Humidity Recorders

By E. B. WHEELER

DURING recent years, the study of atmospheric conditions and their bearing on various industrial problems from the standpoint both of their effects on human efficiency and on manufacturing processes, is a matter that has received much attention, and the use of air conditioning systems, which have been developed in the last few years, has resulted in greatly improved working conditions, as well as in increased outputs of manufactured products of better quality than obtainable when air conditioning was not employed.

It is not so well appreciated, perhaps, that atmospheric conditions have a material effect upon the operation of intricate electrical and mechanical apparatus, such as those found in telephone systems.

Water vapor, and both gaseous and solid impurities in the air, hasten oxidation and corrosion of metals and also reduce the value of the insulation afforded by insulating materials. These effects usually are greatly accelerated if the temperature is high and if the materials are subjected to differences of electrical potential. Telephone apparatus and equipment consist of combinations of materials which are subject to both of these effects and, in general, the parts are small and the materials used in making them must be carefully chosen with regard to the necessary physical and electrical properties required for proper functioning of the apparatus. Therefore, the severe atmospheric conditions, which may be encountered in service, either must be eliminated by the use of air conditioning systems or the apparatus must be designed to withstand those conditions.

Accordingly, in order that the problem may be handled intelligently, accurate information must be available showing the character of the atmospheric conditions which exist in typical localities where telephone equipment is installed, so that the effects of these conditions on proposed designs may be studied under carefully controlled similar conditions in laboratory "humidity rooms." An outline of some of the work which has been done in an effort to obtain such information may therefore be of interest.

The first recourse would seem to be the data recorded by the various stations of the United States Weather Bureau. However, since these data usually represent periodic observations of outdoor conditions which are obtained primarily for meteorological purposes, it was found that while they indicate the general climatic conditions of different localities, they can not be taken to represent typical conditions in central office buildings, and therefore it has been necessary to devise methods by which we might secure such information.

The subject of hygrometry has long been one of the problems to which various investigators have given attention and the results of their work are a matter of record.

Thus it has been recognized [1] that, because of its ease of manipulation and its accuracy if suitable precautions are observed, the ventilated psychrometer is a suitable instrument for use in humidity measurements.

Consideration of the various types of hygrometers, commercially available, indicated however, that none would be suitable if reliable continuous records were to be secured. The use of simple wet bulb —dry bulb hygrometers would require practically constant attendance if frequent observations were made, and the results would not be accurate unless arrangements were made to circulate the air over the wet bulb. A pen recorder of the circular chart type to record wet and dry bulb temperatures had been used during one summer in a telephone central office where the humidity conditions were severe, but the results secured were not considered reliable because of the unsatisfactory method used to ventilate the wet bulb, as well as the sluggishness of the recorder due to pen friction on the chart.

Considerable experience in the laboratory with a recording hair hygrometer also had shown that, in addition to the inaccuracies to which hair hygrometers are commonly subject, the friction in the lever mechanism and between the pen and the chart made the instrument too erratic to be considered of possible use in the work being undertaken. Accordingly, a study was made to determine the possibility of developing apparatus which would overcome the troubles inherent in such recorders.

Development of a Recording Hygrometer

A promising method, developed by D. T. May of the Bell System Laboratories and operated successfully in the laboratory, consisted in the use of accurate and matched mercury thermometers, the stems of which were contained in a camera which would enable the heights of the mercury columns to be photographed upon a roll of sensitized paper. Arrangements were made for shifting the paper between

[1] U. S. Weather Bureau Psychrometric Tables for Obtaining the Vapor-Pressure, Relative Humidity and Temperature of the Dew-Point from Readings of the Wet and Dry Bulb Thermometers, by C. S. Marvin.

Proceedings of the Physical Society of London, Feb. 15, 1922. The Measurement of Atmospheric Humidity, by Sir Napier Shaw.

exposures, and a small exhaust blower was provided for circulating the air over the wet bulb. The whole apparatus was controlled electrically by a clock and was arranged to record the wet and dry bulb temperatures at any desired time interval. When the complete record roll had been exposed it was removed and upon development showed the thermometer readings from which the corresponding humidities could be found in the psychrometric tables. While this type of recorder would no doubt have enabled accurate information to be obtained, it had two inherent objections. These were, first, the bulkiness of the complete equipment which had to be placed at the location where the conditions were to be determined and,

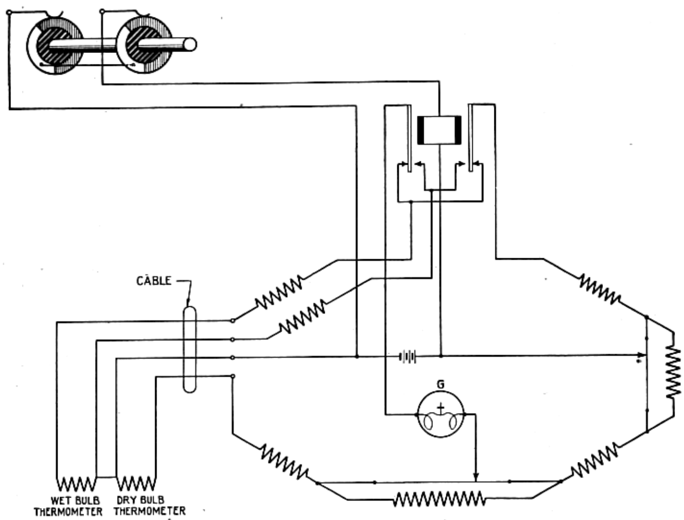

Fig. 1—Bridge Circuit of Difference Recorder

second, the thermometers could not be read because their stems were within the camera box, and therefore, the humidities and temperatures measured could not be ascertained until the record had been developed.

Accordingly, at this time, consideration was given to a type of mechanism which would produce a visible record upon a chart continuously available for observation by the operator. It was found that the Leeds & Northrup automatic recorder had been in commercial use for some time for the measurement of furnace temperatures, by means of thermocouples in conjunction with an automatically adjusted potentiometer circuit. The same type of recorder also had

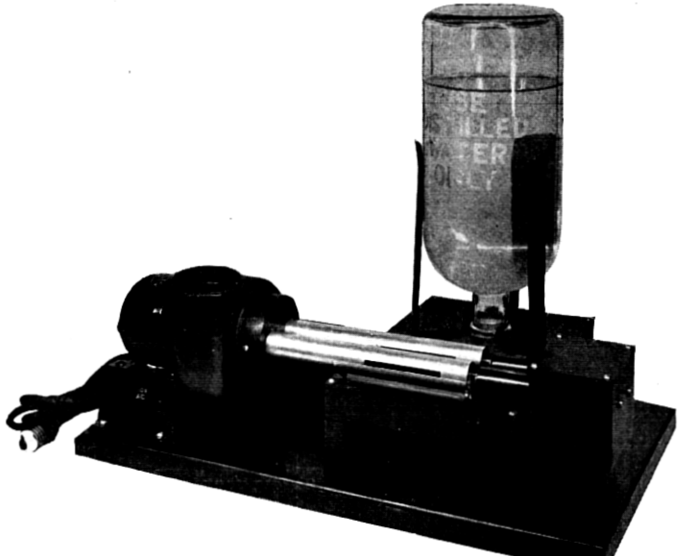

Fig. 2—Wind Tunnel Equipment

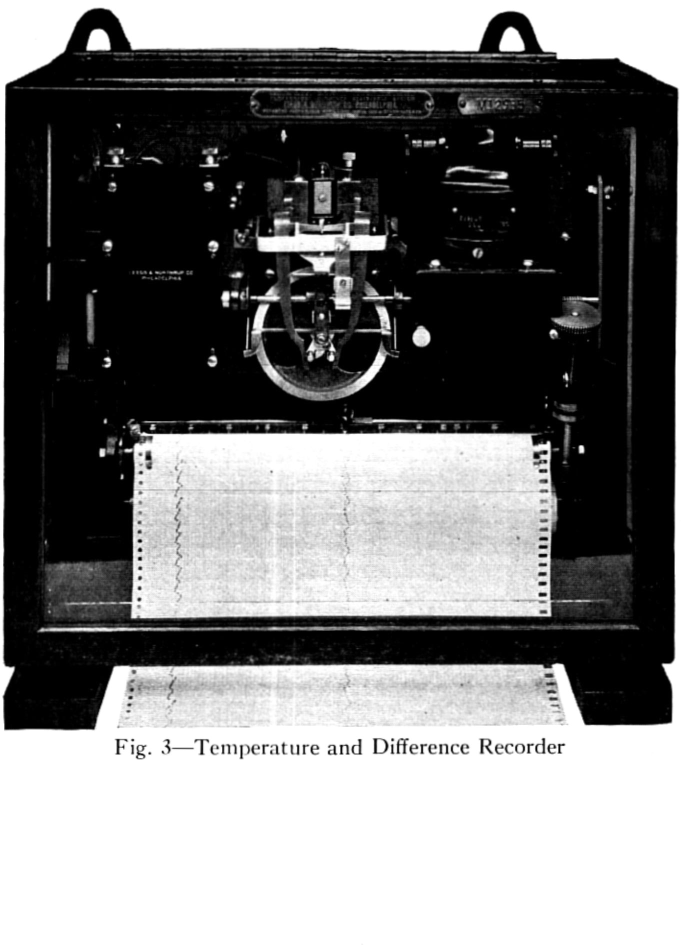

Fig. 3—Temperature and Difference Recorder

been used for recording temperatures and differences between two temperatures by means of resistance thermometers and a Wheatstone bridge arrangement. As it seemed feasible to adapt this instrument to meet our requirements, the double Wheatstone bridge circuit shown in Fig. 1 and the auxiliary wind tunnel equipment with resistance thermometers shown in Fig. 2 were developed. Fig. 3 is an illustration of the Leeds & Northrup recorder used.

This recorder was arranged to measure the resistance of the dry bulb thermometer and the difference between the resistances of the dry and wet thermometers, and to record these values upon a chart. Referring to the circuit diagram Fig. 1, it may be seen that, by means of a relay whose operation is controlled by the commutator on the recorder mechanism, the two Wheatstone bridges, one containing the dry bulb thermometer, and the other containing both the dry and wet bulb thermometers, may be balanced alternately by the recorder. After a sufficient interval has elapsed in each case for the bridge to become balanced the siphon pen is lowered into contact with the chart by a cam mechanism and the point of balance thus recorded. The record thus produced consists of dotted curves showing the successive indications of dry bulb temperature and difference between dry and wet bulb temperatures.

In order to secure the desired accuracy and sufficient sensitivity to follow the changes in temperature, the resistance thermometers used consist of platinum wire wound on mica cards and encased in flat nickel silver tubes with hard rubber ferrules. These are attached to a brass junction box in which is terminated the four conductor cable leading to the recorder mechanism.

The thermometers are enclosed in slotted brass tubes through which the air is drawn by a small blower driven by a universal motor. Mounted below these tubes is a shallow, covered water tank having a slot in the cover beneath the wet bulb thermometer through which the wick projects into the water. The desired water level in the tank is secured by an inverted water bottle, the neck of which projects into another opening in the cover of the tank.

The wind tunnel equipment[2] containing the resistance thermometers may be placed at any desired distance from the recorder mechanism, as the resistances of the thermometer leads have no effect upon the measurements provided they are equal. Leads consisting of a four conductor rubber insulated lead covered cable from 50 feet to 100 feet in length have been used.

[2]The wind tunnel and equipment is quite similar in operation to the "distance hygrometer," *Sci. Am.* June 6, 1914, p. 468.

As one of the difficulties encountered in the use of the wet bulb thermometer consists in the gradual clogging and drying up of the wick due to the accumulation of impurities left in it from the evaporation of the water, together with the dust which settles from the air which is drawn over it, special care must be taken to guard against trouble from this source. The cotton fabric used for the wicks which cover

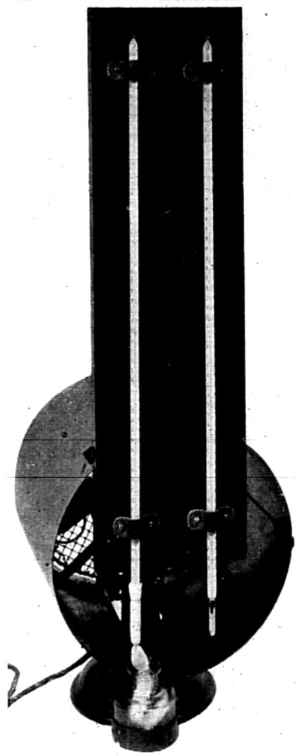

Fig. 4—Ventilated Psychrometer

the wet bulb must be treated to remove all traces of grease, with subsequent thorough washing to remove all traces of corrosive material. After this, the wicks should be handled only with thoroughly cleaned hands before they are placed on the thermometers. These wicks should be changed daily. Pure distilled water must be used in the tanks and they must be cleansed occasionally because they become contaminated by the impurities washed out of the air as it bubbles through the water. By rigid observance of such precautions no difficulty should be experienced in securing accurate records by means of this recorder.

Laboratory Tests

Several of these recorder mechanisms were built and after having been adjusted to operate satisfactorily, each wind tunnel equipment connected to its associated recorder was placed in a laboratory room controlled by air conditioning equipment, and given a run to test its operation under the range of conditions which might be expected to occur at the localities where the recorders were to be installed. During this test, the readings given by the recorder were compared with those obtained with a ventilated psychrometer, Fig. 4, equipped with accurate wet and dry bulb thermometers. Table I following gives a summary of the readings obtained in calibrating one of the recorders, while Fig. 5 shows a typical 12 hour record obtained in one of the laboratory rooms.

TABLE I

Ventilated Psychrometer			Leeds & Northrup Recorder			Per Cent Differ-ence
Dry Bulb Temp. F°	Difference between Dry and Wet Bulb, Temp. F°	Relative Humidity Per Cent	Dry Bulb Temp. F°	Difference between Dry and Wet Bulb, Temp. F°	Relative Humidity Per Cent	
77.9	11.5	54.0	77.8	11.1	55.5	+2.8
77.2	10.2	58.0	77.0	9.9	59.5	+2.6
78.4	0.9	96.5	78.2	0.8	97.0	+0.5
84.4	0.7	97.0	84.4	0.6	97.5	+0.5
83.5	5.6	77.5	83.6	5.6	77.5	0.0
83.7	10.8	59.5	83.4	10.5	60.5	+0.1
98.3	10.5	65.5	98.2	10.5	65.5	0.0
98.3	13.4	57.0	98.3	13.4	57.0	0.0
97.4	1.3	95.0	97.8	1.5	94.5	−0.5
97.2	1.0	96.0	97.6	1.2	95.5	−0.5

Reference to these tabulated values of relative humidities obtained by the two methods indicates that the recorder is capable of giving reliable data particularly through the range of high humidities where the effects on materials or apparatus exposed to these conditions may be large. Difficulty was experienced in comparing the readings of the two instruments due to the sensitivity of the resistance thermometers to slight temperature changes, and also due to the slight differences in temperature between the two sets of thermometers which necessarily occurred because they were not in the same wind tunnel. This difficulty was encountered particularly when the "humidity

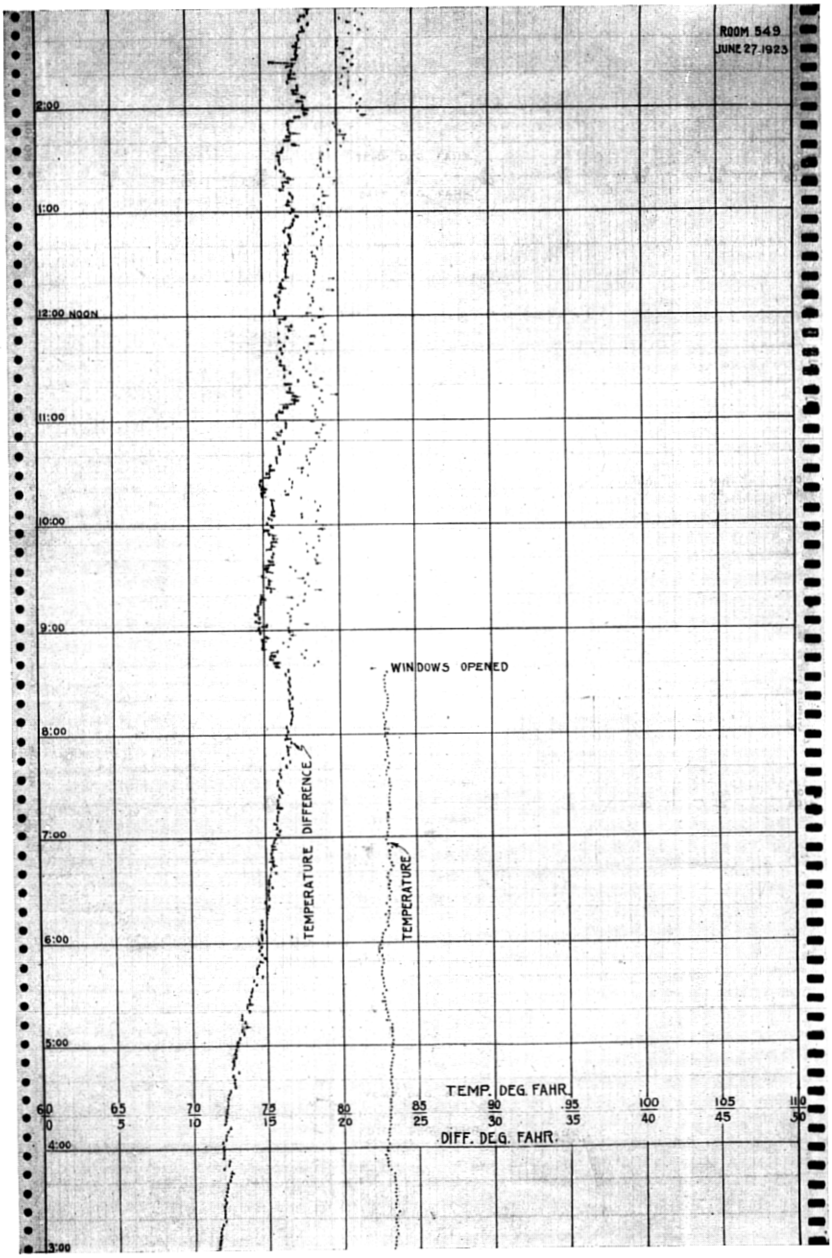

Fig. 5—Record from Temperature and Difference Recorder

room," in which the apparatus was located, was under a thermostatic control which allowed a temperature variation of approximately ±0.5° F. However, the calibration of the resistance thermometers and the sensitivity of the bridges in which they are placed is such that temperatures and temperature differences are recorded with an accuracy of ±¼° F.

Field Trials

In order to determine just what combinations of temperature and relative humidity prevail in widely separated localities of the United States, certain cities were selected in which moisture troubles with

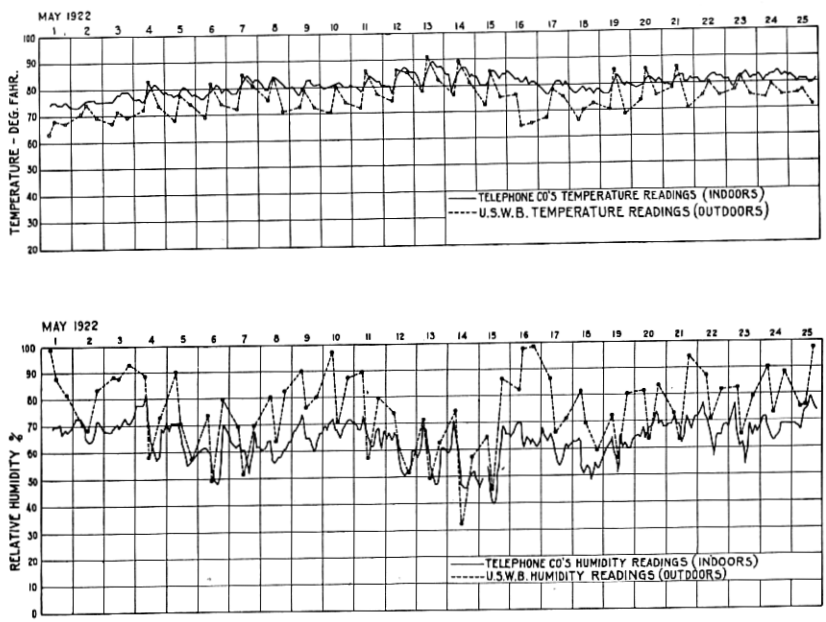

Fig. 6—Comparison of Indoor and Outdoor Temperatures and Relative Humidities at Savannah, Ga.

telephone equipment might be expected to occur, and at which local stations of the United States Weather Bureau were located, so that comparisons might be made between our records of indoor conditions and the observations of outdoor conditions.

Ten of these instruments were installed in central offices in New York (3), Boston, Savannah, New Orleans, Chicago, Minneapolis, Houston and Seattle, from which records have been obtained during the summer months of 1921 and 1922.

From the data accumulated in these cities, comprehensive information has been obtained as to the duration of conditions of average and maximum severity which occur during the humid months. It is of interest to compare the values of the central office conditions of temperature and relative humidity obtained from the recorders, with the corresponding Weather Bureau observations. The curves given in Fig. 6 show a typical comparison from data obtained at Savannah, Ga., during May, 1922. Study of these curves shows that the indoor temperature averaged somewhat higher than that out of doors, and that the indoor relative humidities were seldom higher than 75%, although the outdoor humidities often were higher than 85% for considerable lengths of time. The Weather Bureau data indicate very definitely when rain storms occurred and also periods of high humidity, due perhaps to foggy weather, although such periods are not well defined by the humidity curves showing the indoor conditions.

Since for a given absolute humidity, the relative humidity varies inversely with the change in temperature of the air, obviously it should be possible to keep the relative humidity in a central office building lower than that of the outside air by keeping the windows closed during periods of sudden temperature changes, and by the use of heat in switchboard sections. This latter remedy for humidity troubles has been successfully applied for several years to switchboards installed in some localities. Also the effects upon the indoor humidity and upon the performance of central office equipment, of closing the windows of central office rooms has been the subject of considerable investigation.

In the study of this method of reducing relative humidity, it is very desirable to have records which will show continuously the differences existing between indoor and outdoor temperatures and relative humidities, and in particular to study the effects on the indoor conditions when sudden changes in atmospheric conditions occur such as rain storms when the relative humidity outside reaches 100%. It was found that the automatic recorder described above would lend itself admirably to the study of this problem and that by the use of a simple relay switching mechanism on the recorder, two wind tunnel equipments could be operated with one recorder, enabling temperatures and differences between dry and wet bulb temperatures to be recorded alternately on the same chart for both indoor and outdoor conditions.

A recorder of this type was operated during the summer months of 1921 at the West Street laboratories of the Western Electric Co., Inc., to record the conditions in a well ventilated laboratory room

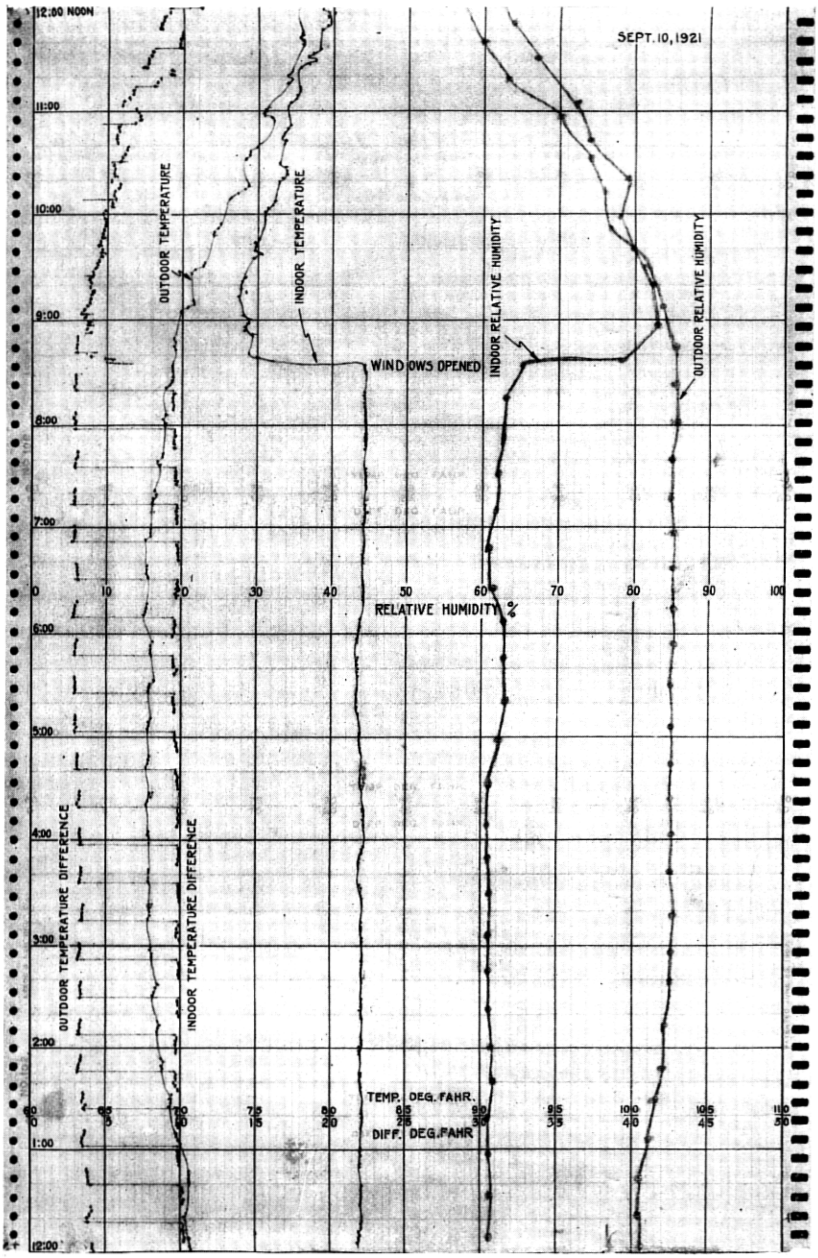

Fig. 7—Record from Double Recorder Comparing Indoor and Outdoor Conditions

about 25 feet x 27 feet and having two windows each in the east and south walls. The wind tunnel equipment was installed at a height of six feet upon a pillar in the center of the room. About ten people normally work in this room. The outdoor conditions were obtained by mounting a wind tunnel equipment in a standard Weather Bureau instrument shelter placed at the top of a tower, 14 feet high, which stands on the roof of a three story building far enough away from walls and other obstacles to permit free circulation of the air.

Figs. 7 and 8 show two typical 12 hour records upon which the indoor and outdoor relative humidities have been plotted from the curves of temperatures and temperature differences recorded by the instrument. A study of these records indicates that large differences often exist between the indoor and outdoor conditions and that the indoor conditions are much less severe than might be expected when the outdoor humidity is high. This difference is particularly noticeable when the windows are closed, but as soon as they are opened the indoor temperature decreases and the humidity generally increases to practically the same value as that of the outside air. Fig. 8 is of particular interest in showing the rapid decrease in the outdoor temperature and increase in relative humidity due to a thunderstorm.

The analysis of the records obtained from a number of recorders which record temperature and difference between dry and wet bulb temperature requires considerable labor in obtaining the corresponding relative humidities from the psychrometric tables and, obviously, periodic values only can be taken unless some rapid mechanical method of doing this is employed. Such methods have been developed and used successfully for this purpose.

A New Direct Reading Humidity Recorder

A much more satisfactory type of recorder is one which, in addition to tracing the temperature curve, traces a curve of the relative humidity. The only instrument of any prominence that has been used in this way is the recording hair hygrometer, the objectionable features of which have already been mentioned.

An improved type of direct reading humidity recorder which has been developed by E. B. Wood, of the Laboratories of the American Telephone and Telegraph Company and the Western Electric Company, employs the Leeds & Northrup automatic recorder mechanism, to which has been added an electrical mechanism which will be described, together with the principle upon which its operation is based.

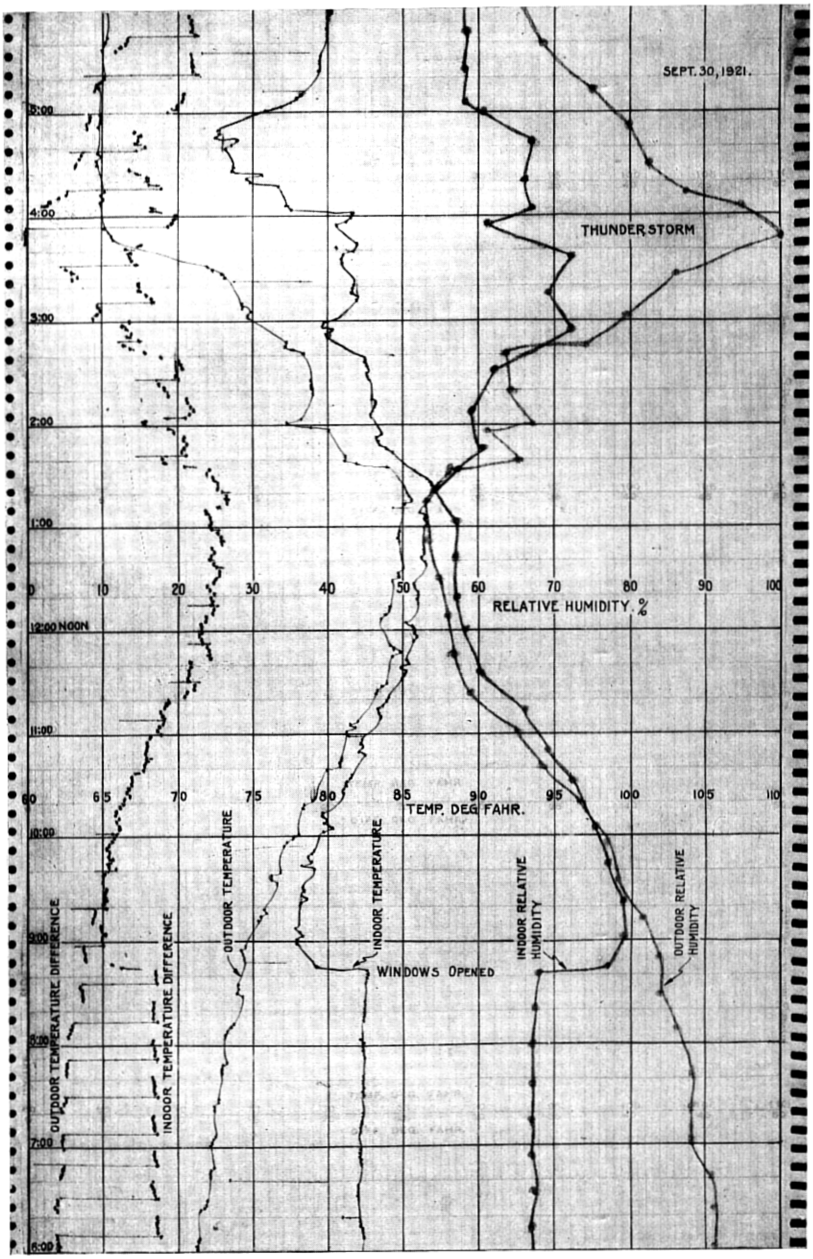

Fig. 8—Record from Double Recorder Comparing Indoor and Outdoor Conditions

This novel improvement depends, for its operation, on the approximate linearity and common intersection of the ordinary humidity curves as shown in Fig. 9.[3]

It is apparent that each of the humidity curves is in effect a straight line and that, with an accuracy sufficient for practical purposes, these curves, representing humidities of from 30% to 100%, converge at a point (a) whose coordinates are (b, c). Assuming that the humidity

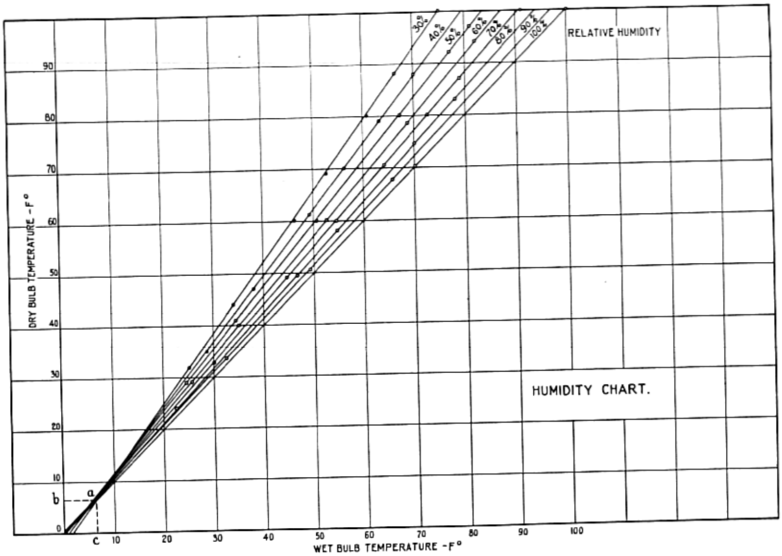

Fig. 9

curves are straight lines passing through point (a), it is apparent that the value of humidity is completely determined if the slope of the particular curve is known, since each curve represents only one value of humidity. It also is apparent that the slope is given by the ratio of dry bulb temperature minus the ordinate of point (a), to wet bulb temperatures minus the abscissa of point (a); or in other words, the relative humidity is completely determined, if the dry bulb and wet bulb temperatures are each known, above the datum coordinates (b, c) of point (a).

If then, a resistance is set off, proportional to the difference between the temperature of the dry bulb and temperature (b), and another resistance is set off proportional to the difference between the temperature of the wet bulb and temperature (c), the ratio between

[3] Bur. Stands. Cir. No. 55, p. 116.

these two resistances will indicate directly the relative humidity corresponding to the dry and wet bulb temperatures. The circuit arrangement by means of which this is accomplished is shown in Fig. 10, and the mechanism of the recorder employing it, is shown in Fig. 11.

The recorder circuit contains three Wheatstone bridges with one battery and galvanometer which are transferred in rotation from

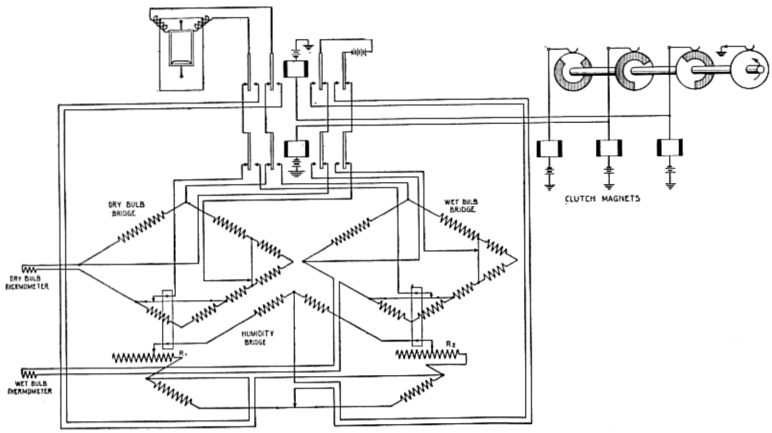

Fig. 10—Circuit of Direct Reading Recorder

each bridge to the next by the commutator and relays shown in the circuit. The three bridges are arranged so that they remain at their last positions of balance until mechanically connected to the balancing mechanism of the recorder by the electric clutch associated with each bridge whose operation also is controlled by the commutator. The first of these bridges, designated the "dry bulb bridge," contains the dry resistance thermometer and mechanically associated with its slide wire contact is a second slide wire contact operating upon a slide wire resistance arm in the third bridge, designated as the "humidity bridge." The second of these bridges, designated as the "wet bulb bridge," contains the wet resistance thermometer, and mechanically associated with its slide wire contact is a second slide wire contact operating upon a second slide wire resistance arm of the "humidity bridge."

The consecutive balancing of the "dry bulb bridge" and "wet bulb bridge" accordingly sets off resistances upon the two slide wire resistance arms of the "humidity bridge" proportional respectively to the temperature differences described in the second preceding paragraph.

The balancing of this bridge accordingly accomplishes the result already described of determining the ratio of the resistances R_1 and R_2 of these two slide wire arms, and consequently, the relative humidity corresponding to the dry and wet bulb temperatures previously

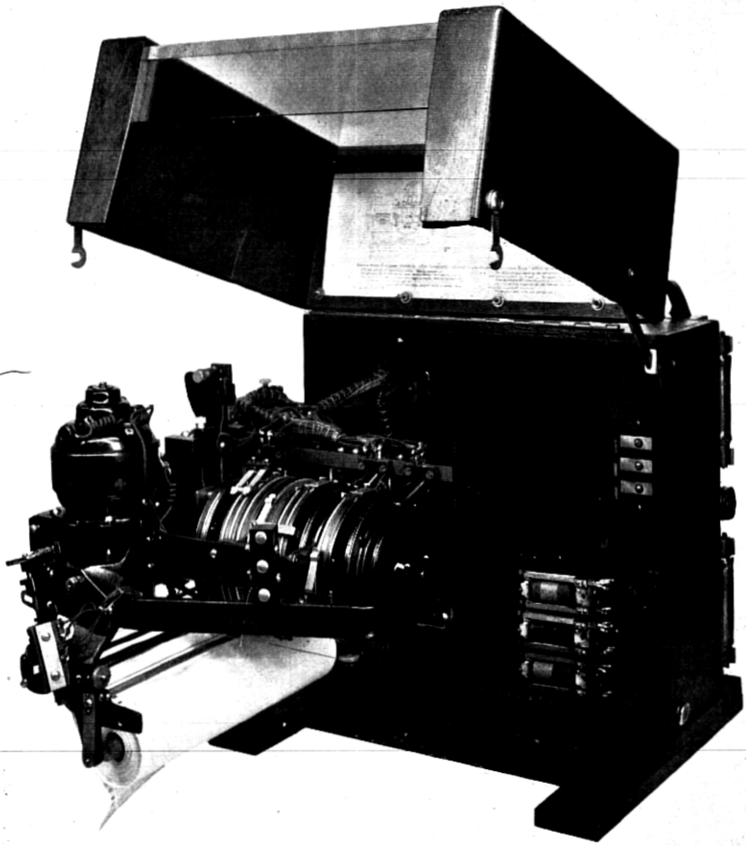

Fig. 11—Direct Reading Recorder

measured on their corresponding bridges. In the operation of the recorder, a period of about 20 seconds is allowed by the commutator to balance each bridge thus completing a cycle every 60 seconds.

The recorder is equipped with two pens one of which is associated with the slide wire of the "dry bulb bridge" thus recording the dry bulb temperature, while the other pen is associated with the "humidity

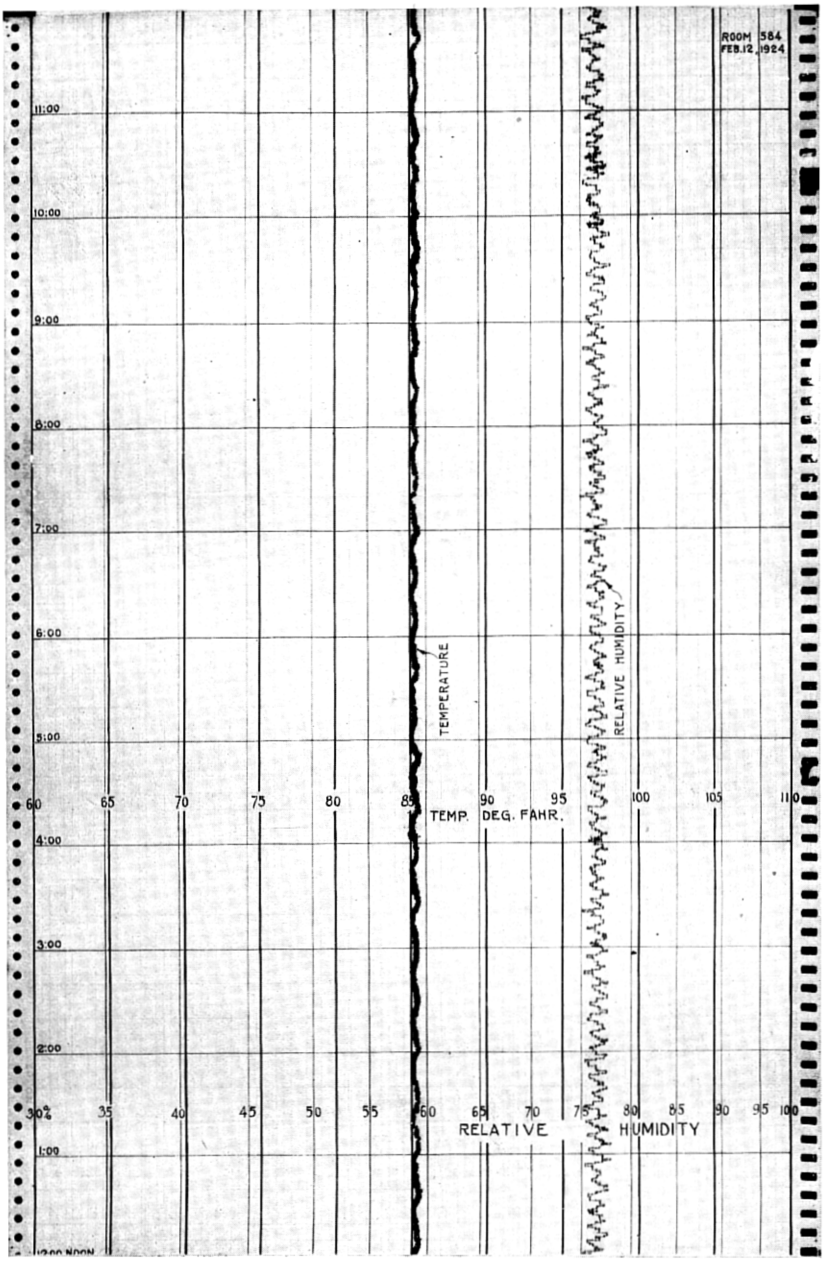

Fig. 12—Temperature and Relative Humidity in a Humidity Room

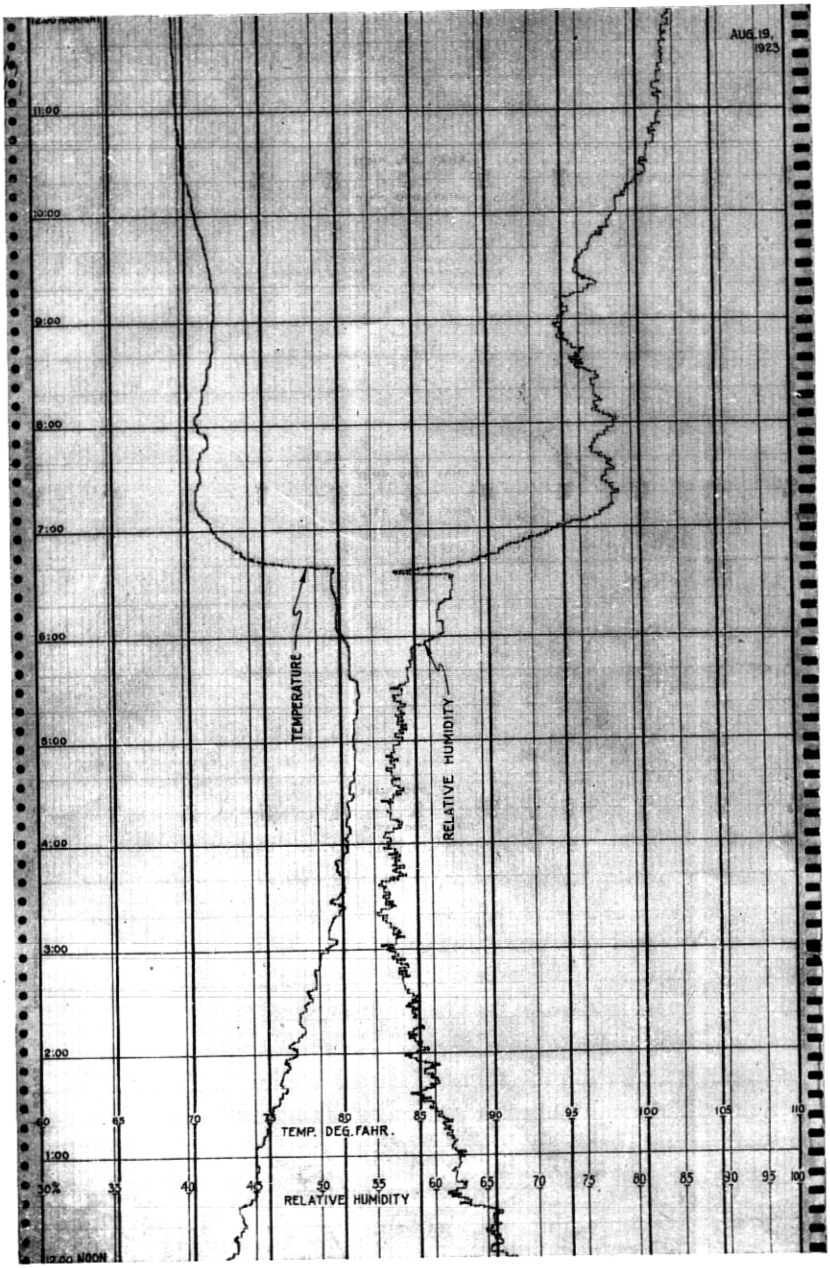

Fig. 13—Outdoor Temperature and Relative Humidity

bridge," thus recording the values of humidity directly. Inasmuch as successive operations of the recorder consist in the restoration of the balance of each bridge, if different from the last position of balance, it is evident that the pens will trace continuously the variations of temperature and relative humidity.

A recorder of this type with its associated wind tunnel mechanism has been used for some time to record the conditions in a laboratory "humidity room." The temperature record given by this recorder is accurate to $\pm\frac{1}{4}°$ F. as in the case of the difference recorder. The accuracy of the humidity record differs for various points on the scale, depending upon the values chosen for certain resistances in the recorder. When the recorder is adjusted for very close accuracy ($\pm\frac{1}{2}\%$ relative humidity) for relative humidities above 90%, the accuracy for lower values of humidity decreases until at 50% the maximum variation from the true value may be as much as $2\frac{1}{2}\%$ relative humidity. If desired, the adjustment may be made to transfer the point of greatest accuracy to any selected lower value of humidity. Experience with this model has suggested changes which should considerably improve this accuracy over the whole range of humidities. Fig. 12 shows a typical 12 hour record of conditions in the "humidity room" while under automatic control of an air conditioning equipment.

This recorder also was used during the summer months of 1923 to record outdoor conditions with the wind tunnel equipment installed in the Weather Bureau instrument shelter mentioned earlier. During this period of 4 months' operation, it required no attention save an occasional oiling of the mechanism and maintenance of the wet bulb equipment, and practically continuous records were secured. The records are of particular interest for observation of the variations of temperature and humidity which take place during changes in weather conditions such as rain storms. Figs. 13 and 14 are reproductions of typical consecutive 12 hour records obtained for outdoor conditions.

From consideration of the humidity recording apparatus which has been developed and the results which have been obtained with it, it may be stated that both the difference recorder and the direct reading recorder are satisfactory instruments with which accurate data may be obtained. However, they are instruments which, in common with other types of apparatus that have been developed to measure humidity, require careful attention of the wind tunnel equipment in order to secure reliable results; also the recorder mechanism itself requires the attention of an operator skilled in its maintenance.

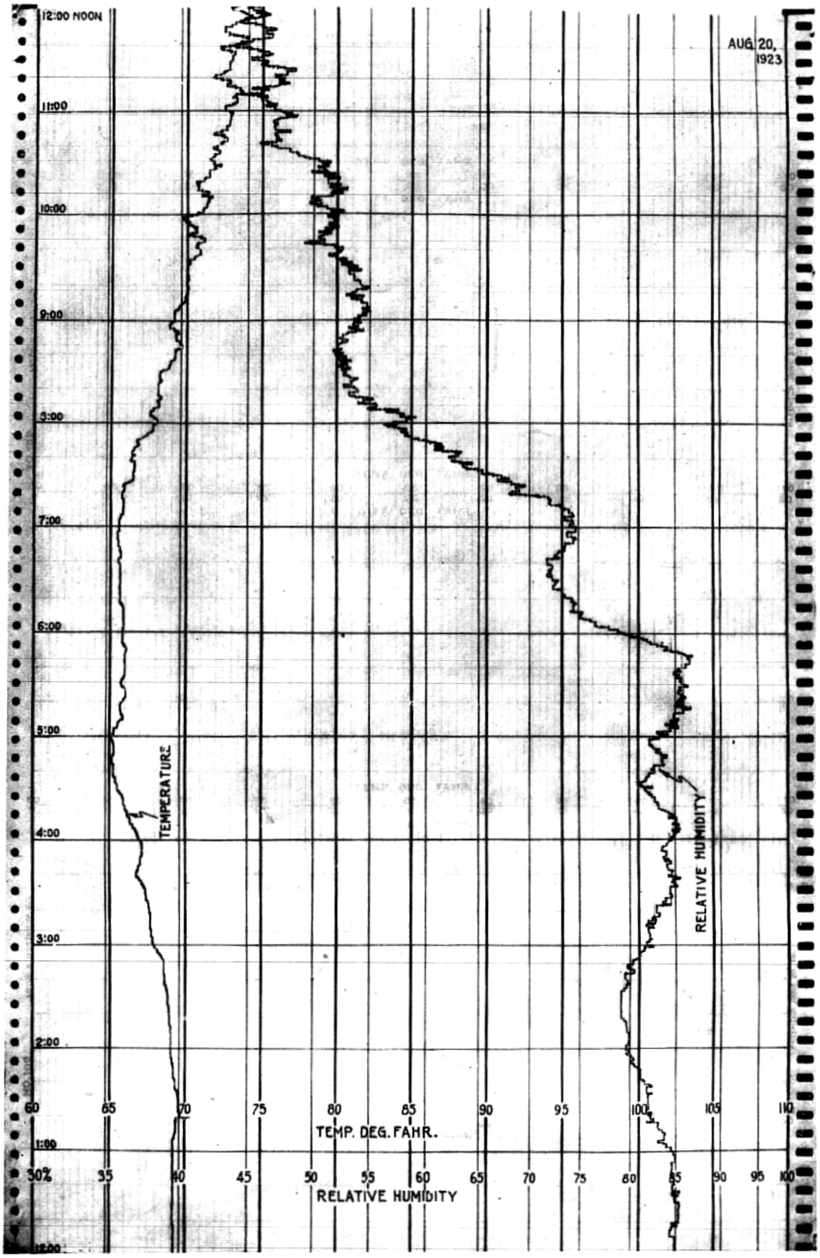

Fig. 14—Outdoor Temperature and Relative Humidity

While the mechanism of the direct reading recorder is more complicated than that of the difference recorder, it is a more useful instrument, both because the humidities may be read directly, thus saving the labor of interpretation of the records, and because the records are more significant. The direct reading recorder, furthermore, may be used to control the functioning of air conditioning apparatus at any desired conditions, at the same time that it is actually recording these conditions. Accordingly, it should prove particularly useful in maintaining proper humidity in apparatus and operating rooms.