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A UNIFORM THERMOMETER EXPOSURE AT METEOROLOGICAL STATIONS FOR DETERMINING AIR TEMPERATURE AND ATMOSPHERIC HUMIDITY.

By VLADIMIR KÖPPEN.

[Sections translated from Met. Ztschr., 1913, **30**: 485–488, 513–523.]

* * * All in all, we are at last in a position to state definitely the errors due to the customary thermometer exposures, to attack the problem of eliminating these errors, and to begin to work toward a uniform manner of exposing thermometers throughout the world. Although it is much to be regretted that we still have no such series of comparisons in tropical and subtropical regions as are available for central and northern Europe, nevertheless the already observed differences due to sun's altitude, cloudiness, and wind velocity enable us to draw quite approximate conclusions for the Tropics also.

The daily means of temperature, so far almost the sole element employed for making climatological comparisons, do not vary greatly even for quite divergent methods of exposure because their daytime and nighttime errors balance each other to a certain extent. The latter is least true for great massive shelters such as those of Wild and Neumayer, because in these the daily heating in the sunshine and the nocturnal damping due to the mass of wood upset the balance so that their records yield too high daily means. On the other side stands the English shelter, which, according to the Potsdam comparisons,[1] gives a prevailing too low daily mean. For the 24-hour means in the English shelter during the long-night months of November to February were 0.2° to 0.3°C. lower than those in the [metallic window] shelter, while from March to October both exposures gave means agreeing within ±0.1°C. Again the mean temperature from thrice daily observations within the English shelter departs from that of the surrounding air determined in the same manner by more than 0.1°C. (at Pavlovsk this holds for June and July only; at Potsdam for these same months and also in January only).

We must demand, however, that not only the daily means but also the individual term-observations shall be comparable, and this also both for our prevailingly cloudy climate and for climates of clear skies and strong radiation. In other words, the monthly means of the term-observations in such climates shall not show systematic errors, i. e., influences due to thermometer exposure, greater than 0.1° or 0.2° C. We must demand that the important climatic element of daily temperature range shall be susceptible of comparative study. At present, even under selected favorable exposures in Potsdam, this element is 20 per cent greater in June when measured in the English shelter than if determined in the Prussian window shelter and still greater if the French exposure is used.

Hellmann is right in the closing sentence of his report[2] when he says, "It is quite inappropriate to employ two fundamentally different methods of thermometer exposure, such as the window shelter and the ground shelter, in one and the same meteorological réseau, for we thereby greatly reduce the comparability of the observations and particularly of the individual term observations."

This statement, however, is to be extended to the whole globe. We must endeavor to establish a network of comparable observations embracing the whole globe, and must not be content with a Prussian, a French, a German-Colonial, and various other concepts of air temperatures. Naturally, it will require many years to actually attain this ideal; therefore the sooner we begin to strive toward it the better for all.

It will be impossible to adopt a window exposure, or any other such location in the shadow of a building, for our universal uniform exposure. To be sure, such an exposure most readily avoids disturbances due to radiation, and in our climate it yields quite good comparable means. But there are to be considered—

(1) The air in such a shadow is an exception, while the air over an open surface is the rule; hence the former may

[1] Hellmann *in* Bericht, Preuss. Meteorol. Instit., 1911, pp. 64–68.
[2] Hellmann *in* Bericht, Preuss. meteorol. Instit., 1911, p. 83.

not be regarded as the true representative of the local climate.

Of the two climates possessed by every locality the principal climate is its climate in the sun and not its climate in the shade—the "climate in the sun" meaning the actual properties of the air over open fields and not, of course, the indications of a thermometer openly exposed in the sun.

(2) The heights of the houses, the orientation of the wall, the relative locations of neighboring buildings are rarely all exactly the same for two different window exposures. The various measures adopted under these circumstances for the purpose of screening the thermometer from the sun at certain hours of the day are rarely effective. Screens can indeed protect the thermometer against the sun's rays, but can not prevent the adjacent wall and its contiguous air from heating up. If the thermometer is exposed in an angle then the ventilation is too greatly checked.

We must therefore resort to shelters standing in the open. The slighter departures of thermometers in the English shelter from the true air temperature teach us:

(*a*) That there is an actual urgent necessity for the extensive exclusion of the reflected radiation by means of the double louvers; that is, to expose the instruments in darkness as contrasted with the bright, "open screening" of the French and the Glaisher stands.

(*b*) That the thermometers depart more from the true air temperatures when exposed in large, massive shelters, such as those of Wild and of Neumayer which obstruct the wind movement, than they do in small shelters. The departure is due on the one hand to the stronger warming by the sun and on the other to greater lag behind the changes in the air temperature.

The departures from the true air temperatures, as still shown in the English shelter, are indeed smaller than those found in the other styles of exposure, but they are similar in direction, viz, too great influence of radiation and too small air movement during calms.

CONDITIONS NECESSARY FOR DETERMINING AIR TEMPERATURE.

Before turning to the discussion of methods for eliminating these errors, we may give brief consideration to the conditions necessary in determining the true temperature of the air.

(1) The screening must, in addition to protecting against rain and injury, ward off radiation without causing the thermometer reading itself to depart from the temperature of the air to be measured.

(2) The longer the time during which the air is in contact with an irradiated surface or a radiating surface, or the longer the path across such surfaces followed by the wind, the less able is the air to bring such a surface to the original air temperature.

(3) The greater the storage capacity of any object for heat, the slower and smaller its changes in temperature as compared with those of the air in contact with it.

These considerations may be applied to our problems as follows:

By reason of (1) it is desirable that the temperature of the inner surfaces of the screen and shelter shall depart very little from the temperature of the air, and the same holds for the exterior surfaces so far as they may be able to affect the temperature of the air that bathes the thermometers. For this reason we must (*a*) devise a screen having very slight absorption and radiation and *keep it in that condition;* (*b*) introduce a thermally bad conductor between the inner and the outer surfaces of the screen; best of all would be to introduce a mass of air at the desired temperature. Both these objectives are excellently attained in the Assmann aspiration-psychrometer.

By reason of (2) it is necessary that both the thermometer and the screening shelters [3] be as small as possible along the direction of the air current, and the velocity of that current must be so large that the air remains a very short time in contact with the shelter. As the horizontal component of the air movement about and within the shelter is certainly much greater than the vertical, we are chiefly concerned with the former.

Condition (3) requires that all parts whose temperature can influence that of the air or of the thermometers, shall have the smallest possible mass and thermal capacity; and that reservoirs of stagnant air shall be eliminated. It must be borne in mind, however, that transitory changes in temperature affect but a shallow superficial layer of a poor thermal conductor, while the whole mass of a metal object will be warmed through or cooled off; thus the thermal capacity of wooden parts is smaller, in general, than that of metallic parts.

The above conditions are quite well fulfilled by the small 1883 model of the English shelter. It probably affords adequate protection against reflected radiation and weak insolation. The radiation from a high standing sun, however, and the nocturnal radiation against a clear sky both falsify its internal temperature readings to an extent that far exceeds the permissible limits for climatological investigations.

There was a very early demand for a screen to protect the English shelter against these radiations. Thus Gaster, during the discussion over the new English shelter before the London Meteorological Society on November 21, 1883, stated that when he spread a large sunshade over a Stevenson shelter he found the inside forenoon temperature to stand 1.4°C. lower than that within a neighboring unscreened shelter. On the same occasion, Dr. Marcet reported that in Cannes it had been necessary to set up the Stevenson shelter in the shadow of a house in order to eliminate the strikingly excessive maximum, and that one of his compatriots there had built a shed over it. Dr. Marcet thought that if such a "sheltered screen" were found necessary in southern France the same foresight must also be needed in England. Stow [4] thought that appropriate modifications would adapt the Stevenson shelter to all climates, although it might perhaps be desirable to provide a triple roof with felt or straw in the middle for tropical stations. I have already mentioned the shading of the louvered screens in the Tropics (Samoa, Tonga).

Among all meteorological elements it is the temperature and the moisture of the air whose determination is subject to the same conditions and partially measured with the same instruments. We measure air pressure indoors, the wind at the highest, almost inaccessible points of our buildings, the rain as near as possible to the ground and in wind-sheltered localities but naturally not in the rain-shadow or under the eaves. For the observation of atmospheric temperature and moisture, on the contrary, our object is to secure uniform measurements of these properties, which we have selected for geographical comparisons, by exposing the instruments to the greatest possible mass of air and screening them as perfectly as possible from all other influences. Furthermore, these conditions must be fulfilled as perfectly as possible not

[3] The measurements by Knoch and by Barkow, quoted in foot note 5 show that the greater portion of the air current never enters the shelter but merely flows round it.

[4] See Archive d. deut. Seewarte, 1887, No. 2, p. 46.

only for the observations at term-hours but also for all the intervening time, on account of the registering and recording instruments. Experience shows that Assmann's aspiration-psychrometer is the best device for securing the necessary simultaneous exclusion of radiation accompanied by adequate ventilation. An uninterrupted artificial ventilation is so costly, however, and its installation generally so troublesome that probably it is feasible at large observatories only. Aside from its high price, M. 175, the nature of the aspiration-psychrometer makes it unsuitable for the usual term-observations by an average observer. In such a case also the location of its air intake must be just as carefully selected and adhered to as in the case of a fixed thermometer exposure; the readings must accurately follow the instructions; and it would be necessary to replace the original thermometers by others somewhat less sensitive to allow of a quiet reading of both thermometers on days with the well-known rapid fluctuations, since it is desired to secure the mean temperature of the last two minutes. Determinations with the portable Assmann aspiration-psychrometer have more the character of a physical experiment—invaluable for checks on accuracy—rather than an equivalent for the systematic uniform observations of a meteorological réseau. The registering apparatus and self-recording thermometers in any case require, in addition, a fixed mounting and exposure.

Experience has shown that the box closed on all sides by double, oppositely inclined louvers, which is called the "English shelter" and which allows air to pass through but admits very little light or radiation, may be regarded as the most efficient fixed thermometer exposure for the determination of the temperature and the moisture of the air. This shelter also affords the instruments excellent protection from injury and dampness. Therefore the essentials of this screen must be retained, but we must seek to eliminate its remaining shortcomings so far as we know them. Both the shelter and the instruments it is to screen must be mutually adapted and reconstructed. When the Stevenson shelter was devised there was no thought of exposing in it clock-driven, recording instruments. Later as these recording instruments, particularly the small-model "Richards" came more and more into use they were housed in the shelter as best one could. Since they thereby interfered with particularly the maximum and minimum thermometers—which seemed indispensable—it was therefore decided to enlarge the shelter without heeding the warning example of Wild's large shelter and Aitken's experiments. The thermographs and hygrographs still thus employed are, moreover, merely planned like Richard's first effort—his barograph. Their bulky glass cases constitute reservoirs of heat and of differently tempered air, they hinder wind, and are in entire contradiction to a rational device for determining air temperature. If the wind comes from the direction of the case, then the temperatures both of the laterally attached thermograph element and of the psychrometer are falsified.

Bearing this in mind, and also the interrelation of air temperature and moisture, I have had Mr. C. Schneider build a thermohygrograph based upon our experience with the kite meteorograph. The thermohygrograph, in spite of its open scale (1° = 2 mm., 1 per cent = 0.5 mm.) weighs but 1.4 kg., the thermometric element is freely exposed in all directions and is separated by the aluminum base-plate from the drum which alone is inclosed in a case. Its dimensions are: 32 cm. wide, 14.5 cm. deep, and 31.5 cm. high. (See fig. 4.)

For the installation of this thermohygrograph and psychrometer I have modified the small-model "English screen" of the Prussian Meteorological Institute. (1) The depth of the screen is diminished about 10 cm.—i. e., from 29 to 19 cm. inside measure; (2) in its left or western side, for a length of 35 cm. the floor and the three lower louvers are removed and a new similar floor inserted 13 cm. higher, thus making a step, part of whose tread swings round for convenience in placing and adjusting the thermohygrograph. The lowest louvers of the left side were shifted to the right margin of the cut-out portion, thus making a louvered box 14 × 19 × 10 cm. inside measurement, into which project the bulbs of the thermometers 11 cm. below the base plate of the thermohygrograph; (3) the ventilation of the lower and essential part of the shelter was improved by beveling the frame parallel with the louvers above it, thus making an opening similar to the others. The upper part of the shelter may, on the other hand, be simplified, since its purpose is merely protection from the rain and mechanical injury.

The number of stations equipped with registering apparatus—first-order stations of the Vienna Meteorological Congress—is growing rapidly. It is not to be expected that all the second-order stations equipped with a psychrometer and barometer but not a registering apparatus, should be converted into first-order stations; both the cost of apparatus and the impossibility of discussing such a mass of records prevent this.

However, it is notorious that the English shelter gives, even in middle and northern Europe, with clear sky and weak wind, temperature readings 1°C. too high in the afternoon and about ½°C. or more too low at night. These errors must be even greater in lower latitudes and with stronger radiation. Since in climatology we work with differences of the tenth part of a degree, we should not be satisfied with such service after having discovered these facts, but must endeavor to remove these errors.

This may be attained in two ways. A smaller shelter will diminish the errors, but to obviate them one must either screen the shelter from strong radiation or introduce an artificial ventilation of the instruments. By "strong radiation" in this connection is meant the direct insolation from the sun standing high in the heavens and the radiation to the zenith. The English shelter can be regarded as a sufficient protection against approximately horizontal rays and terrestrial radiation. The wind need not and should not be hindered of free access to the principal under part of the shelter.

Since the obstruction of the wind is one of the greater evils and since we can better afford, under extreme conditions, a few errors in radiation, we may adopt solar altitudes of 20° or higher as those against which we need additional protection. We thereby secure the great advantage that we can freely expose the entire lower half of the shelter to the wind. If only a point were to be thus screened, then such solar altitudes would require a cylindrical screen having its axis parallel with the earth's axis; the upper or poleward edge would be cut at right angles to the axis, but the bottom would be cut off horizontally. Since the entire lower half of the screen, together with the sensitive parts of the thermometer and of the thermograph, require protection from the sun's rays, the shape of the screen is more complicated and its development becomes more difficult in order to avoid an unnecessarily large screen.

The ingeniously designed nomographic tables of my colleague, Prof. Stück, have stood me in very good stead here, aiding in determining the azimuths of the sun when at altitudes of 20° at the solstices in every geographical latitude. Since these meteorologically important shadow conditions are nowhere available in a lucid and convenient arrangement, the most important particulars may find room in the following table, for which I am indebted to Prof. Stück. The time is true time; refraction is neglected. The azimuths are given for both the sun's altitude and the hour of the day. As the table shows, if the evening observation is taken at 9 p. m., it will always be after sunset for localities up to latitude 60°, and if taken at 8 p. m. for localities up to 48°.

TABLE 1.—*The sun's positions.*

Lat. N.	Time of—		Azimuth (a. m. = east; p. m. = west).				Sun's altitude.		
	Sunrise.	Sunset.	h = 0°.	h = 20°.	7 a. m.	8 a. m.	7 a. m.	8 a. m.	Noon.
I. June 22 (equation of time +1¼*min*).									
°	A. M.	P. M.	° *N.*	° *N.*	° *N.*	° *N.*	°	°	°
0	6.0	6.0	66.5	64.9	65.8	63.4	13.7	27.3	66.5
10	5.7	6.3	66.1	68.5	68.4	68.5	17.6	31.4	76.5
20	5.4	6.6	64.9	71.4	71.7	74.7	21.1	34.6	86.5
30	5.0	7.0	62.6	73.7	75.6	81.7	23.9	36.6	83.5
40	4.6	7.4	58.6	75.6	80.2	89.2	26.0	37.4	73.5
50	3.9	8.1	51.7	76.9	85.2	96.8	27.3	36.9	63.5
60	2.7	9.3	37.1	77.4	90.4	104.0	27.6	35.1	53.5
70	....	....	....	76.1	95.6	110.4	27.1	32.1	43.5
80	....	....	....	67.7	100.5	115.7	25.7	28.2	33.5
II. December 22 (equation of time −2*min.*).									
			° *S.*	° *S.*	° *S.*	° *S.*			
0	6.0	6.0	66.5	64.9	65.8	63.4	13.7	27.3	66.5
10	6.3	5.7	66.1	60.3	63.9	59.3	9.5	22.5	56.5
20	6.6	5.4	64.9	54.3	62.8	56.2	5.0	17.1	46.5
30	7.0	5.0	62.6	45.6	62.4	54.1	0.4	11.4	36.5
40	7.4	4.6	58.6	30.8	....	52.9	....	5.4	26.5
50	8.1	3.9	51.6	....	....	52.6	....	....	16.5
60	9.3	2.7	37.1	....	....	....	....	....	6.5

The fact that the extreme northerly or southerly azimuth for a solar altitude of 20° at the summer solstice is almost the same between latitudes 40° and 70°, differing but a few degrees even down to latitude 20°, greatly simplifies the problem of constructing the shading screen. In order to simplify the future construction of this screen I needed to design but three forms of the same, adapted respectively to use in latitudes 0°–10°, 10°–25° and higher than 25°. For practical purposes the poleward corners (wings) are clipped off vertically instead of along an element of the cylinder. The description of the screen will be given farther on. In constructing the screen, I choose such soft roofing material as may be locally available, such as straw, reed, palm leaves, grass, or foliage, just as is done for the Indian thermometer shelter. Such roofing when 10 to 20 cm. thick, has the advantage that insolation and nocturnal radiation do not penetrate to its under surface, as the constituent straw or leaves of this surface are freely bathed by the air, their temperature is not seriously different from that of the air itself. For the uppermost roofing of the shelter, I employ a soft roofing of the same kind, a 5 to 10 cm. layer of the same material instead of the wooden board of the English screen. This roofing and partly the screen itself so far weaken radiation to the sky that the louvered shelter itself cuts out what remains.

The proposed universal thermometer exposure is thus in a certain sense a combination of the two methods at present most widely used, reduced to the smallest practicable scale and executed in a more appropriate manner.

VENTILATION.

The question of ventilation remains to be examined. The effect of air motion on the thermometer in a shelter is two-fold. On the one hand, the wind sweeping past and through keeps the shelter itself at a temperature which more nearly approaches the temperature of the air, the stronger the wind, the smaller the shelter, and the weaker the radiation to which the shelter is exposed. Just as the shelter, or at least parts of it, often remain at a temperature not inconsiderably different from that of the air, so in similar manner the thermometer in its turn experiences through the radiation of the shelter walls, heat or cold which needs to be removed by air flowing past. According to observations in Potsdam, the horizontal air motion in an English shelter amounts to about one-seventh (14.3 per cent) of the wind velocity close above the screen.[5] It is obvious from this that even at an average wind velocity of 4 to 5 m/sec., the air motion at the thermometer sinks under 0.7 m/sec. and can be sufficient only when the temperature of the shelter walls differs but little from the temperature of the air. If the shelter is shaded and small the latter condition is secured; but should the wind velocity outside of the shelter fall to under 1 m/sec. while the radiation from the ground, etc., is strong, then even these measures will not avail. Under such conditions only artificial ventilation by means of an aspirator will give us error-free temperature determinations. There must be uninterrupted artificial ventilation for registers and self-recording extreme thermometers. Since most stations will find it too difficult and expensive to maintain such a permanent artificial ventilation, it will generally have to be omitted, so that it becomes all the more important to perfect the natural ventilation and the screening against radiation. Artificial ventilation at term-observations for the dry bulb (that is, exposed thermometer) also may all the more appropriately be considered here since many réseaus (e. g., the Prussian and the Deutsche Seewarte) have already employed powerful psychroaspirators to secure that approximately uniform air current past the wet-bulb thermometer which is required for the proper application of the psychrometric formula.

DETAILS OF THE THERMOMETER EXPOSURE.

We will now proceed to the description of the individual parts of the proposed thermometer exposure. These consist of:

(*a*) A uniform shade screen with its support for all stations measuring temperature.

(*b*) Larger louvered shelters for first-order stations, and smaller shelters for the second-order stations.

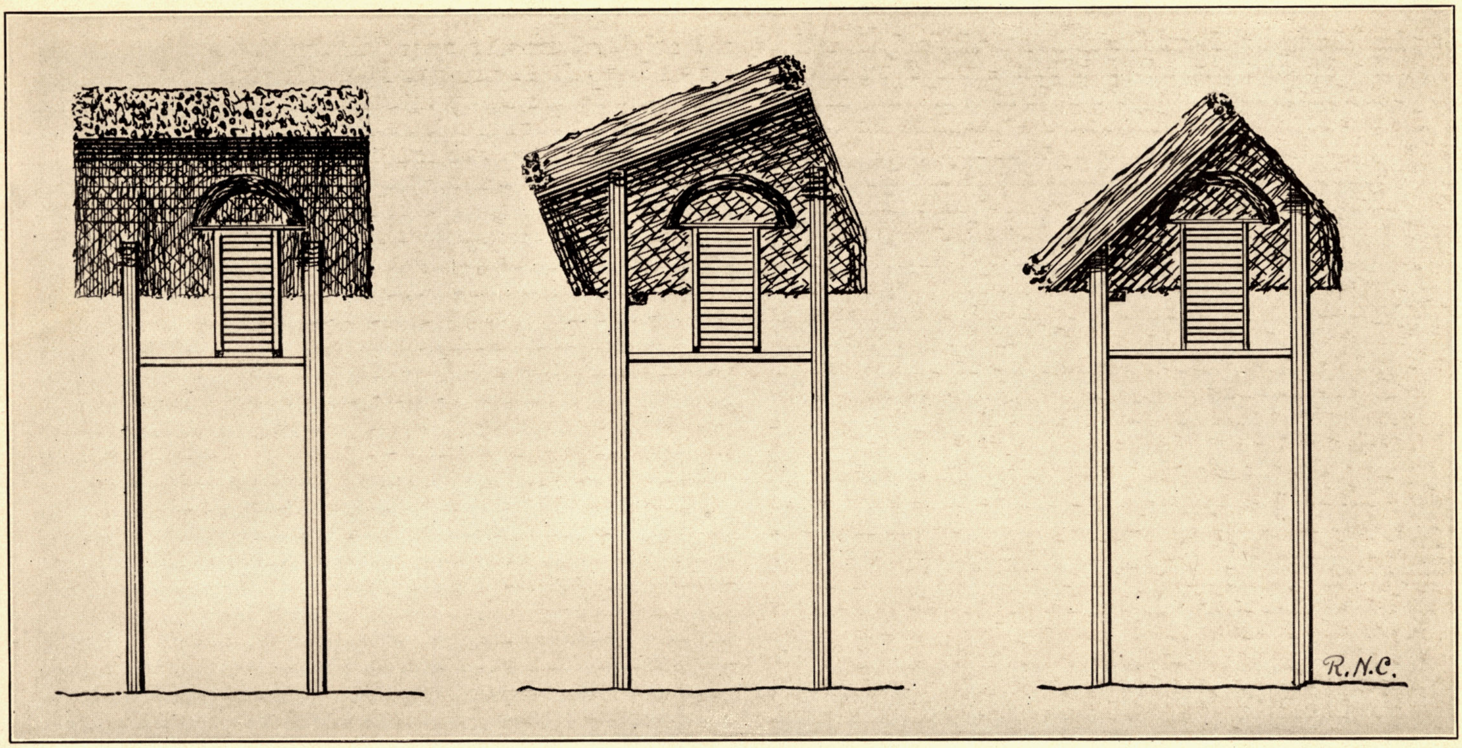
(*c*) The instruments, which are the psychrometer and thermohygrograph at stations of the first order; and psychrometer and extreme thermometers, or extreme and exposed thermohygroscope at stations of the second order.

(*d*) An aspirating device for the psychrometer.

Of these parts, the accessories (*a*), (*b*), (*d*) serve to support and protect the principal part, (*c*), so that it may indicate truly. In this cooperation the straw or other soft roofing guards the shelter from strong radiation—both solar and terrestrial—while the louvered shelter screens the instruments[6] from the weaker radiations of

[5] *Knoch* finds the relation is 16 per cent inside a shelter in the field (Abhdlg., Preus. met. Instit., 3, p. 6); while *Barkow* finds 14 per cent inside a shelter on the tower, and varyng greatly with the wind directions (Jhrb., Preus. met. Instit., 1909, p. 99.)

[6] The straw screen alone, in common with the French shelter and the older English "open" shelter, would give much too high temperatures by day, and too low temperatures by night.



Tropical. Subtropical. Extratropical.

FIG. 1.—Köppen's "screened shelter"; side elevations of the three models.

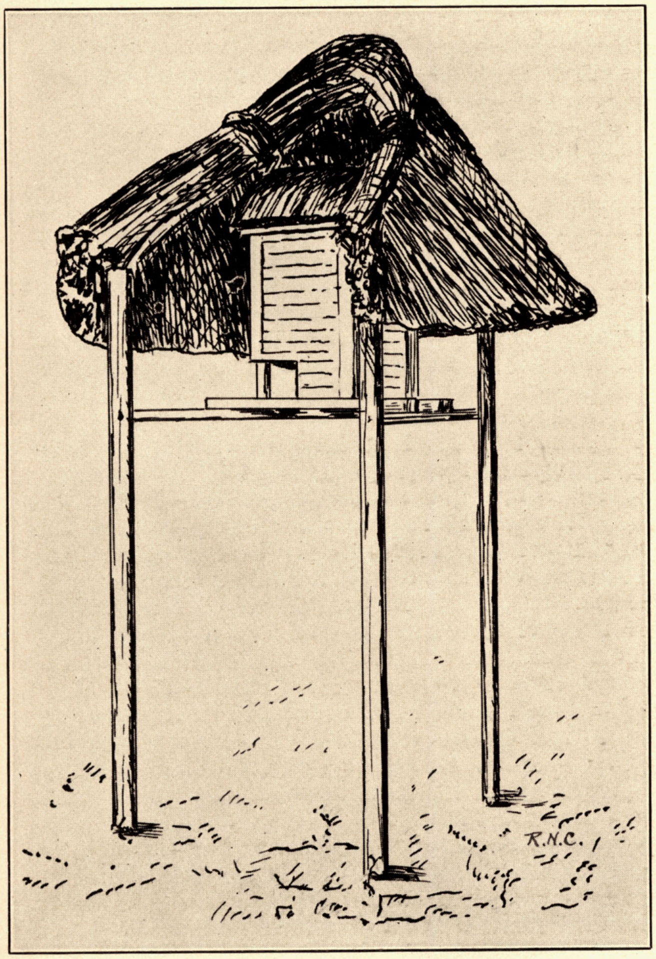


FIG. 2.—The extratropical screened shelter as it would appear in use.

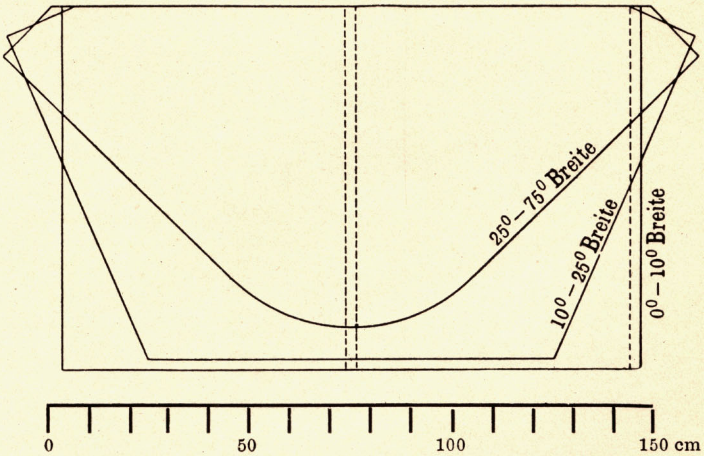


FIG. 3.—Patterns for the screens for the shelters of figure 1. (Breite=latitude.)

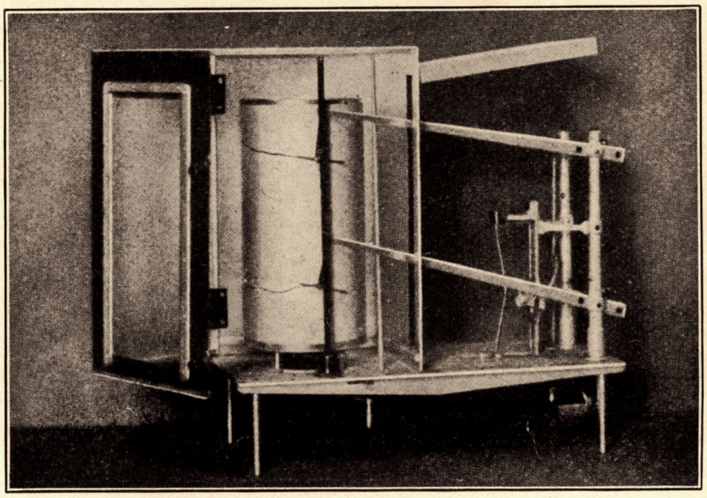


FIG. 4.—Photograph of Köppen's improved thermohygrograph, recording on rectangular coördinate paper.

the ground and other objects, from rain and from mechanical injury. Finally the aspirator has to make the wet-bulb thermometer independent of the wind and also to insure correct dry-bulb indications during calms.

A. Screen and frame.—The screen support consists of four 6-cm. posts for latitudes between 10° N. and S., as shown in figure 6. Three 8-cm. posts serve in all higher latitudes. The posts carry a frame of 4 battens at a height of 190 cm. above the ground, and this frame bears the instrument shelter. The two northern posts are on a true east-west line and 130 cm. between their outer surfaces, the third post, on the south, is 120 cm. from each of the others, again measuring between outer surfaces. The necessary braces should be of small cross section in order not to interfere with ventilation, and partly replaced by wires.

In constructing the screen a coarse-mesh wire netting of galvanized iron or steel wire is cut to that one of the patterns of figures 1 and 3 appropriate for the latitude of the station, is bound with stronger wire, and fastened to the five parallel wooden strips shown by dotted lines (fig. 3). In this condition, the net can be conveniently rolled and shipped; but since it may be easily distorted, a paper pattern of its form should accompany it. Upon reaching its destination, it is shaped and bound to flexible rods, preferably of rattan. Two crosspieces, 130 cm. long, are then fastened at front and back, giving the screen its cylindrical bend whereby its lower edge becomes horizontal. Such soft roofing as is locally available is then fastened to the netting by means of soft wire. The front crosspiece is permanent and eventually rests upon the tops of the two fronts posts [7] but the rear crosspiece is only temporary.

After the tops of the three post ends are fashioned, as shown in figure 1, the completed shade screen is placed upon them. The middle and two outer parallel sticks are firmly screwed to the post ends, adjusting the horizontal lower edge of the screen so that it is 25 cm. above the frame supporting the louvered shelter, or 215 cm. above the ground. A horizontal crosspiece is fastened to the north side of the southern post [8] and supports the edge of the screen which is firmly fastened to it. This completes the fastening of the screen.

It should be noted that in order to secure the necessary shade in the morning and evening the bottom edge of the screen must project northward beyond the outer side of the post, as follows: For the extratropical form, 10 cm.; for the equatorial form about 25 cm.; and for the intermediate form about 15 cm.

The rear [southern] edge must extend 25 to 30 cm. beyond the southern post or posts. The dimensions are those of the shade screen for the larger shelters (with registering apparatus). Although the small shelter is 15 cm. narrower and 9 cm. shallower, I recommend that the same shade screen be used for it, then if a second-order station should install a thermohygrograph, only a new shelter need be supplied.

B. The louvered shelter.—(*a*) This is equipped as follows for stations of the *first order:* The external dimensions, including the inner roof, are identical with those of the small model "English shelter" of the Prussian Meteorological Institute, except that the depth is 10 cm. less. The measurements are:

Outside: 59 cm. wide, 30 cm. deep, 53(70) cm. high.
Inside: 48 cm. wide, 19 cm. deep, 47 cm. high.

The southward sloping board, forming the outer roof of the English shelter, is replaced by an arched straw roof, whose center rises 15 cm. above that of the inner roof.

In order to conform more closely than in the past with Aitkens's principle of restricting temperature-influencing objects to minimum dimensions, I have pushed in the lower part of the eastern louvers of the shelter 35 cm., so that the thermometer bulbs of the psychrometer are placed in a space 14 (W—E) × 19 (N—S) cm. As in the English screen, both this lower level and the upper level of the shelter floor is composed of three small boards which are so placed that as much air as possible can reach the thermograph element and the thermometer bulbs, while at the same time all radiation [9] from the ground is excluded. At the upper level, which receives the thermohygrograph, the middle board is fastened rigidly, forming the support of the revolving frame carrying the lateral boards.

(*b*) For *stations of the second order* the dimensions of the louvered shelter are:

Outside: 44 cm. wide, 21 cm. deep, and 46 (63) cm. high.
Inside: 33 cm. wide, 10 cm. deep, and 40 cm. high.

These dimensions will admit even maximum and minimum thermometers; while the width may be further reduced by 4 cm. if they be replaced by the thermohygroscope to be described later. Such small shelters need not have a step in the floor; but otherwise the construction may be identical with that of the shelters for first-order stations.

There should be an essential difference between the upper and lower parts of either sized shelter. In the English screen the temperature at noon on clear days is markedly higher in the upper than in the lower portion and therefore the departure from the true air temperature is there greater. It is, therefore, advisable (1) to shift all essential receiving instrument parts to the lower portion, (2) to construct this portion carefully with a view to securing greatest possible ventilation while protecting against radiation and the flow of air from the upper to the lower part. At the same time the air circulation between the two portions should not be so obstructed that possible overheated air in the lower portion can not easily escape to the upper part. The mode of exposure here proposed accomplishes this by placing the thermometer bulbs of the psychrometer and also the element of the thermograph in the lower portion, while the latter is also screened by the base of the apparatus. Under these conditions it does no harm if the upper part of the shelter is at times partially exposed to the sun's rays, and the five upper double louvers of the always shaded back may be replaced by single louvers. In the lower part of the shelter, on the other hand, all care has been taken to increase accessibility to the air and at the same time exclude light from the interior. In particular the much too narrow outer opening under the lowest louver has been enlarged to the standard by cutting a double bevel on the lower rail of the frame.

Kassner's recent suggestion (Met. Ztschr. 1912, **29:** 32,428) to leave a space between the two strips of each double louver is hardly essential since the vertical air motion, upon which the proposition is based, occurs only under extraordinarily unfavorable circumstances as compared with the horizontal movements. However, it

[7] A lighter stick stretches from the center of this front crosspiece to the summit of the front edge of the screen.

[8] In the equatorial pattern this is replaced by a second crosspiece attached to the rear edge of the screen and at the level of the roof of the louvred shelter.

[9] *Fenwick W. Stow* reports that during June and July, 1873, in England, the mean daily maxima in a louvered shelter *open beneath*, were 0.8°C. higher than corresponding readings in a similar shelter with a floor (Qtly. jour., R. Met. Soc., London, 1874-5, 2:50).

might be advantageous during still days to allow the warm air which gathers in the angles of the lowest double louvers during calm intervals, to escape above out of the vicinity of the receiving parts of the instruments before the next wind puff drives it against them. But, since the louvers warp out of shape more readily when they do not meet at right angles, a number of holes bored in the upper part of the slats are preferable to the long gap.

Both the louvered shelter and its support must be painted with a bright-colored oil paint. Since I have not found any data* on the heating of wood when painted with various materials, I have myself made several such experiments. I took a number of small cylindrical blocks, as nearly alike as possible, bored out the center and filled it with mercury and inserted therein the bulb of a thermometer. The blocks had received three coats of an oil paint, except the black one which received a soot coating. The blocks when thus prepared were exposed to intense sunshine between double windows for the prevention of draft. Under these conditions the rather thinly soot-covered billet attained a temperature about 6°C. higher, and those painted with ocher and venetian red [Totenkopf] a temperature about 4°C. higher than that reached by the block painted with white lead. The heating of the block coated with glazurit (zinc-white and dammar varnish) was still less, although this block differed by only 0.3°C., in the mean, from the block with white-lead coating. The old observations of Melloni, according to which white lead has the same radiating and absorbing power as lampblack, must therefore, be based on error.

Within the shade screen the louvered shelter rests on two horizontal sticks running east and west; the southerly one is 32 cm. distant from the southern post, and the northerly one is about the width of the shelter farther in front. The small-sized shelter will be placed in the center of the arched screen roof; the large shelter, however, will be placed to the left so that the center of the screen falls in the middle between the dry thermometer and the thermograph element, while the left-hand side of the shelter containing the clockwork stands farther to the left than does the right-hand side to the right. In our latitudes at the height of summer the evening sun grazes the left-hand side of the shelter without seriously affecting the instrument parts (drum and recording pens) there located. The right-hand side containing the psychrometer is much more in need of protection.

The cross supports in the shade screen for latitudes 10° N.–10° S., must be set so far toward the nearest pole, that the door side of the shelter is only 40 cm. from the chord of the corresponding edge of the screen, while the rear wall is fully 65 cm. from the other screen edge (in the small shelter each of these distances is increased by about 4½ cm.). With such an exposure the shelter, even at lat. 10°, can never be reached by the high sun.

In climates with very strong radiation, if the position of the thermometer in the shelter becomes notably affected—say more than 0.2°C.—by the rays of a sun standing even lower than 20°, the matter should be remedied by using a movable screen that will not interfere with ventilation, rather than by bringing the fixed screen down lower. Such a movable screen may well be a strip of coarsely woven bagging 25 cm. wide and ½ to 1 m. long. Wooden strips are tacked on at its upper edge and across its middle, between which points the bagging is doubled, but it is single and merely hemmed at its bottom edge. Two screw hooks in the marginal stick serve to hang it to the lower edge of the shade screen. The 2 mm. meshes of the sacking let the air flow through and give a half-shadow which gets denser as the sun ascends; the wind can lift the under edge of this curtain. After making an observation, this curtain is hung on that side on which the sun will shine from that time to the next observation.

It is often necessary, in order to secure good temperature readings, to place the thermometer shelter where it will be necessary to guard it from mischievous persons. For this purpose wire netting of 10 cm. mesh can be stretched from the under edge of the screen roof to the ground, with a door of the same material between the two north posts.

C. Instruments.—The question of artificial ventilation will be further considered when discussing the psychrometer. Here I wish to express only the wishes (1) that the smallest division of the scale be not less than 0.8 to 1.0 mm.; (2) that the thermometer bulbs be made as small as is consistent with such scale dimensions. If it is desired to have, for example, a thermometer reading to $\frac{1}{5}$ degree, the degree should be 4 to 5 mm. long; on the other hand if one adopts a thermometer reading to $\frac{1}{2}$ or a whole degree (and after a little practice in estimating, such scales are almost equally accurate) then this thermometer should have preferably a cylindrical and a smaller bulb than is now usual in Germany, in order that it may rapidly follow the changing temperature and have a slight radiation error.

Stations of the first order will also have self-recording apparatus for air temperature and air moisture. If this apparatus is as good as it can and should be made to-day, then the maximum and minimum thermometers and the hair hygrometer can be omitted. If they be desired, however, then they should be placed in a separate, similarly screened shelter, and not be allowed to cause an unnecessary increase in size of, or obstruction to the ventilation of the shelter. It must not be forgotten that while the extreme thermometer can indeed be read very accurately to $\frac{1}{10}$ degree, this accuracy is illusory. The errors due to radiation and local factors of the thermometer exposure are trifling in the daily mean temperature, but *are at their largest in the extreme temperatures.*

Thermohygrograph.—Mr. Constans Schneider, of Hamburg, has built a suitable thermohygrograph to meet the requirements I have given. It traces on a relatively large scale in ink (1° C. = 2 mm.; 1 per cent humidity = 0.5 mm.; for one revolution[10] in 3½ days, 1 hour = 3⅓ mm.) on coördinate paper fixed on a drum. The coördinates are rectangular and in a system of the inventor's, that has already been successfully used on many barographs.

* See *Coblentz, W. W.*, Diffuse reflecting power of various substances. Bull., U.S. Bureau of Standards, 1912, v. 9 (Reprint No. 196.)

[10] There is a great lack of uniformity in the dimensions of self-recording instruments, particularly among those for the smaller stations, due notably to the varying selection of 1-day and 7-day record cylinders. *Experience has shown* that a legible and readily decipherable meteorogram must have 1 hour on the time scale correspond in length to *the space of 1 or 2 degrees (cent.) on the temperature scale.* If $1^h > 2°$, the thermogram is too flat and the paper consumption needlessly large; if $1^h < 1°$, the curve is too steep and then in order to read the time satisfactorily one must have immoderately large pen deflections and hence must use Bourdon tubes in place of the cheaper and more durable bimetallic thermal element. The bimetallic element readily gives the quite adequate pen deflection of 2 mm. per centigrade degree. This would allow about 3 mm. for 1 hour on the time scale so that a drum 30 cm. in circumference, such as has stood the test for kite meteorographs, would easily hold records for 3¼ days when allowing 3⅓ mm. per hour after keeping a reserve space of 15 mm. for a possible 4½ hours additional record and 5 mm. *dead space for the bar of the paper clip. Such dimensions would probably* require most stations to change the sheets Mondays, in the morning, and Wednesdays, *in the evening. This time scale is exactly twice that of the small-model Richard*, whose records, although popular for general purposes, are of limited scientific applicability for the very reason that their time scale is so small.

In the case of the hygrogram, it is sufficient to have 1 per cent = 0.5 mm. A large scale requires too great a magnification. A perfectly uniform sale for the hygrograph requires such an amount of adjusting, and so increases the price of the instrument, that it is better to accept only approximate uniformity in that region of the scale above 60 per cent and to prepare individual graphical correction curves for each instrument after standardizing it.—*Author.*

Hanging pens 36 mm. long are suspended obliquely at the end of the pen-arms, and glide along a perpendicular rod of rhombic cross section, being held against it by their own weight. This system has not as yet been tested in the open. The recording drum is held in place on the clockwork by friction only. It is protected from moisture by a square tin case whose front and left side are hinged, door-like, to the rigidly fastened back and right side, and can be swung open when the cover is lifted. The clockwork within the recording drum is further protected by a waterproof case. To change the record-sheet the fresh strip is stretched over a duplicate drum in the house; then the board upon which the apparatus stands is turned round, the case opened, the old drum lifted out and replaced by the new one, and the two pens charged with ink if necessary. The clock is wound without a key, while the case is closed, by means of a ratchet wheel whose lever sticks out from beneath the case and is moved back and forth. Thus the instrument need not be moved from its place in the shelter for any of these operations. The elements are a hair hygrometer and a bimetallic thermometer, built by C. Schneider himself, who has had much experience in making them for the kite and balloon instruments of the Hamburg kite station. The transmission mechanism of the hair hygrometer is adopted from the Richard kite meteorograph. It has the advantage of permitting a fairly uniform scale, but also the disadvantage that the transmission consumes a large amount of the little force available. The entire frame of the apparatus is made of nickel aluminum.

Figure 4 shows the thermohygrograph open. In later examples the hygrometer hairs will be longer and placed under the base-plate beside the thermometric element.

For second-order stations without registering apparatus, the dimensions of the louvered shelter are so chosen that the bulbs of the psychrometer and of the maximum and minimum thermometers stand off about 5 cm. from the louvers. Accurate observations are needed to determine whether, as some contend, the louver walls at this distance can affect the temperature readings. If the inner louvers have a temperature noticeably different from that of the air outside the shelter, then the temperature of the air in the shelter also will be incorrect. I believe that this danger is avoided by the arrangement here proposed whereby no strong radiation can fall upon even the outer louvers. The thermometers lie with their upper ends in wire rests which are inserted in notches cut in the inner louvers of the west side of the shelter; near the bulb-ends stands a vertical wooden rod carrying strong wire hooks as supports which permit the shifting[11] of the maximum and the minimum thermometers according to the change of season, in conformity with the instructions of the Prussian Meteorological Institute. * * *

If it is desired to place also a hair hygrometer in the shelter, then the space above and to the right should be chosen for it, in order to affect all four thermometers as little as possible. According to its mounting, it may either be hung behind the thermometers, or placed on a thin board. The inner louver in this place can be omitted.

D. Artificial ventilation.—The question of artificial ventilation comes up, primarily, in connection with the wet-bulb thermometer, because it there has a double task, viz, both to protect against radiation—as in the case of the dry-bulb—and particularly to make possible the use of a uniform psychrometric constant, because under the varying ventilation of nature that constant, strictly speaking, should be changed as the ventilation varies. For this purpose, the Assmann "Psychroaspirator" (price 45 marks) is already in wide use in Germany. In applying this aspirator to louvered-shelter exposures it is advisable to lengthen the originally short tube between the wet bulb and aspirator[12] until it passes out through the lateral louvers, in order that the shelter may be kept closed from the time aspiration begins to the time of reading.

With such a powerful air current at hand (in present psychroaspirators it amounts to about 3 m/sec.) it is but a step to extend its use to the ventilation of the dry-thermometer in those cases of calm weather and strong radiation where natural ventilation is insufficient; and simply by bringing both bulbs into the same current. I have experimented in this line; but since a similar modification of Assmann's aspiration apparatus will shortly be described by Assmann himself, I shall not go further into this matter.

Since a convincing test of the new thermometer screen must be made in a climate of strong radiation, Dr. C. Dorno in Davos has most kindly undertaken to compare it over a long period with the Assmann aspirated thermometer and the English shelter. The instruments and also the screens were contributed for this purpose by the Prussian Meteorological Institute and the German Seewarte. Similar comparisons will be instituted at the Hamburg kite station, whose predominantly cloudy and windy weather makes, indeed, much less demands upon protection from radiation, although not less than does the native weather of the English screen itself.

WEATHER BUREAU TERMS USED TO DESIGNATE STORMS.

[Dated: Weather Bureau, Sept. 25, 1915.]

Cyclone.—As used by the Weather Bureau the term "cyclone" is the name of any atmospheric system in which the barometric pressure diminishes progressively to a minimum value at the center, and toward which the winds blow spirally inward from all sides. The system overspreads an approximately circular or elliptical area at least 50 miles, generally several hundred miles, and often over one thousand miles in diameter. A cyclone is any such system of winds, except a tornado which is rarely greater than a mile in diameter, or a whirlwind which is seldom more than a few yards across. North of the Equator the inflowing winds move in a counter-clockwise direction. South of the Equator the spiral inflow is clockwise in direction of motion. The name does not signify any degree of intensity, and is applied to storms of little as well as to those of great intensity. On weather maps cyclones appear as systems of a few or many closed concentric isobars of elliptical or nearly circular form, and indicate a progressive decrease in the atmospheric pressure to a minimum at the center. Arrows showing the direction of the wind indicate a gyratory inflow from all sides.

Classification.—For purposes of analysis and technical discussion cyclones may be divided into a great many classes. For the purposes of forecasting, non-technical

[11] The maximum and minimum thermometers of the Prussian Institute lack the metal backs of the United States Weather Bureau instruments, and they lie horizontally in metal brackets in front of the vertical wet- and dry-bulb thermometers hanging behind them. The bracket with the maximum and minimum is shifted with the seasons, to avoid interfering with readings of the wet- and dry-bulb thermometers.—C. A., jr.

[12] Meteorol. Ztschr., Wien, Jan., 1891, 8:13.