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(Department of Hygiene, Hebrew University, Jerusalem, Palestine.)

A New Kata-thermometer.

By WALTER KOCH, M.D., Ph.D.

(Received 29th January 1947.)

After it had turned out that dry bulb and wet bulb alone were poor judges of human comfort, repeated attempts were made to design more suitable scales and instruments. Among the latter the kata-thermometer, in spite of its short-comings has found a very wide distribution (1); later investigations, however, established that the kata-thermometer was rather an efficient anemometer for low wind-speeds. Consequently different means have been devised to arrive at a true estimate of human thermal comfort (2, 3, 4, 5, 6, 7, 8). One of these methods, the Effective Temperature Scale (3), is being used throughout the U.S.A. with good success. Unfortunately, the estimation of Effective Temperatures (E.T.) calls for three measurements, viz., dry bulb temperature, wet bulb temperature and wind-speed. As wind-speeds are generally determined from readings of the kata-thermometer, it has been tried to modify the kata-thermometer as to make it a direct-reading instrument for Effective Temperatures, without using dry-bulb or wet-bulb.

The E.T. scale and kata-readings do not have a common denominator. The E.T. is based on comfort-votes, while the cooling-rate is a physical expression (milligramme calories dissipated from one square centimetre of the kata-thermometer per second). In the first step let us consider how E.T., dry kata and wet kata compare in still air. Taking e.g. the 21.7° C. E.T. line as shown by YAGLOU and DRINKER (9) (fig. 1), then the uppermost point of this line (corresponding to 100% relative humidity) represents a dry-bulb and wet-bulb reading of 21.7° C. Assuming an air-movement of 0.1 m/sec¹, the cooling rate of the dry kata is 4.12 and of the wet kata 9.25². The next point (90% relative humidity) represents a dry-bulb reading of 22.2° C. and a wet-bulb reading

¹ In charts of E.T. "Still" Air is assumed to have a velocity of between 15-25 ft/min, equalling 0.076-0.127 m/sec.

² Hill's formulae were used for the dry kata; cooling-rates of the wet kata were computed according to Bedford's formula (personal communication):

$$H' = (1.115 v^{0.4} + 0.268) \cdot (28.65 - 0.409t' - 0.00946t'^2 - 0.000224t'^3),$$

where H' stands for wet cooling-rate, t' for wet bulb temperature (°C.), and v for wind speed (metres per second).

of 21.1° C., the corresponding kata-readings being 3.99 (dry) and 9.70 (wet) respectively. Proceeding further along the 21,7° C. E.T. line, it will be seen that the dry-kata readings decrease (since dry-bulb temperatures *increase*), while the wet kata yields higher readings (since the wet-bulb temperatures *decrease*). We may, therefore, say that an E.T. of 21,7° C. can be represented by dry cooling rates ranging from 2.37-4.12 and wet cooling rates ranging

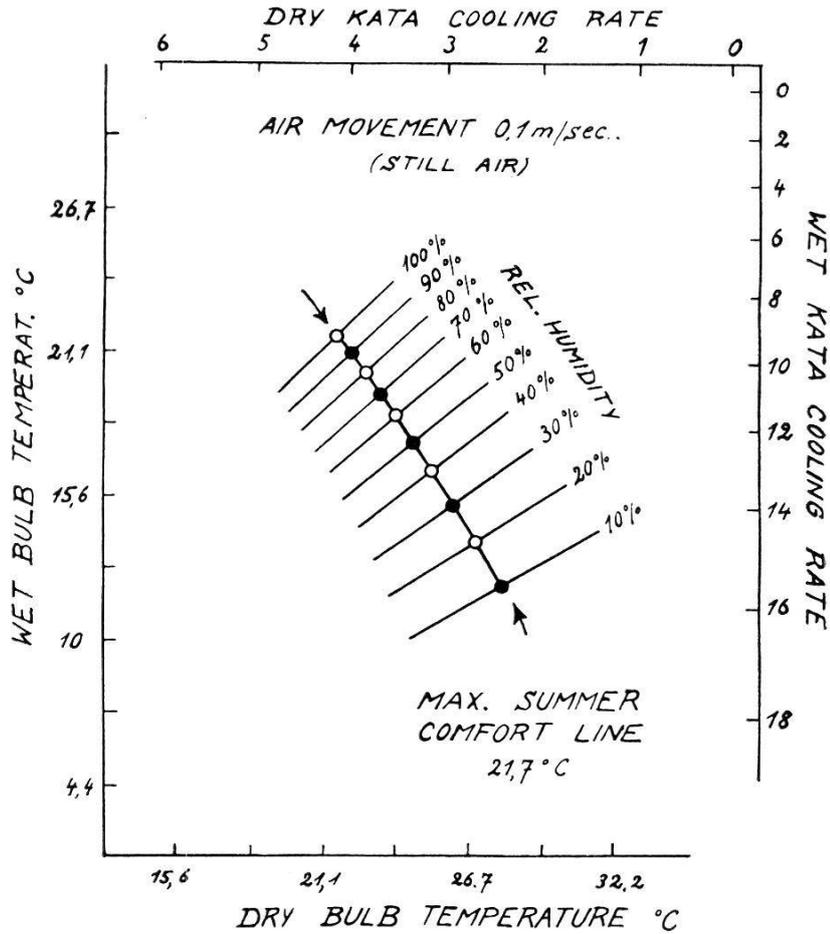


Fig. 1. 21,7° C Effective Temperature. Line (arrows) plotted vs. dry and wet Kata Cooling Rate.

from 9,25-15,6, assuming still air (0,1 m/sec). Thus neither the dry nor the wet kata-thermometer alone will allow an estimate of E.T. However, both taken together determine a definite point on the 21.7° C. E.T. line; consequently, there should also be a kata-thermometer, partly dry and partly wet, whose cooling-rate would be closely related to E.T. line 21,7° C.

Assuming the dry part of such a kata-thermometer to be x , its wet part $1 - x$, and its cooling-rate H_s , the following equation is valid:

$$H \cdot x + H' \cdot (1 - x) = H_s,$$

where H stands for dry cooling-rate and H' for wet cooling-rate.

Inserting actual figures, this equation becomes for the uppermost point of the 21.7° E.T. line (21.7° E.T., 100% R.H., still air): $4.12x + 9.25 \cdot (1 - x) = H_s$. Doing the same for all other points of the line, two sets of equations are obtained (fig. 1, circles, fig. 1, dots):

$$\begin{array}{ll}
 (100\%) : 4.12x + 9.25 \cdot (1 - x) = H_s & (90\%) : 3.99x + 9.70 \cdot (1 - x) = H_s \\
 (80\%) : 3.81x + 10.55 \cdot (1 - x) = H_s & (70\%) : 3.67x + 11.0 \cdot (1 - x) = H_s \\
 (60\%) : 3.51x + 11.55 \cdot (1 - x) = H_s & (50\%) : 3.29x + 12.35 \cdot (1 - x) = H_s \\
 (40\%) : 3.03x + 12.85 \cdot (1 - x) = H_s & (30\%) : 2.81x + 13.7 \cdot (1 - x) = H_s \\
 (20\%) : 2.59x + 14.75 \cdot (1 - x) = H_s & (10\%) : 2.37x + 15.6 \cdot (1 - x) = H_s \\
 \hline
 17.06x + 58.95 \cdot (1 - x) = 5H_s & \text{and} \quad 16.13x + 62.35 \cdot (1 - x) = 5H_s \\
 \text{whence } x = 0.785 \text{ and } H_s = 5.22.
 \end{array}$$

This means that a kata-thermometer with 78.5% of its surface dry and 21.5% of its surface wet will read 5.22 as soon as the E.T. is 21.7° C. and the air is still.

The calculation given above obviously calls for an extension, as an instrument solely indicating maximum comfort in still air would not be of much use. Table I and II which are complementary show area of wet surface and cooling rate a kata-thermometer should have in order to yield E.T.s at different temperatures and wind-speeds. Thus e.g. the first two entries in both tables mean: At 17.8° C. E.T., $v = 0.1$ m/sec, the wet area is 22.7%, $H_s = 6.92$.

TABLE I.

Percentage of wet surface of a kata-thermometer, partly dry and partly wet, whose cooling rates should correspond to Effective Temperatures.

Effect. Temp. (° C.)	Wind-Speed				Mean of Rows
	0,1	0,5	1,0	1,5 m/sec	
17.8	22.7	19.1	16	13.8	17.9
18.9	18.8	18	15.3	15.4	16.9
20.0	21.5	21	18	15.4	18.98
21.1	23.5	21.8	18.8	16.7	20.2
21.7	21.5	23.5	20	18.4	20.85
22.2	21.8	23	20.5	19	21.08
23.3	24.3	25	22.6	20.4	23.08
24.4	25	27.1	23	22.3	24.35
25.6	25.6	27.1	25.3	24.7	25.7
26.1	26.1	28.2	27.2	24.7	26.55
Mean of Columns:	23.08	23.38	20.67	19.08	

As it is difficult to prepare a finger-stall which wets a well-defined part of the kata-thermometer it has been decided to sinter part of the surface of the bulb. The empty kata-thermometer is heated and dipped into powdered glass; this is repeated until a sintered layer of about 1-1½ mm. results. Then the kata-thermometer is filled with alcohol in the usual way, calibrated and sealed.

TABLE II.

*Cooling rates of kata-thermometers, partly dry and and partly wet,
whose wetted areas have been listed in Table I.*

Effect. Temp. (° C.)	Wind-Speed				Mean of Rows
	0,1	0,5	1,0	1,5 m/sec	
17.8	6.92	10.5	11.52	12.39	10.33
18.9	6.8	9.76	10.59	11.75	9.73
20.0	5.91	9.3	10.18	10.18	9.05
21.1	5.57	8.66	9.39	10.08	8.43
21.7	5.22	8.49	9.16	9.82	8.17
22.2	5.0	7.96	8.75	9.39	7.78
23.3	4.68	7.37	7.9	8.46	7.10
24.4	4.21	6.72	7.13	7.5	6.39
25.6	3.72	5.84	6.37	6.88	5.70
26.1	3.51	5.56	6.13	6.29	5.37
Mean of Columns:	5.15	8.02	8.71	9.34	

When determining the factor of the kata-thermometer hot air is used for warming up. In actual use the kata-thermometer is heated by immersing the bulb into hot water. After withdrawing this part of the bulb which has not been sintered is carefully wiped, the sintered surface area remaining wet. The relation-

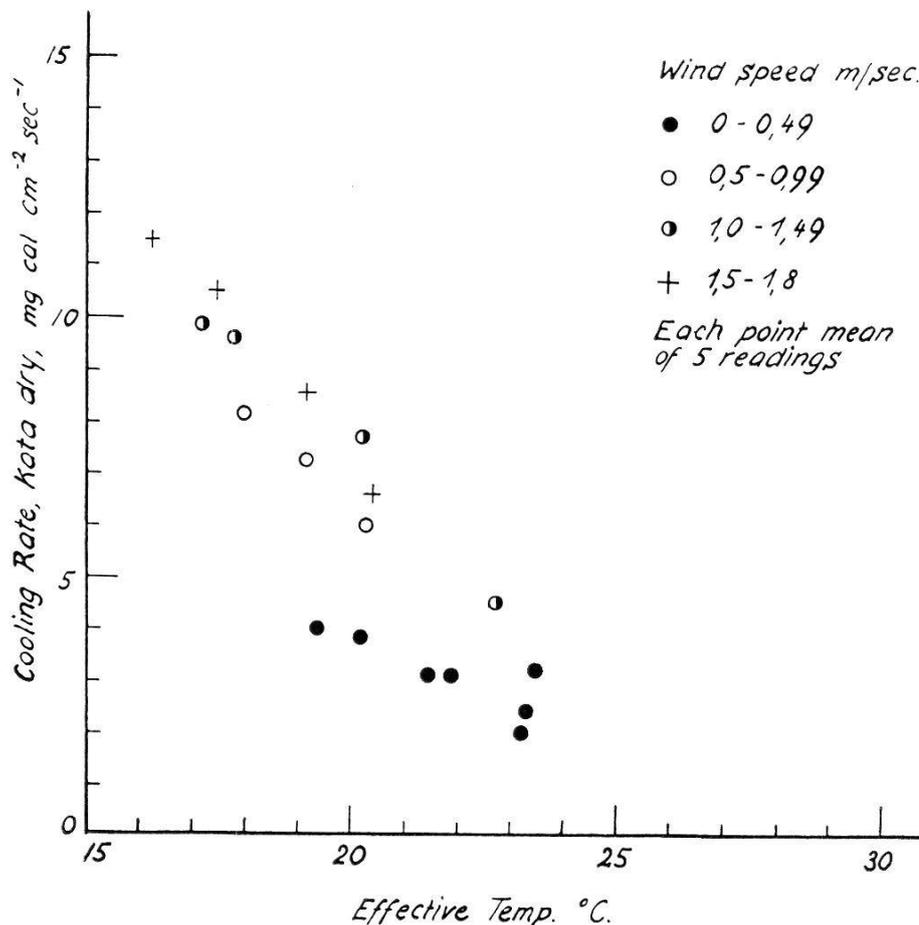


Fig. 2. Standard kata dry vs. Effective Temperature.

ship dry : wet area is easily calculated from the resulting cooling-rate H_s (see above).

As the kata-thermometer is unduly sensitive to wind, neither dry nor wet cooling-rates as indicated by the naked kata-thermometer allow an estimate of Effective Temperatures (fig. 2 and 3). The sintered kata-thermometer is therefore inserted into a small cage (fig. 4). The outer surface of this cage can be covered with a fabric which reduces the undue cooling action of higher wind-speeds; at the same time, however, evaporation from the wet

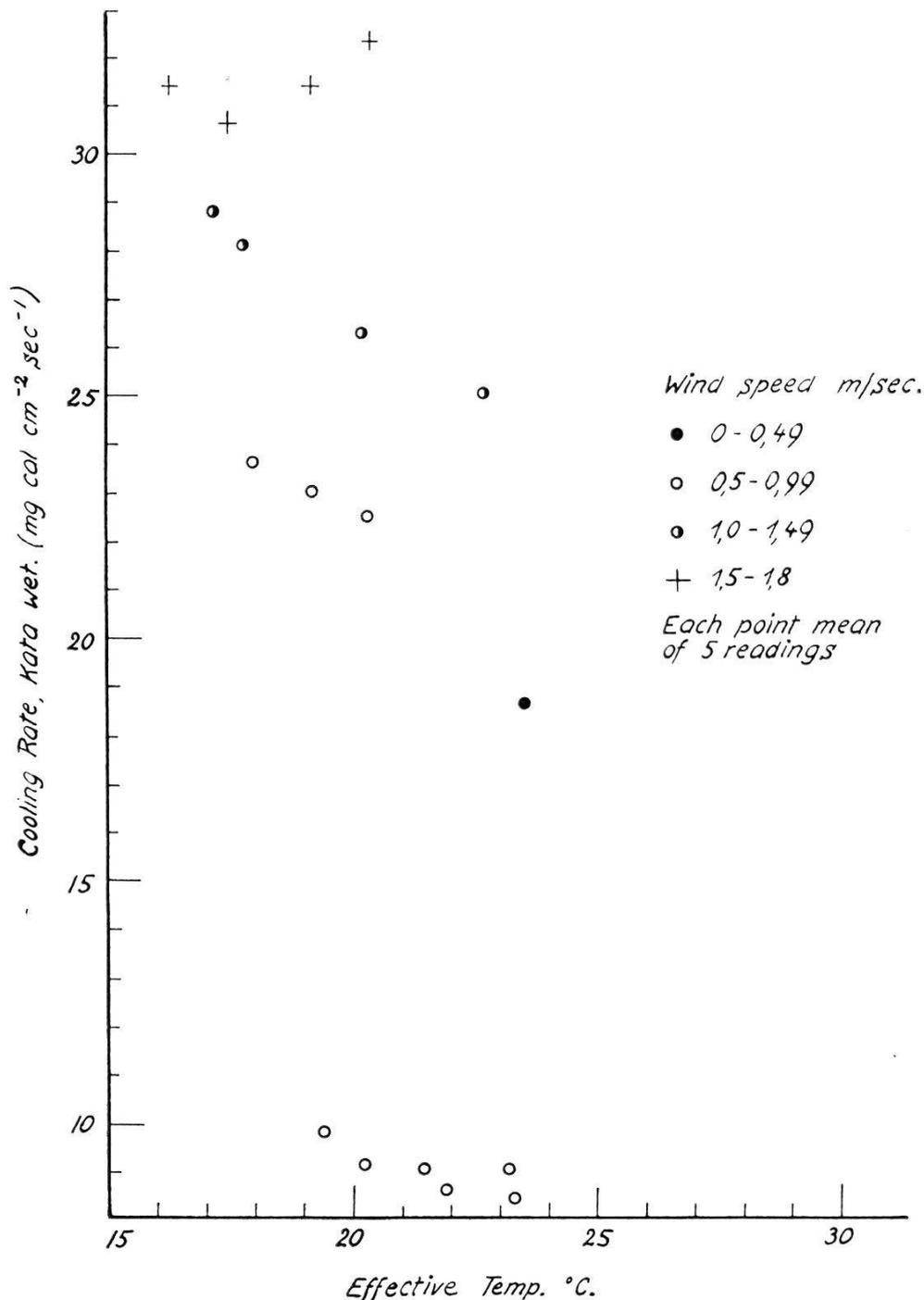


Fig. 3. Standard kata wet vs. Effective Temperature.

surface is hampered as well. In order to compensate for this the wet area is increased beyond the calculated figure. A wet area of 30% gives within the range tested a rather good fit. Fig. 5, 6 and 7 show the shielding action of wool, silk and linen respectively.

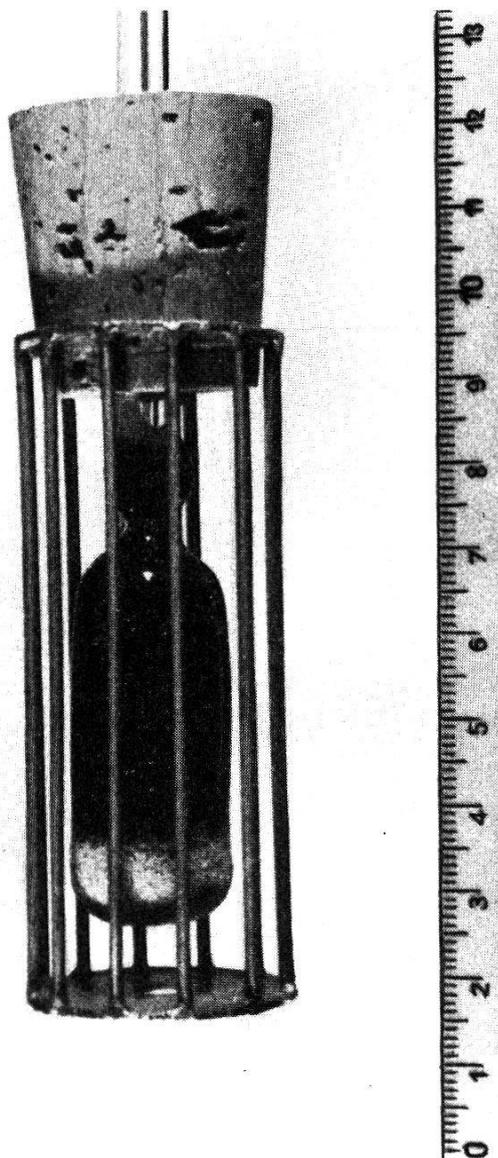


Fig. 4.

Tested between 16° C. and 24° C. E.T. the mean-error of a single reading is 0.405° C. E.T. for linen, irrespective of wind-speed. When estimating E.T. with the proposed instrument cooling-rates need not be actually calculated. As the factor of each instrument, cooling-time and cooling-rate are related:

$$\text{Cooling-rate} = \frac{\text{Factor}}{\text{Cooling-time}}$$

cooling-times can be plotted directly vs. E.T.

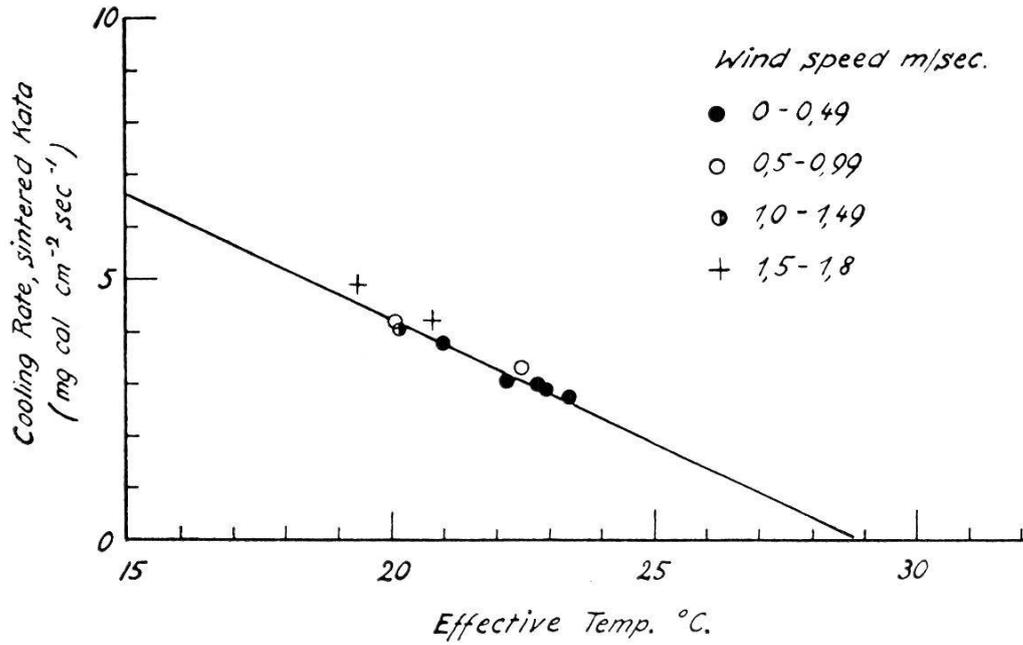


Fig. 5. Sintered kata in cage with wool cover vs. Effective Temperature.

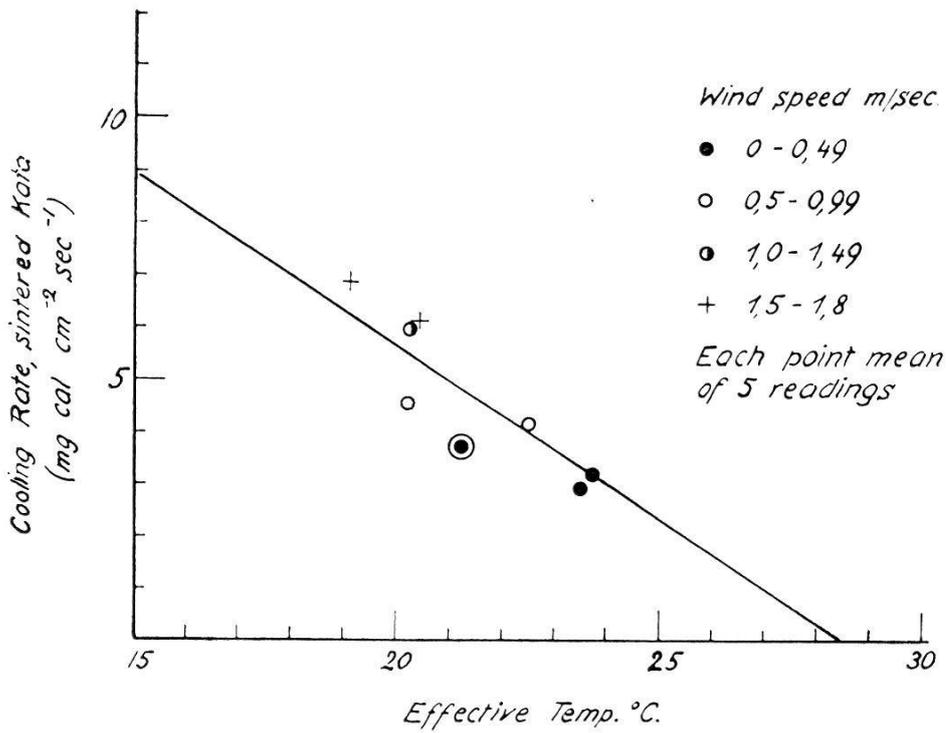


Fig. 6. Sintered kata in cage with silk cover vs. Effective Temperature.

Summary.

Effective Temperatures and Cooling-Rates are to a certain extent correlated. A new Kata-Thermometer is described whose surface is partly dry and partly wet. The action of wind on this instrument is reduced by shielding with a fabric. Readings of the proposed instrument allow a fair estimate of Effective Temperatures between 16° C.-24° C. E.T.

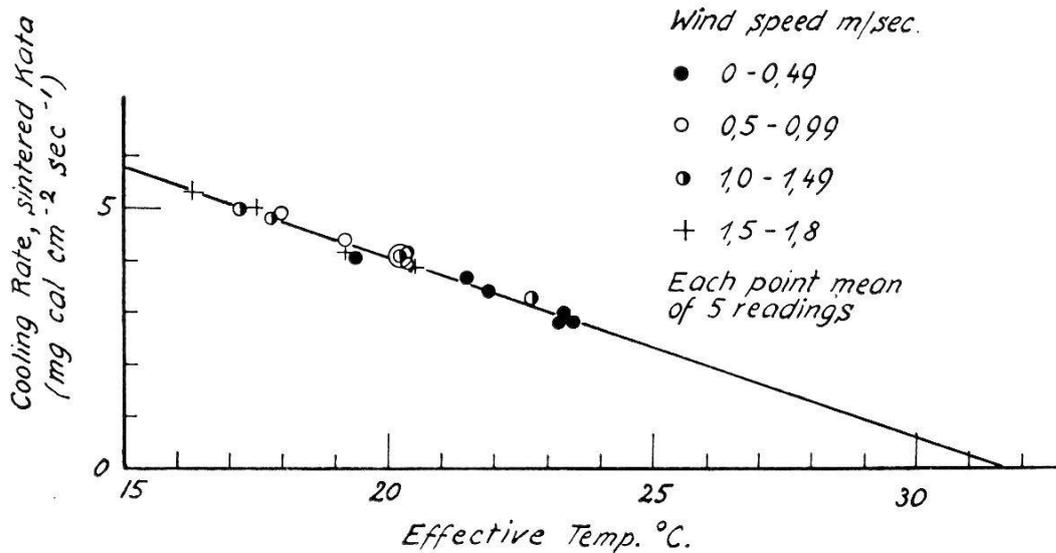


Fig. 7. Sintered kata in cage with linen cover vs. Effective Temperature.

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Zusammenfassung.

Effektive Temperatur und Abkühlungsgeschwindigkeit stehen bis zu einem gewissen Grade in Beziehung zueinander. Der Autor beschreibt ein neues Kata-Thermometer, dessen Oberfläche teils

feucht und teils trocken gehalten wird. Die Einwirkung des Windes auf das Instrument wird durch einen Stoffschirm verringert. Ablesungen auf dem vorgeschlagenen Instrument erlauben eine ziemlich genaue Schätzung der effektiven Temperaturen zwischen 16° und 24° C E. T.

Résumé.

Il existe une certaine relation entre la température effective et la vitesse de refroidissement. L'auteur décrit un nouveau kathermomètre dont la surface est en partie maintenue sèche, en partie humide. L'action du vent sur cet instrument est diminuée à l'aide d'un écran en tissu. Cet instrument permet d'estimer avec une assez grande précision les températures effectives entre 16° et 24° C. T. E.
