ON TEMPERATURES OF EXPOSED RAILS AT AGRA.

NOTE PREPARED BY

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Summary :—

Daily maximum and minimum temperatures of a rail laid horizontally and another fixed vertically on the ground were taken at Agra during the period May 1927 to January 1928 with a break in July and part of August. These temperatures are compared with each other and with those shown by thermometers in a standard Stevenson screen. The minimum temperatures are also compared with "grass" minimum temperatures. Tables of mean monthly temperatures, percentage frequencies of different ranges of temperature, monthly mean diurnal ranges of temperature, morning and afternoon cloudiness and the highest and lowest temperatures observed in each month are given.

Curves of diurnal variation of rail and air temperatures based on observations made on 6th February 1927 are also given.

A metal body exposed to the sky is ordinarily colder in the morning and warmer in the afternoon than the surrounding air on account of the difference between the radiative and absorptive properties of the metal and air. The temperatures of rails exposed under Indian conditions are of interest to Engineers in connection with the construction of railways, telegraph lines and bridges. As no definite data are available on the subject, a small investigation was undertaken to find the maximum and minimum temperatures of rails exposed (1) horizontally on the ground as for railway lines and (2) vertically as for telegraph posts. Some hourly observations of temperature were taken on a few days in October 1926 and February 1927, but the main series of observations discussed in the present note are those of maximum and minimum temperatures extending over the period 13th May 1927 to 20th January 1928 with a break in July and partly in August.

The horizontal rail was 4 ft. 10 in. in length and was laid over broken stones spread out to a height of 4 inches on the open grounds of the Upper Air Observatory, Agra. A vertical hole about 1 inch deep was bored in the rail at a distance of 15 inches from one end and half filled with mercury and the bulb of the thermometer was inserted in the hole.

The vertical rail was 16 ft. in length and had a hole bored in its side at a height of 4 ft. 2 in. from the ground for receiving the bulb of the thermometer and a cork round the stem of the thermometer closed the mouth of the hole from the outside when the thermometer was in position. Suitable supports were fixed

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to the two rails to keep the thermometers in position without risk of breakage. The maximum thermometers were read at about 17 hrs. and replaced by minimum thermometers after setting. The latter were read the next morning at about 9 hrs. and replaced by maximum thermometers.

Table 1 gives the monthly means of the minimum temperatures recorded in each month in the Stevenson screen and the differences between these and the means of the minimum temperatures shown by the vertical rail, ground rail and grass minimum thermometers. The number of observations on which the several averages are based are given under *n*. The "grass" minimum thermometer was supported horizontally on two wooden forks at a height of about two inches from the earth, the ground underneath being kept free from growth of any kind including grass. The early morning cloudiness expressed in tenth parts of the sky are also given in the last column. The data are represented graphically in Fig. 1.

TABLE 1.

Monthly mean minimum temperatures.

Month.	Stevenson screen. t		Grass minimum. t_1		Ground rail. t_2		Vertical rail. t_3		Morning cloudiness in tenths of sky.
	n	t	*n*	$t-t_1$	*n*	$t-t_2$	*n*	$t-t_3$	
		°F.		F°.		°F.		°F.	
May 1927	*18*	78·0	*18*	5·1	*16*	4·2	*18*	1·9	2·1
June "	*30*	82·1	*23*	3·5	*30*	2·9	*30*	1·4	3·7
July "	*31*	79·6	*27*	1·5	...	...	...	...	7·8
Aug. "	*26*	77·3	*26*	0·6	*22*	0·9	*25*	0·8	8·6
Sept. "	*28*	72·5	*29*	1·5	*25*	1·4	*27*	1·3	3·2
Oct. "	*31*	64·1	*24*	2·8	*31*	2·9	*30*	1·9	2·6
Nov. "	*30*	52·5	*30*	4·0	*29*	3·4	*29*	1·8	2·4
Dec. "	*25*	46·9	*25*	4·2	*25*	3·4	*25*	1·8	2·8
Jan. 1928	*19*	44·7	*19*	3·6	*18*	3·3	*19*	2·2	3·8

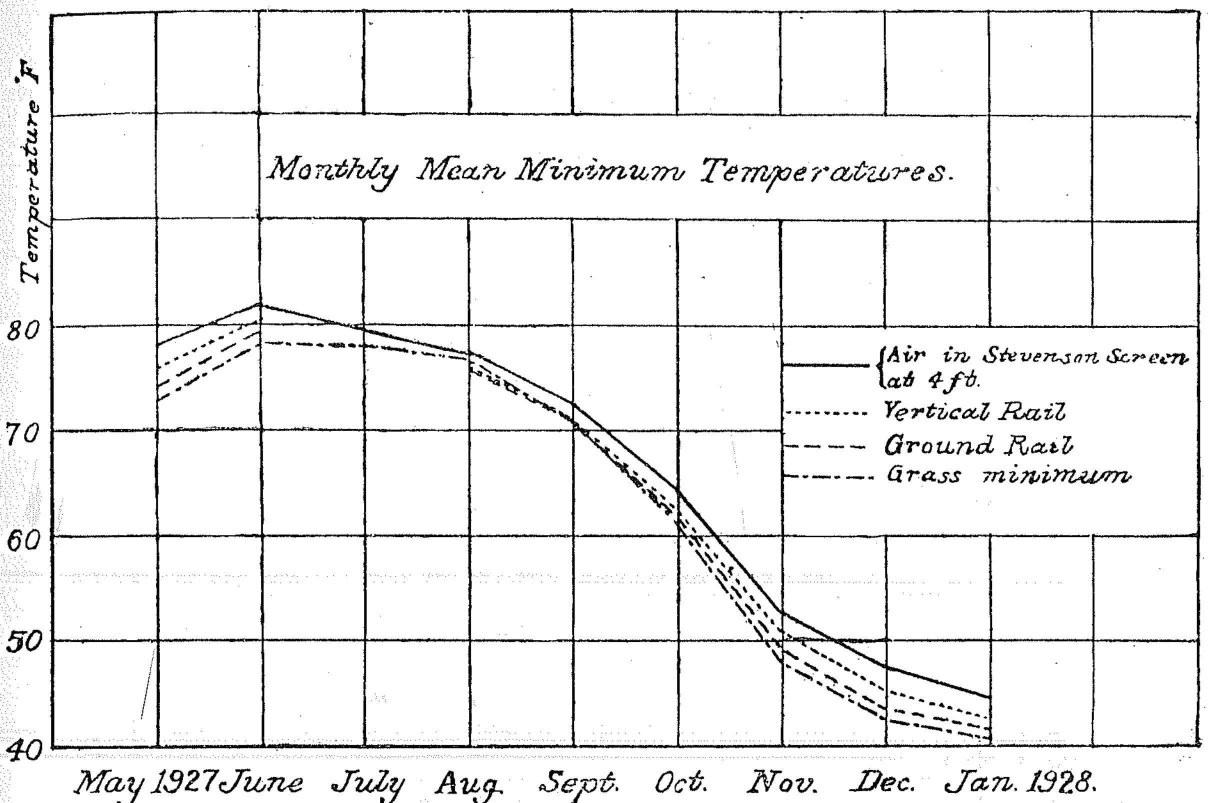

Fig 1.

It will be noticed that minimum thermometers in the different exposures give readings in the following order:—Stevenson screen highest, then vertical rail, ground rail and grass minimum. The last two, however, differ by very little; even the largest monthly difference does not exceed 1°F. and during the wet months, the difference is practically *nil*. The vertical rail also shows the same monthly minimum temperature as the ground rail in the monsoon months, but shows higher values in other months, the largest excess 2°F. being in the dry, hot month May.

Table 2 gives the percentage frequencies of occurrence of different ranges of minimum temperature in each of the months. As the ground rail and grass minimum temperatures show very little systematic difference, only the average of the frequencies of these two are given.

The largest scatters of all the temperatures occur in June and November. The former is the month of transition between the hot and monsoon seasons and the latter when post monsoon conditions give place to those of the winter. The figures for November show two distinct maxima, one maximum corresponding to that for October and the other to that for December. This double maximum in November is not however shown in the data of every year. Examining the Stevenson screen minimum temperature data of the years 1922—26, the double maximum was evident in 1922 and 1925 but not in the other years or in the mean. There are no minimum temperatures above 85° F. in May, while there is a considerable number in June. This is due to the rapid falling off of "night radiation" consequent on the increase of moisture-content of the

TABLE 2.

Percentage frequencies of different ranges of minimum temperatures.

Ranges of temperature. °F.	May 1927.			June 1927.			July 1927.			August 1927.			September 1927.			October 1927.			November 1927.			December 1927.			January 1928.		
	t	$\frac{t_1+t_2}{2}$	t_3	t	$\frac{t_1+t_2}{2}$	t_3	t	t_1	t_3	t	$\frac{t_1+t_2}{2}$	t_3	t	$\frac{t_1+t_2}{2}$	t_3	t	$\frac{t_1+t_2}{2}$	t_3	t	$\frac{t_1+t_2}{2}$	t_3	t	$\frac{t_1+t_2}{2}$	t_3	t	$\frac{t_1+t_2}{2}$	t_3
30—34·9 .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	...
35—39·9 .	...	...	...		...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	17	3	...	12	4	21	27	32
40—44·9 .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	17	24	21	24	68	52	32	51	37
45—49·9 .		...	.	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	33	15	27	64	12	36	37	17	26
50—54·9 .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	3	7	13	14	8	8	4	11	...	5
55—59·9 .	...	...		...	...	...	...	...	...	...	...	...	...	4	4	16	41	33	23	23	24	4	...	4	.	...	...
60—64·9 .	...	4	...	...	8	...	...	...	...	...	...	...	18	43	41	45	31	33	17	7	10	...	...	...	.	...	...
65—69·9 .	...	19	...	3	8	7	...	...	...	...	...	...	64	35	37	35	11	27	3	...	...	...	...	...	...	...	...
70—74·9 .	33	47	50	13	11	13	3	8	...	12	15	16	18	19	18	3	9	3	...	...	...	...	...	...		...	...
75—79·9 .	33	21	28	13	27	20	55	69	...	85	85	84	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
80—84·9 .	33	10	22	40	27	30	35	19	...	3	...	...	...	...	...	...	...	...	...	...	...	...		...	...	...	...
85—89·9 .	...	...	...	20	15	23	6	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
90—94·9 .	...	...	...	10	4	7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

t = Air in Stevenson screen. t_1 = Grass. t_2 = Ground rail. t_3 = Vertical rail.

atmosphere with the progress of monsoon conditions in the upper layer of the atmosphere over Agra. The smallest scatter occurs in August, the month of maximum humidity and cloudiness.

Table 3 gives the monthly mean maximum temperatures in the Stevenson screen and the differences between these and the mean temperatures of the ground and the vertical rails. The mean cloudiness between 12 and 16 hrs. is also given.

As might be expected, the ground-rail monthly maxima are always higher than the vertical rail maxima and the latter higher than the air maxima. The difference between the temperatures of ground-rail and of air at 4 feet depends primarily on the maximum intensity of sunlight and on the wind movement. The former is a function of the altitude of the sun at noon and the transparency of the atmosphere. It is interesting to note that the maximum monthly value of $t'_2—t'$, 29°F., occurred in the cloudiest month August. This is because, in this month, when the sky does clear, the intensity of sunlight is high, as the average maximum altitude of the sun is about 77°, and the dust content of the atmosphere is small owing to the monsoon rains. No observations are available for July, but the difference is expected to be large in this month also.

TABLE 3.

Monthly mean maximum temperatures.

Month.	Stevenson screen. t'		Ground Rail. t'_2		Vertical Rail. t'_3		Cloudiness between 12 and 16 hrs.
	n	t'	*n*	$t'_2—t'$	*n*	$t'_3—t'$	
		°F.		°F.		°F.	
May 1927	*18*	106·6	*16*	26·4	*14*	14·0	2·6
June ,, ...	*30*	105·8	*25*	24·5	*30*	12·1	3·7
July ,, ...	*28*	94·3	..	...	...	...	7·7
Aug. ,, ...	*24*	88·7	*26*	29·1	...	...	9·2
Sept. ,, ...	*30*	93·2	*30*	28·0	*29*	14·3	3·5
Oct. ,, ...	*31*	92·7	*31*	25·4	*31*	15·3	2·4
Nov. ,, ...	*30*	79·9	*29*	23·4	*29*	16·3	3·7
Dec. ,, ...	*24*	77·0	*24*	24·7	*24*	18·9	4·6
Jan. 1928	*19*	70·8	*19*	22·7	*18*	17·8	4·1

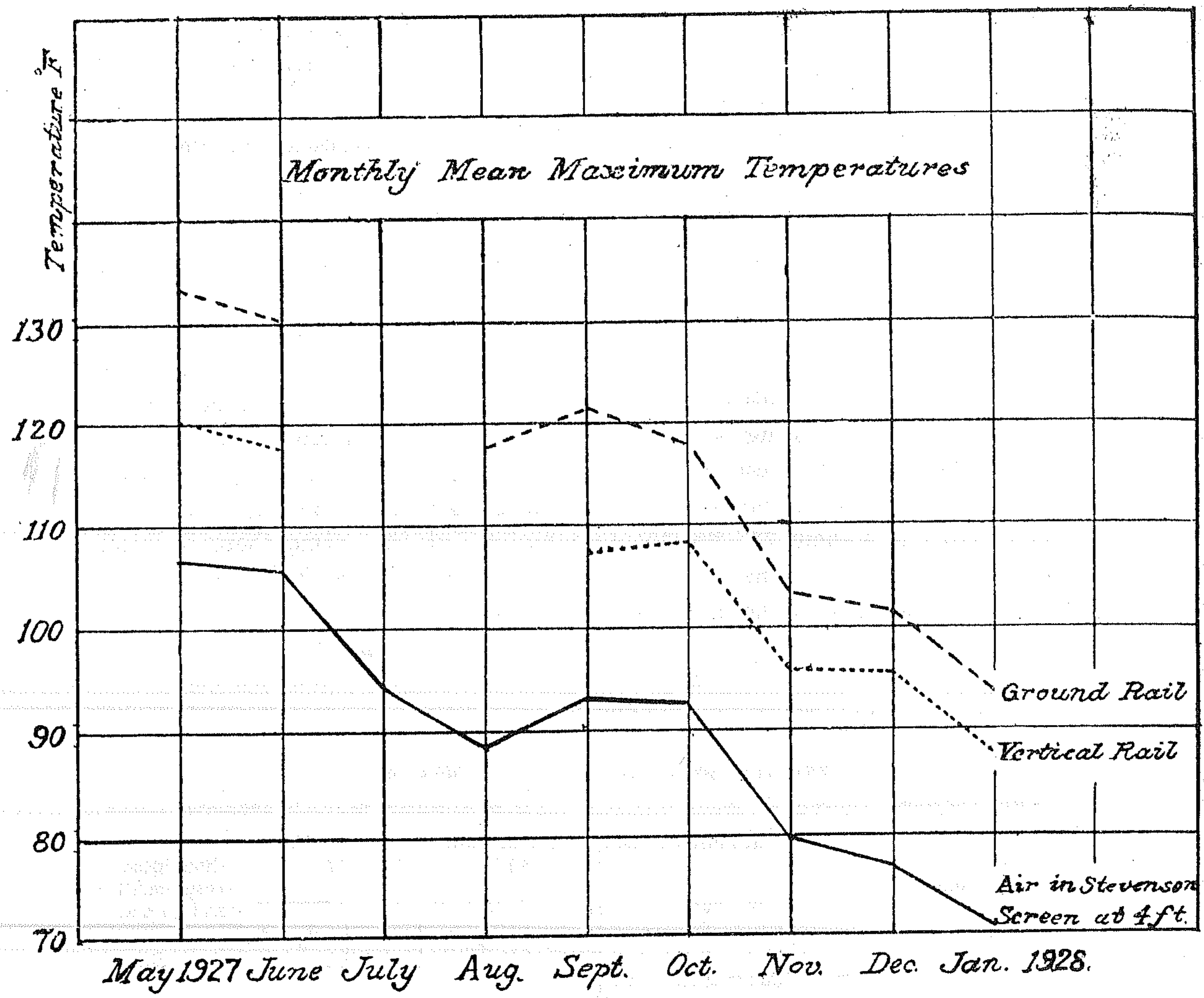

Fig. 2

Another interesting feature shown by these data is that the difference between the highest temperature attained by the horizontal and vertical rails is smaller during the months November, December and January than during the other months. The reason is fairly obvious. The maximum altitude of the sun is lowest during the winter months, the lowest value 40° occurring on December 21st (the latitude of Agra being 27° N.). At noon in the winter months, the energy received in unit time by a unit area either horizontal or vertical would be practically the same. At other hours, the vertical surface would have the advantage. On the other hand, in a month like June when the sun is nearly vertical, a horizontal surface would receive much more energy than a vertical one, and the difference of temperature between the horizontal and vertical rails would therefore be greater. The fact that one side of the horizontal rail is always in contact with the ground while the vertical rail is surrounded on all sides by moving air would always make the maximum temperature of the former higher.

Table 4 gives the percentage frequencies of occurrence of different maximum temperatures.

TABLE 4.

Percentage frequencies of occurrence of different maximum temperatures.

Range of temperature. °F	May 1927.			June 1927.			August 1927.			September 1927.			October 1927.			November 1927.			December 1927.			January 1928.		
	t'	t'_2	t'_3	t'	t'_2	t'_3	t'	t'_2	t'_3	t'	t'_2	t'_3	t'	t'_2	t'_3	t'	t'_2	t'_3	t'	t'_2	t'_3	t'	t'_2	t'_3
50—59·9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	5	...	...
60—69·9	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	...	...	4	...	...	16	...	...
70—79·9	...	...	...	...	...	...	4	4	...	3	...	...	3	...	...	43	...	3	67	4	4	79	11	17
80—89·9	...	...	...	3	...	...	58	4	...	27	...	3	13	3	3	50	14	17	29	...	12	...	11	28
90—99·9	...	...	...	3	3	4	38	8	...	70	3	10	84	...	6	...	10	41	...	21	58	...	68	56
100—109·9	72	...	...	80	3	8	...	23	...	...	10	49	...	6	54	...	48	38	...	75	25	...	11	...
110—119·9	28	...	29	13	3	44	...	42	...	...	23	38	...	42	36	...	28	...	...	...	...	...	...	...
120—129·9	...	25	71	...	27	44	...	15	...	...	47	...	...	50	...	...	...	...	...	...	...	...	...	...
130—139·9	...	75	...	...	60	...	...	4	...	...	17	...	...	...	...	...	...	...	...	...	...	...	...	...
140 and above	...	...	...	...	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

t' = Air in Stevenson screen. t'_2 = Ground Rail. t'_3 = Vertical Rail.

The mean monthly diurnal ranges of temperature are given in table 5.

TABLE 5.

Mean monthly diurnal ranges of temperatures.

Month.	Diurnal Range.			Cloudiness.
	Stevenson screen.	Ground Rail.	Vertical Rail.	
	°F.	°F.	°F.	
May 1927	28·6	59.2	44·5	2·3
June ,,	23·7	51·1	37·2	3·7
July ,,	14·7	...	...	7·7
Aug. ,,	11·4	41·4	...	8·9
Sept. ,,	20·7	50·1	36·3	3·3
Oct. ,,	28·6	56·9	45·8	2·5
Nov. ,,	27·4	54·2	45·4	3·1
Dec. ,,	30·1	58·2	50·8	3·7
Jan. 1928	26·1	52·1	46·1	3·9

The diurnal ranges and cloudiness are shown graphically in figure 3. The dependence of diurnal ranges on cloudiness is clearly marked. The ranges are least in the monsoon months at Agra, *viz.*, July and August.

Considering monthly averages, the ground rail has a higher range than the air, the excess varying from 26°F. to 31°F. while the corresponding excess for the vertical rail lies between 13°F. and 20°F.

The highest maximum and minimum temperature and also the largest range of temperature observed on any day during each month are given in table 6.

TABLE 6.

Month.	Air at 4 ft.			Ground rail.			Vertical rail.		
	Lowest min.	Highest max.	Largest range.	Lowest min.	Highest max.	Largest range.	Lowest min.	Highest max.	Largest range.
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
May 1927	73·6	113·2	35·3	68·3	139·7	66·1	71·5	124·4	48·0
June ,,	69·7	111·8	41·3	63·2	142·0	78·8	66·9	127·8	58·5
July ,,	74·5	105·9	21·0	...	...	...	...	...	...
Aug. ,,	72·5	97·9	18·9	71·5	130·0	54·6	71·9	...	...
Sept. ,,	67·0	99·9	31·5	64·6	133·7	69·1	64·1	11 ·9	54·7
Oct. ,,	56·1	96·1	35·7	52·6	127·5	69·9	53·6	118·6	59·2
Nov. ,,	42·5	89·1	37·9	37·7	117·3	70·7	39·0	108·3	62·6
Dec. ,,	41·9	82·6	37·6	37·9	109·5	68·7	39·8	104·4	60·4
Jan. 1928	36·9	77·0	33·3	34·7	105·7	60·8	35·0	99·7	59·9

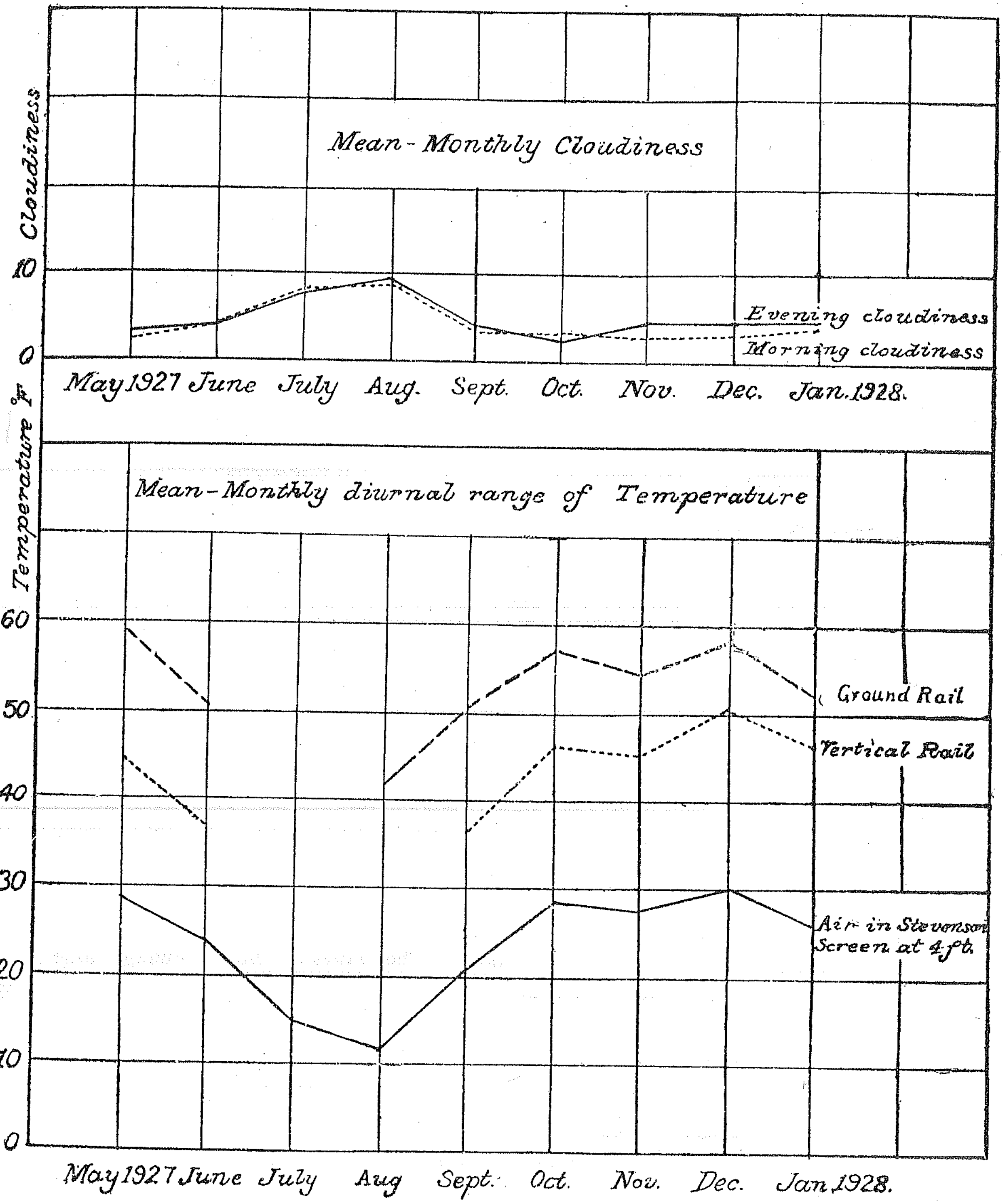

Fig. 3.

An attempt was made to find the effect of morning wind on the difference between Stevenson screen minimum and ground minimum temperatures and of afternoon wind on the difference between Stevenson screen maximum and vertical rail maximum temperatures. Wind measurements are available only at the Dines head which is at a height of about 70 ft. above ground and these winds were therefore used. Owing to the small variance of the wind from day to day and the numbers of controlling factors involved, the effect could not be brought out clearly.

As has been indicated in the introduction, some hourly observations of the ground-rail, the surface of the ground, the vertical rail and of air in the Stevenson screen were taken on 5 days in October 1926 and in February 1927. The ground temperatures were taken by means of a "surface" thermometer* and air temperatures by means of an Assmann. The surface thermometer (fig. 4) was made by inserting the bulb of a small mercury thermometer in a properly shaped cylindrical fold in a plate of copper about 1·5 cm. square and covering the non-plane side of the plate with felt.

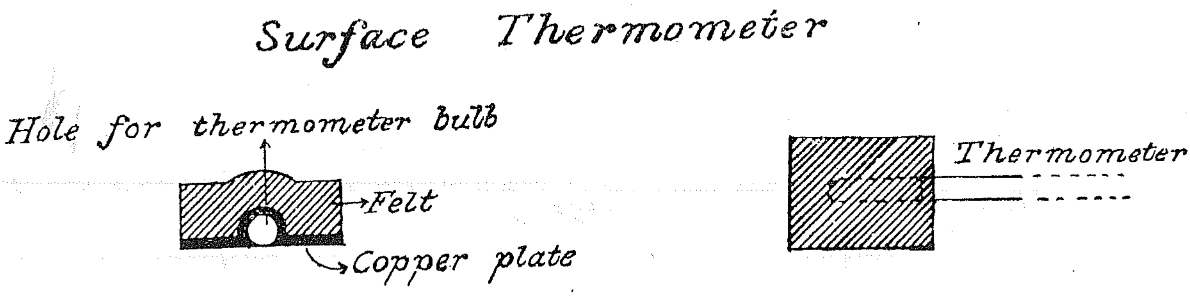

Fig. 4.

The copper plate was moved over the surface whose temperature was to be determined until the reading became constant. To show the nature of the diurnal variation of the temperatures, the values obtained on the 6th February 1927 are shown graphically in figure 5. The day was slightly clouded with cirrus and alto-cumulus clouds. The lag of the air temperature behind those of the rails and ground in the afternoon and the higher temperature of the vertical rail in the morning are noteworthy features and their general explanation does not present any difficulties.

Some observations were also taken on a few clear days to see how the temperature of the vertical rail varied with height. The rail temperatures were taken with the surface thermometer described above. The values in the following table show the nature of the results obtained.

TABLE 7.

Date and time.	Air in Stevenson screen.	Ground temperature.	Temperature of Vertical rail.					Remarks.
			Ground level.	2 ft. above ground.	4 ft. above ground.	6 ft. above ground.	10 ft. above ground.	
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	
25th October 1926 at about 14 h. 45 m.	88·0	116·8	102·7	104·0	102·9	101·8	...	
5th February 1928 at about 14 h. 10 m.	68·9	78·3	79·2	82·2	80·1	80·6	79·7	Rain on previous night and soil moist.

* The surface thermometer was designed by Mr. G. Chatterji, Meteorologist.

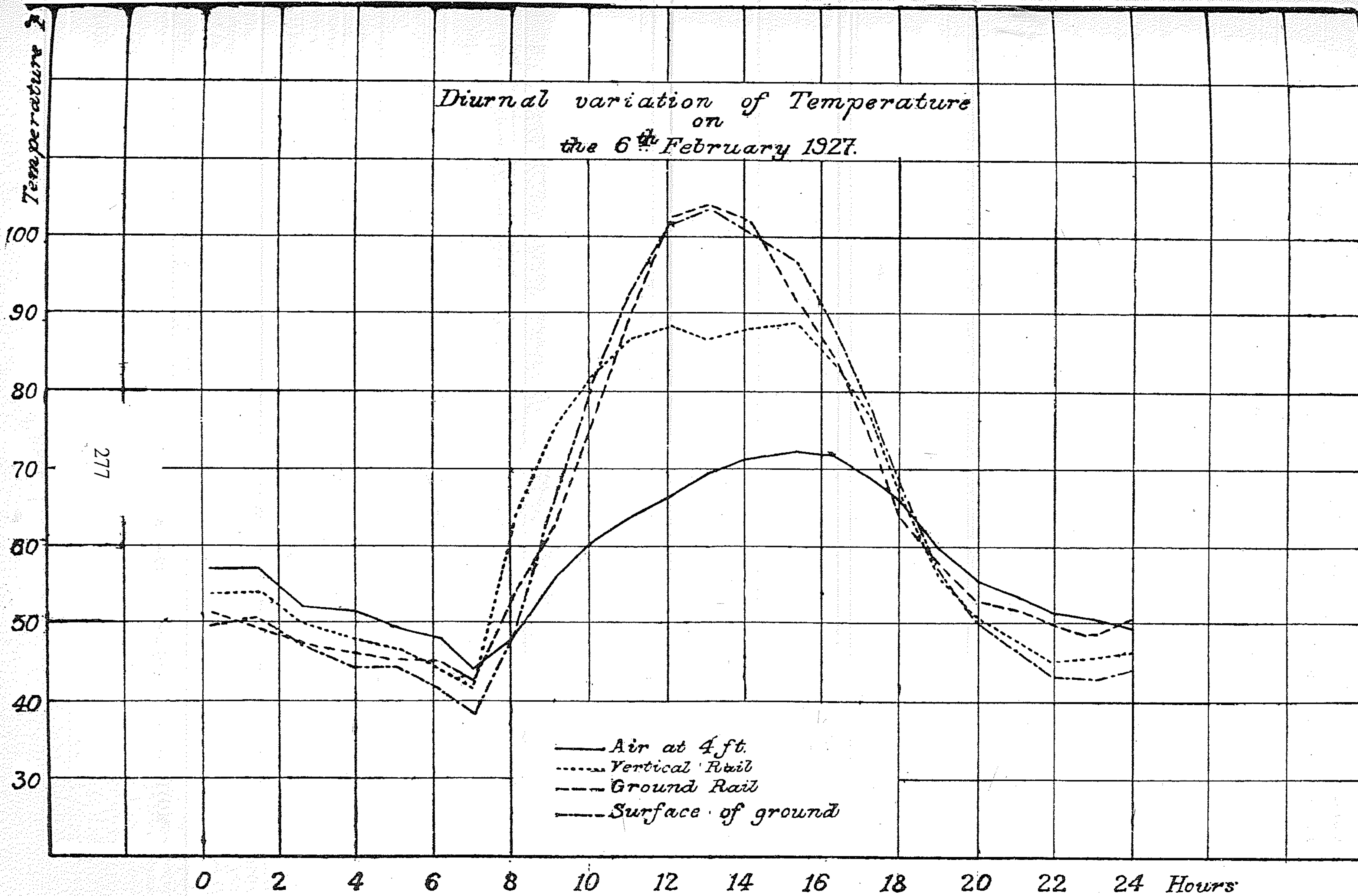
Diurnal variation of Temperature on the 6th February 1927.
Temperature
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
14
16
18
20
22
24
Hours
Air at 4 ft.
Vertical Rail
Ground Rail
Surface of ground

Fig 5.

The temperature of the rail at 2 ft. above ground was higher than that at ground level on both the occasions and is no doubt due to the conduction of heat from the rail into the soil, the lower end of the rail being at a depth of about 4 ft. within the earth. The decrease of temperature above 2 ft. is mainly due to increased ventilation. It will be noticed that the temperature at 4 ft. may be taken as a fair average for the temperature of the rail even during the hottest part of the day.

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