85	74	60%	"

JUNE 8 — AFTERNOON

TIME		TEMPERATURES DEG. FAHR.						AIR CONDITION	
Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	psychrometer dry bulb	psychrometer wet bulb	relative humidity	cond. of sky
1:00 P.M.	15 min.	87	92	96	100	85-	75	64%	Cloudy
1:05 "	5 "	86.5	91	94	97.5	85	75	64%	"
1:15 "	10 "	89	93	100	103	85	75	64%	"
1:30 "	15 "	88	95	101	104	85.5	75	63%	"
1:35 "	5 "	87	92	97	100	85.5	75	63%	"
1:40 "	5 "	87	92	96	99	85	75	64%	"
1:45 "	5 "	86	90	94	96	85	75	64%	"

At this time it began to rain

JUNE 9 — MORNING

9:00 A.M.	---	79	84	89	92	76	73	90%	Cloudy
9:05 "	5 min.	78.5	83	87	90.5	76	73	90%	"
9:08 "	3 "	79.5	84	89	92	76	74	95%	"
9:10 "	2 "	80.5	84.5	91	94	76	74	95%	"
9:12 "	2 "	79.5	85	91	94	78	73	82%	"
9:18 "	6 "	78.5	83.5	87	91	78	73	82%	"
9:20 "	2 "	77.5	82	85	88	77	73	80%	"
9:25 "	5 "	77.5	81	84	87	77	72	79%	"
9:27 "	2 "	77.5	81	83	85.5	77	71	76%	"
9:30 "	3 "	77	80	82	84	77	71	76%	"
9:40 "	10 "	79	81.5	86	87.5	77	72	79%	"
9:45 "	5 "	79	83	87.5	90	77	73	80%	"
10:00 "	15 "	78	82	84	86.5	77	72.5	80%	Clearing
10:15 "	15 "	81	85.5	91	95	78	73.75	82%	Windy
10:30 "	15 "	82	88	95.5	101	80	74	77%	Hazy
10:45 "	15 "	83	89	95	100	80	73.75	77%	Clearing
11:00 "	15 "	82	87	91	95	81	74	75%	"
11:08 "	8 "	83.5	87	92.5	90	81	74	75%	"
11:10 "	2 "	84	89	96	101	81	74	75%	Clear
11:15 "	5 "	83	89.5	96	102	81.5	74	74%	"

JUNE 9 — MORNING

TIME		TEMPERATURES DEG. FAHR.						AIR CONDITION	
Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	psychrometer reading dry bulb	psychrometer reading wet bulb	relative humidity	cond. of sky
11:20 A.M	5 min.	84	89	95	100	81.5	74	74%	Hazy
11:23 "	3 "	82.5	89	94	98	81.5	74	74%	Cloudy
11:30 "	7 "	83.5	89	95	99.5	82	74	70%	"
11:45 "	15 "	82	88	92	97	81	74	75%	"
12:00 "	15 "	82.5	89	93	98	81	74	75%	"

The sun was covered with clouds most all the morning.

JUNE 9 — AFTERNOON

2:00 P.M.	--	83	85	87	89	82	75	73%	Heavy Cloudy
2:15 "	15 min.	82.5	85.5	88.5	89	81	75	78	"
2:30 "	15 "	84	86.5	91	93	82	75	73	"
2:35 "	5 "	86	89	96	99	82	75	73	"
2:40 "	5 "	83.5	89	92	95	82	75	73	"
2:45 "	5 "	83	86	89	91	82	75	73	"
2:50 "	5 "	85.5	88	93	96	83	75	69	"
2:57 "	7 "	86	90	97	100	83	75	69	"
2:58 "	1 "	87	91	99	102.5	83.5	75	68	"
2:59 "	1 "	88	92	101	104	84	75	66	"
2:60 "	1 "	84	92	99	102	82	75	73	"
3:00 "		82.5	87	89	91.5	81	74.5	76	sun cov.
3:02 "	2 "	84	87	91	93.5	82	74.5	73	"
3:04 "	2 "	85	88	93.5	97	82	75	73	"
3:06 "	2 "	86	89	95	99	83	75	73	breeze
3:07 "	1 "	87.5	91	98	102.5	83	75	73	hazy
3:10 "	3 "	87	91.5	98	102.5	83	75	73	clear
3:14 "	4 "	88	92	99	104	84	75	67	"
3:15 "	1 "	88.5	93	101	106	84	75	67	"
3:16 "	1 "	89	94	103	108	84	75	67	"
3:25 "	9 "	89	94	102	107.5	84	75	67	"
3:30 "	5 "	87.5	93	99	104	84	75	67	"

JUNE 9

AFTERNOON

TIME — TEMPERATURES DEG. FAHR. — AIR CONDITION

Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	psychrometer reading dry bulb	psychrometer reading wet bulb	relative humidity	cond. of sky
3:35 P.M.	5 min.	87.5	93	99	104	83	74.5	67%	cloud over sun
3:40 "	5 "	85.5	89	92	96.5	82	75	73%	hazy
3:43 "	3 "	87	90	95	100	83	74.5	67%	Cloudy
3:45 "	2 "	84	87	90	93	83	74.5	67%	"
3:50 "	5 "	83	87	90	92.5	82	74.5	72%	"
3:55 "	5 "	82.5	86	87	89	82	74	69%	"
4:00 "	5 "	83	86	88	89	82	74	69%	"

COOL BREEZE BLOWING ALL DAY

June 10

MORNING

9:00 A.M.	--	74.5	77	80	81	74	69	77%	no sun
9:15 "	15 min.	74.5	78	83	85	74	69	77	clouds
9:30 "	15 "	74.5	78.5	82	84	74	69	77	"
9:45 "	15 "	76	80	85.5	89	74	69	77	"
9:55 "	10 "	77	81	87	90	74	69	77	"
9:56 "	1 "	78	82	89	93	75	69	75	"
9:58 "	2 "	79	84	91	95	75	70	80	"
9:59 "	1 "	79.5	85.5	94	98.5	75	70	80	"
10:00 "	1 "	78.5	86	94	99	76	71	81	clearing
10:05 "	5 "	78.5	87	93	99	76	71	81	"
10:10 "	5 "	78.5	86.5	93	99	76	71	81	"
10:12 "	2 "	79	87	94	99.5	77	71	75	"
10:15 "	3 "	78	85	90	95	77	71	75	"
10:22 "	7 "	79	84	89	94	77	71	75	"
10:23 "	1 "	80	85	90.5	96	77	71	75	hazy
10:25 "	2 "	80	85.5	91.5	97	77.8	71	71	"
10:30 "	5 "	78	85	90	94.5	76	71	81	clouds
10:33 "	3 "	78	84	88	92	76	71	81	"
10:36 "	3 "	77.5	83	86	89.5	75	71	83	"
10:38 "	2 "	77	82	85	87	75	71	83	"
10:40 "	2 "	77	81	84.5	87	75	71	83	"

JUNE 10 — MORNING

TIME — TEMPERATURES DEG. FAHR. — AIR CONDITION

Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	Psychrometer Read. dry bulb	wet bulb	Relative humidity	Cond. of sky
10:45 A.M.	5 min.	76.8	81	84.5	87	76	71	81%	Cloudy
10:50 "	5 "	76.5	80.5	84	86	76	71	81	"
11:00 "	10 "	78	82	86.5	90	75.5	71	79	Breeze
11:10 "	10 "	80	84	89	92	77	71	76	hazy
11:15 "	5 "	78.5	83	87	89.5	77	71	76	"
11:23 "	8 "	77	81	83.5	85.5	76	71	81	"
11:30 "	7 "	77	80	83	84	76	71	81	"
11:45 "	15 "	78	81	84	87	76	71	81	"
12:00 "	15 "	79	84	89	94	77	71	76	"

Through this day the weather was cool, and the sun was hidden by clouds most of the day.

JUNE 11 — MORNING

9:00 A.M.	--	81	85	89	90	79	72	70	Clear
9:05 "	5 min.	82.5	86	92	94	79	72	70	"
9:14 "	9 "	79	86	91	94	79	72	70	Cloudy
9:15 "	1 "	82.5	85.5	91	95.5	79	72	70	Hazy
9:16 "	1 "	84	87	95	99	79	72	70	Clear
9:23 "	7 "	79	86	91	94	78	71	70	Cloudy
9:25 "	2 "	80	85	89	92.5	78	71	70	Hazy
9:28 "	3 "	82.5	87	84	93.5	79	72	70	Clear
9:30 "	2 "	82.5	88.5	96	100	79	72	70	"
9:35 "	5 "	83	89	97	102	79	72	70	"
9:38 "	3 "	79.5	88	93	96	78	71	70	Cloudy
9:40 "	2 "	79	85	89	92	78	71	70	"
9:43 "	3 "	81.5	86	91	94.5	78	71	70	Hazy
9:45 "	2 "	82.5	87	93	97	79	71	67	"
9:53 "	8 "	82.5	88	95	99	79	72	70	"
9:55 "	2 "	83.5	89	97	102	79	72	70	Clear
10:00 "	5 "	82	90	98	102	79	72	70	"

JUNE 11 — MORNING

TIME		TEMPERATURES DEG. FAHR.						AIR CONDITION	
Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	Psychrometer Readings Dry bulb	wet bulb	Relative humidity	Cond. of sky
10 :15 A.M	15 min.	84	92.5	103	107	80	72	68	hazy
10:20 "	5 "	84.5	93	103	107.5	81	73	70	"
10:25 "	5 "	84	92	100	105.5	82	73	67	Clear
10:30 "	5 "	83	89	94.5	99.5	81	73	70	"
10:32 "	2 "	84.5	91	98.5	103.5	82	73	67	"
10:35 "	3 "	85.5	92	101	106	82	73	67	"
10:40 "	5 "	84	91.5	98.5	102.5	82	73	67	Hazy
10:45 "	5 "	83	90	96	100.5	81	73	70	"
11:00 "	15 "	85.5	91	98	103.5	83	73	63	Clear
11:10 "	10 "	83.5	91	96.5	101	82	73	63	Hazy
11:15 "	5 "	82.5	89	93.5	98	81	73	70	"
11:30 "	15 "	82	88	91.5	95	81	72	70	"
11:45 "	15 "	83	89	94.5	99.5	81	72	70	"
12:00 "	15 "	84	92	100	105	82	73	63	"

Clear, cool breeze, broken clouds occasionally covering sun.

JUNE 11 — AFTERNOON

1:45 P.M.	---	89.5	93	97	99	86	75	63	Hazy
2:00 "	15 min.	88	94	101	104	86	75	63	"
2;02 "	2 "	90	95	103	107	87	75	58	Clear
2;05 "	3 "	88.5	95	101.5	106	87	74	56	Cool wd.
2:10 "	5 "	89	95	101.5	106.5	87	74	56	Clear
2:15 "	5 "	89	95	101	106	87	75	58	"
2:23 "	8 "	90	96	103	108	87	75	58	"
2:30 "	7 "	89.5	95	101	107	87	75	58	Cool wd.
2:35 "	5 "	89	96	102.5	108	87	75	58	Clear
2:40 "	5 "	89	94.5	99.5	105	87	75	58	"
2:45 "	5 "	89	94.5	101	106.5	87	75	58	"
2:53 "	8 "	90	94.5	100.5	107	88	75	54	"

JUNE 11 AFTERNOON

TIME TEMPERATURES DEG. FAHR. AIR CONDITION

Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	Psychrometer Reading dry bulb	wet bulb	Relative humidity	Cond. of sky
2:54 P.M.	1 min.	91	96	103	109	88	75	54	Clear
3:00 "	5 "	88	94.5	100	103.5	86	73	56	Cloud
3:01 "	1 "	86.5	93	99	101	86	73	56	"
3:06 "	5 "	85	89.5	91.5	93	85	73	57	"
3:10 "	4 "	84.5	88	89	90	84	72	55	Hazy
3:15 "	5 "	84.5	86.5	89	89	84	72	55	"
3:23 "	8 "	84.5	86.5	89	89	84	72	55	Cloudy
3:30 "	7 "	84	86.3	89	89	83.9	73	60	"
3:33 "	3 "	84.5	86.5	90	90	84	73	59	Hazy
3:35 "	2 "	85	87	91	91.5	84	73	59	Sun
3:36 "	1 "	86	88	93	94.5	84	73	59	"
3:37 "	1 "	88.5	90	97	100	85	73	57	"
3:40 "	3 "	89	92	100	102.5	85	73	57	"
3:41 "	1 "	87	92	99	101.5	85	73	57	"
3:45 "	4 "	85	90	93.5	95.5	84.5	73.5	60	"
3:46 "	1 "	85	89	92.5	94.5	84	73	59	Wind
3:50 "	4 "	84.5	88	91	92	84	73	59	"
3:55 "	5 "	85.5	88	92	94	83	73	62	"
3:57 "	2 "	87.5	89	95	97	84	73	58	"
4:00 "	3 "	86	90.5	97	99	83	73	62	"
4:10 "	10 "	88.5	93	101	105	85.5	74.5	61	Clear
4:15 "	5 "	87.5	93	98.5	103.5	84	73	58	"
4:20 "	5 "	85.5	92	97	100	84	73	58	"
4:25 "	5 "	87.5	91	97	101	85	74	60	"
4:30 "	5 "	88	92	98.5	103	85	74	60	"
4:35 "	5 "	89	93	100.5	105	86	74	60	"
4:40 "	5 "	90	95	104	108.5	86	75	62	"
4:45 "	5 "	88.5	95.5	104	108.5	86	75	62	"
4:50 "	5 "	89	95.5	104	108.5	86	75	62	"
5:00 "	10 "	88.5	93	101	105	85	74	60	"

JUNE 12 — MORNING

Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	Psychrometer Read. dry bulb	wet bulb	Relative humidity	Cond. of sky.
	TIME	TEMPERATURES DEG. FAHR.				AIR CONDITION			
9:00 A.M.	----	77.5	80	85	87	75	70	79	Cloudy
9:15 "	15 min.	75.5	80	84.5	87	75	70	79	Windy
9:20 "	5 "	76.5	81	85.5	88	75	70	79	"
9:25 "	5 "	75	80	83.5	86	75	70	79	"
9:30 "	5 "	78.5	82.5	88.5	92.5	77	70	72	"
9:45 "	15 "	77.5	82	87	91	76	71	80	"
9:54 "	9 "	77	82	86.5	90	76	70	77	"
10.00 "	6 "	76.5	81	85	88.5	76	70	77	Cloudy
10:10 "	10 "	76	79	82.5	84.5	75.5	70	78	"
10:15 "	5 "	76	79.5	83	85	75	70	79	"
10:25 "	10 "	75.5	79	81.5	83.5	75	70	79	"
10:30 "	5 "	76	79	83	85	75	70	79	"
10:45 "	15 "	76.5	79.5	83.5	86	75	69	76	"
11:00 "	15 "	76.5	80	83	75.5	75	69	76	Wind, cool
11:15 "	15 "	77	80.5	85	87	76	70	77	"
11:18 "	3 "	75.5	80	83	84.4	75	69	76	"
11:30 "	12 "	75.5	78	80	82	75	70	79	"
11:45 "	15 "	76	78	81	83	75	70	79	"
12:00 "	15 "	77	80	82.5	85	76	70	77	"

JUNE 12 — AFTERNOON

2:00 P.M.	---	83	86.5	91	94	82	71	59	Clear
2:15 "	15 min.	82	86	90	93	80	71	65	"
2:30 "	15 "	84.5	91	98	102	82	72	62	"
2:45 "	15 "	83	89	93	95.5	81	72	66	"
3:00 "	15 "	84	90	96	100	82	72	66	"
3:05 "	5 "	81	87.5	92	94	80	71	65	Cloud
3:10 "	5 "	84.5	88	95	99	82	71	59	Clear
3:12 "	2 "	82	88	94	97	81	71	64	Cloud
3:15 "	3 "	83	86.5	91.5	95	81	71	64	Clear
3:16 "	1 "	84	87.5	93	97.5	81	71	64	"

JUNE 12 — AFTERNOON

TIME — TEMPERATURES DEG. FAHR. — AIR CONDITION

Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	Psychrometer Read. Dry bulb	wet bulb	Relative humidity	Cond. of sky
3:20 P.M	4 min.	82.5	88	94	97	81	71	64%	Hazy
3:25 "	5 "	85.5	90	97	101.5	82	72	66	Clear
3:26 "	1 "	86	91	98.5	103	82	72	66	"
3:30 "	4 "	84	90.5	98.5	101.5	81	71	64	Wind
3:45 "	15 "	84	85.5	92	98	81	72	66	"
3:50 "	5 "	84	85.5	95	98	81	72	66	"
4:00 "	10 "	83	88	93	97	81	72	66	"
4:05 "	5 "	83.5	88	93.5	98	81	72	66	"
4:15 "	10 "	82.5	87.5	92.5	95.5	81	72	66	"
4:25 "	10 "	81	84	85	90	80	72	68	Hazy
4:30 "	5 "	81	84	87.5	90	80	72	68	"
4:45 "	15 "	81.5	85	90	92	80	71	65	"
5:00 "	15 "	82.5	87.5	92	95	81	72	66	"

JUNE 13 — MORNING

10:30 A.M.	--	79	88	97.5	99	79	64	43	Hazy
10:40 "	10 min.	79	88.5	98.5	100	79	64	43	Clear
10:45 "	5 "	80	89.5	99	102	79	64	43	"
10:50 "	5 "	80.5	90	99	102	79	64	43	"
11:00 "	10 "	80	90	99	102.5	79	64	43	"
11:15 "	15 "	80	90	99	102	79	64	43	"
11:23 "	8 "	80	89	97	101	79	65	49	"
11:30 "	7 "	81	89	100.5	103.5	79	65.5	51	"
11:35 "	5 "	80	91	101	103.5	79	65.5	51	"
11:45 "	10 "	80.5	91.5	97	100	79	65	49	"
11:50 "	5 "	81	89	98	101	79	65	40	"
12:00 "	10 "	81.5	90	99	102	80	65	48	"
12:15 "	15 "	81.5	90.5	99.5	103	80	65	48	"
12:20 "	5 "	82	91	99.5	102.5	79	65	49	"
12:30 "	10 "	80.5	91.5	97.5	100	79	65	49	"
12:45 "	15 "	82	90	97	100.5	80	65.5	50	"

JUNE 13 — MORNING

TIME	TEMPERATURES DEG. FAHR.						AIR CONDITION	
Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	Psychrometer dry bulb	Reading wet bulb	Relative humidity	Cond. of sky
12:55 A.M.	10 min.	83	91	99	102	81	65.5	45	Clear

JUNE 13 — AFTERNOON

1:00 P.M.	5 min.	81.5	91	98	101	80	65	45	Clear
1:10 "	10 "	82	89.5	95	99	81	65	43	"
1:15 "	5 "	83	91	100.5	103.5	82	65	40	"
1:24 "	9 "	84	94	104	106	82	65	40	"
1:30 "	6 "	83	91.5	99	103	82	65	40	"
1:40 "	10 "	83	92	99	102.5	81	65	43	"
1:45 "	5 "	83.5	92	99	102.5	81	65	43	"
1:55 "	10 "	84	92.5	100.5	104	82	64.5	39	"
2:00 "	5 "	85	93	102.5	106	82	64.5	39	"
2:15 "	15 "	85	92.5	101	105	82	66	43	"
2:30 "	15 "	84.5	92	100	104	82	66	43	"
2:45 "	15 "	84.5	91.5	99	103	81	65	43	"
3:00 "	15 "	85.5	94	104	106.5	81	65	43	"
3:02 "	2 "	84.5	92	98	102	82	65	40	"
3:15 "	13 "	85.5	92	99	104	81	65	43	"
3:30 "	15 "	85	93	102	105.5	80	65	45	"
3:45 "	15 "	83.5	88.5	94.5	98	80	65	45	"
3:55 "	10 "	86	94	104	106	82	65	40	"
4:00 "	5 "	84.5	93	102	105	82	65	40	"
4:15 "	15 "	86	93.5	103	106.5	82	65	40	"
4:30 "	15 "	85.5	83.5	102.5	105.5	82	65	40	"
4:45 "	15 "	85.5	84	103	106.5	82	65	40	"
5:00 "	15 "	84.5	92	101	104	82	65	40	"

JUNE 14 — MORNING

TIME TEMPERATURES DEG. FAHR. — AIR CONDITION

Time of Day	Duration of run	Air	Alum. bulb	Plain bulb	Black bulb	Psychrometer Reading Dry bulb	wet bulb	Relative humidity	Cond. of sky
9:00 A.M.	---	78	85	91	94	77	64	50%	Clear
9:15 "	15 min	79	86.5	93	95	77	65	50	"
9:30 "	15 "	78	86	93	96	77	65	50	"
9:45 "	15 "	79.5	87.5	96	99	79	66	50	"
9:53 "	8 "	79	86	92.5	95	79	65	47	"
9:55 "	2 "	80	86.5	93	96	79	65	47	"
10:00 "	5 "	78	86.5	92.5	95	78	65.5	50	"
10:15 "	15 "	82.5	90	99	101	80	67	51	"
10:35 "	10 "	82.5	92	101.5	103.5	81	65	43	"
10:45 "	10 "	82	90.5	98.5	101.5	81	65	43	"
11:00 "	15 "	81	88	93	97	80	65	45	"
11:05 "	5 "	81	89	86	99	79	68	57	"
11:15 "	10 "	82	91	100	103	80	67	51	"
11:30 "	15 "	80.5	89	96	100	79	67	53	"
11:45 "	15 "	83	93	103	105	80	67	51	"
12:00 "	15 "	82	91	100	103	80	67	51	"

June 14 — AFTERNOON

1:30 P.M.	---	86	95	104.5	107	84	68	43	"
1:45 "	15 min.	86.5	93	101	105	83	67	43	"
2:00 "	15 "	87.5	94	101	105	84	67	40	"

APPROVAL SHEET

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statements made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

Name Chas. E. Ferris

Title Prof. Mech. Eng.