THE DEVELOPMENT OF A NEW WIND CHILL TEMPERATURE CHART

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Overview

1. Definitions
2. Development of Original Chart
3. Application to Humans and Problems
4. Usage of Modern Heat Transfer Theory
5. Results of Human Trials
6. New Chart Now in Use

Definitions

1. Wind Chill Factor - The effect of wind on making a person feel colder. It creates increased heat loss from the skin due to forced convection.

2. Wind Chill Temperature - That dry bulb temperature without wind* which would create the same rate of heat loss as the actual air temperature and wind speed.

* Since there is always motion of the body even in still air, the relative air speed has been assumed to be 3 mph (1.34 m/sec), a moderate walking speed.

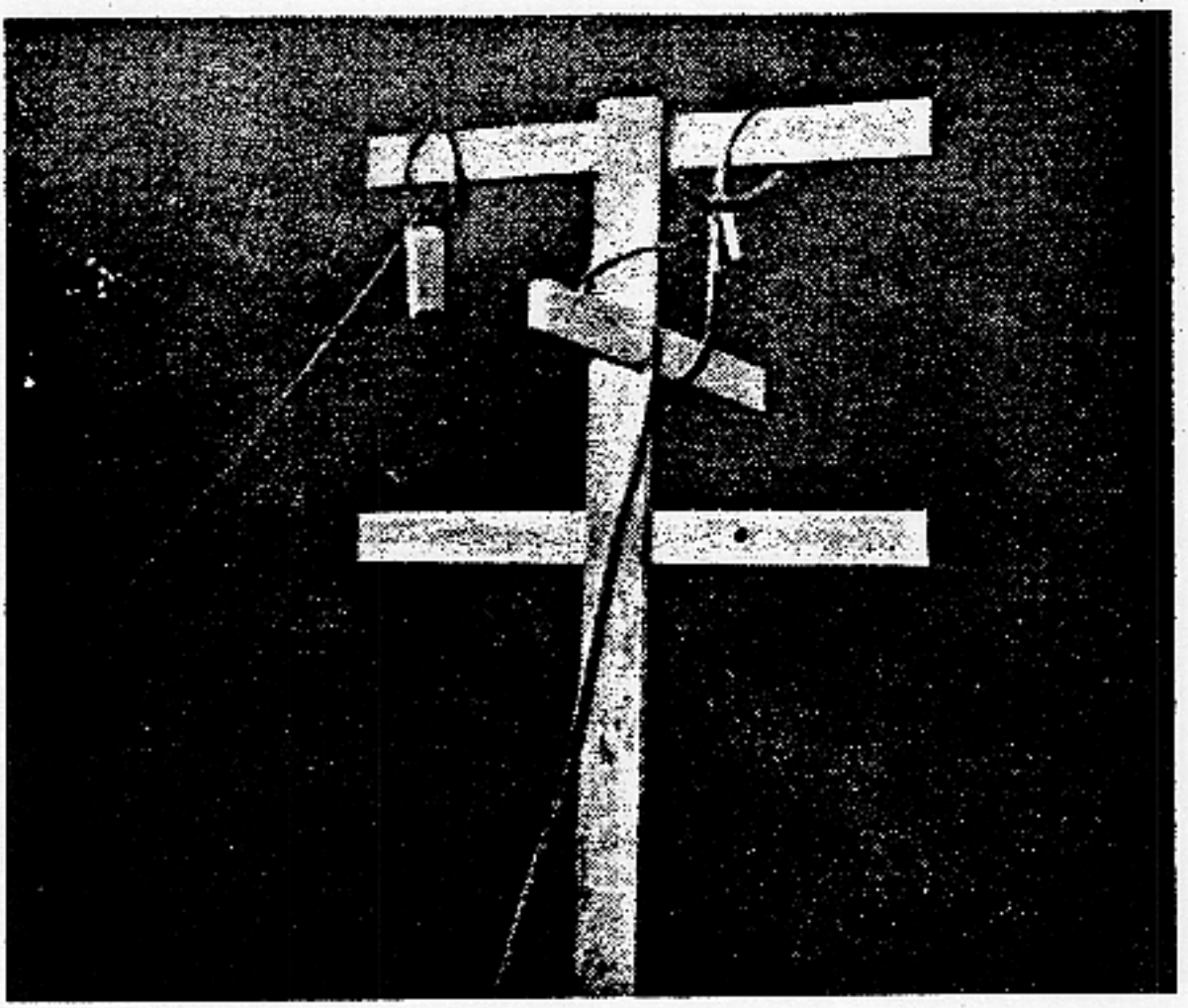
Development of the Wind Chill Factor

Study by the U.S. Army in Antarctica 1940-1941 by P.A. Siple, a geographer, and C.F. Passel, a geologist (S&P).

Based on the time to freeze 250g of water in a $\frac{1}{8}$ inch thick Pyrolin cylinder 5.875" long x 2.259" in diameter.

One thermohm immersed in the center of the water.

Douglass) could conveniently read each instrument. The temperature of the air was recorded every 5 minutes to the second decimal point in



Photograph by Charles Shirley, U. S. N.

FIG. 1. Relative comfort thermometer suspended in the open atmosphere above the Science Building at Little America III. The pyrolin cylinder, left, contains 250 grams of water. The temperature change is recorded by means of a thermohm suspended in the water. Air temperature thermohm is suspended on the right.

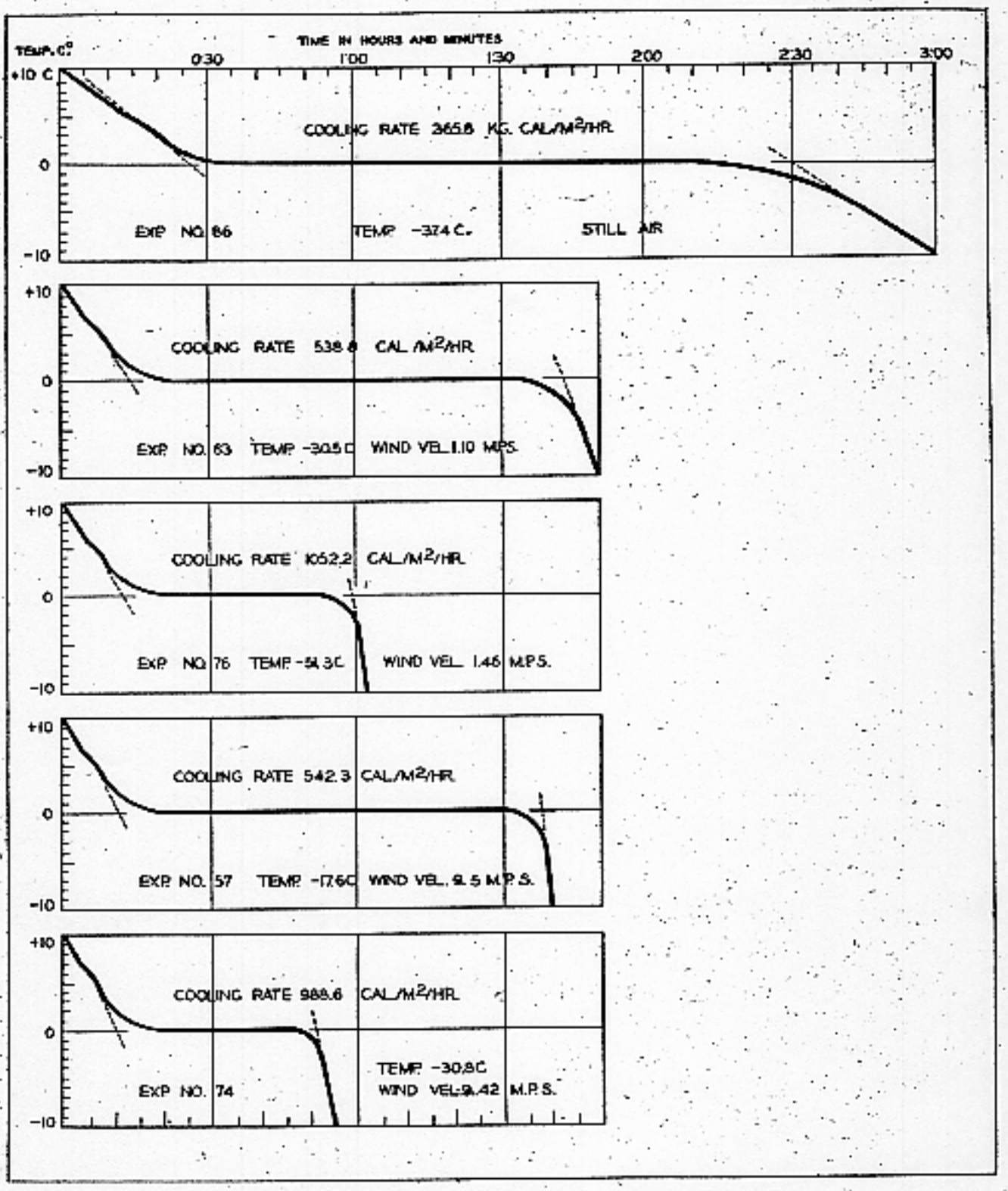


FIG. 3. Comparative cooling rates under various atmospheric conditions.

These graphs show the comparative cooling rates of the cylinder for 5 selected experiments. Note the irregularity of the cooling curve between 10 and 0. This is interpreted as the settling of 4° C. water in the bottom of the cylinder. After the water reached uniform density, cooling again became uniform. Undoubtedly this peculiarity was due to the construction of the thermohm.

All temperatures refer to mean air temperature during the period of actual freezing. Wind velocities are the mean of all measurements made during the freezing period. Cooling rates are actual measurements. However, they do not differ more than 4.4 per cent from the mean cooling rates calculated by formula.

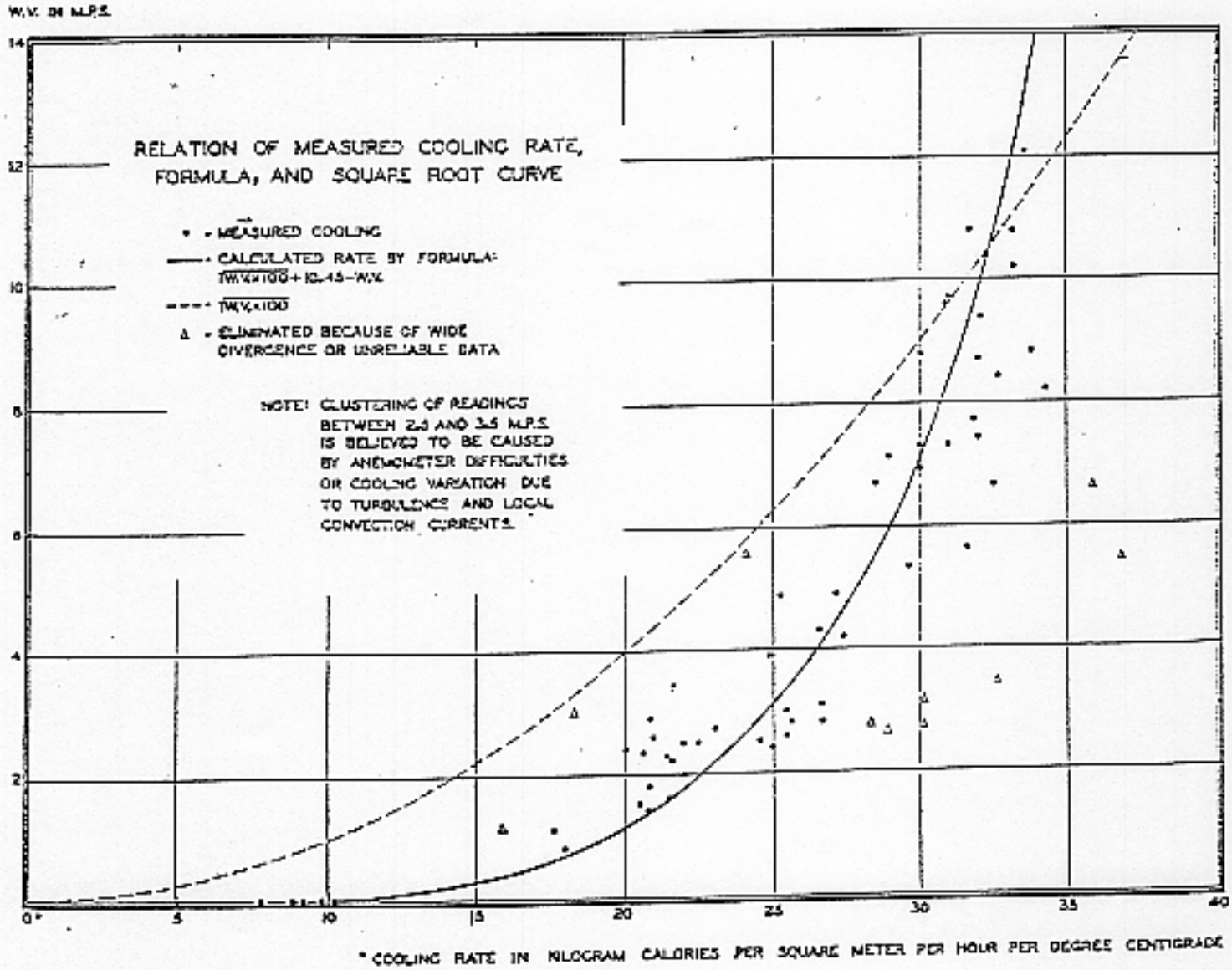


Fig. 1. Wind Velocity vs. Convection Heat Transfer Coefficient
From Siple and Passel, 1945.

S&P Heat Transfer Coefficient

$$Kcal/hr-m^2-{}^{\circ}C = \frac{(Heat\ of\ Fusion)\ x\ (Volume\ Water)}{(Time)\ x\ (Surface\ Area)\ x\ (Avr.\ Temp.)}$$

$$h = 10\ v^{0.5} + 10.45 - v$$

v in meters/sec

Heat Transfer Rate $Q = h\ A\ (T_s - T_a)$

Alternatively, $Q = (\Delta T) / R$

Problems With S&P's Analysis

1. Data are available only for moderate wind speeds and are widely scattered.

2. Coefficient h is parabolic, peaking at 25 m/s (56 mph).

3. Ignored thermal resistance of the pyrolin container (0.01 m^2K/w vs. 0.03 m^2K/w average for forced convection).

4. Included radiation heat transfer (0.25 m^2K/w average resistance).

5. Assumed a human skin temperature much too high.

Application to Humans

1. S&P assumed a human skin temperature constant 33°C (91.4°F) and a calm air speed of 1.79 m/s or 4 mph.

2. If $Q_{wc} = Q_{actual}$ then
   $WCT = 33 - 0.0454\,(10v^{0.5} + 10.45 - v)\,(33 - T_a)$

3. Present wind chill chart based on this equation.

4. $WCT = T_s\,[\,1 - 0.0454\,(h)\,] + 0.0454\,h\,T_a$

5. Since 0.0454 (h) is always > 1, lowering T_s raises WCT.

Heat Transfer Theory Approach

For S&P's experiments:

1. Forced convection for a cylinder in crossflow.

2. Added container resistance in series.

3. Added radiation heat transfer in parallel.

4. Solved forced convection with Churchill-Bernstein eq.

Churchill-Bernstein Equation (1977)

$$Nu_D = 0.3 + \frac{0.62\,\mathrm{Re}_D^{0.5}\,\mathrm{Pr}^{0.33}\left[1+\left(\frac{\mathrm{Re}_D}{282000}\right)^{.625}\right]^{.8}}{\left[1+\left(\frac{0.4}{\mathrm{Pr}}\right)^{0.67}\right]^{0.25}}$$

$$Nu_D = \frac{hD}{k}$$

Solved with TK Solver by method of DeWitt
Input D, L, T_a, T_s, v

For S&P experiment, T_s assumed to be 0°C

To Solve for WCT

$$Q_{wc} = Q_{actual}$$

$$h_{still} (T_s - WCT) = h_{actual} (T_s - T_a)$$

$$\text{If } T_s = 0\ ^{\circ}C,\ WCT = h_{actual}\ T_a / h_{still}$$

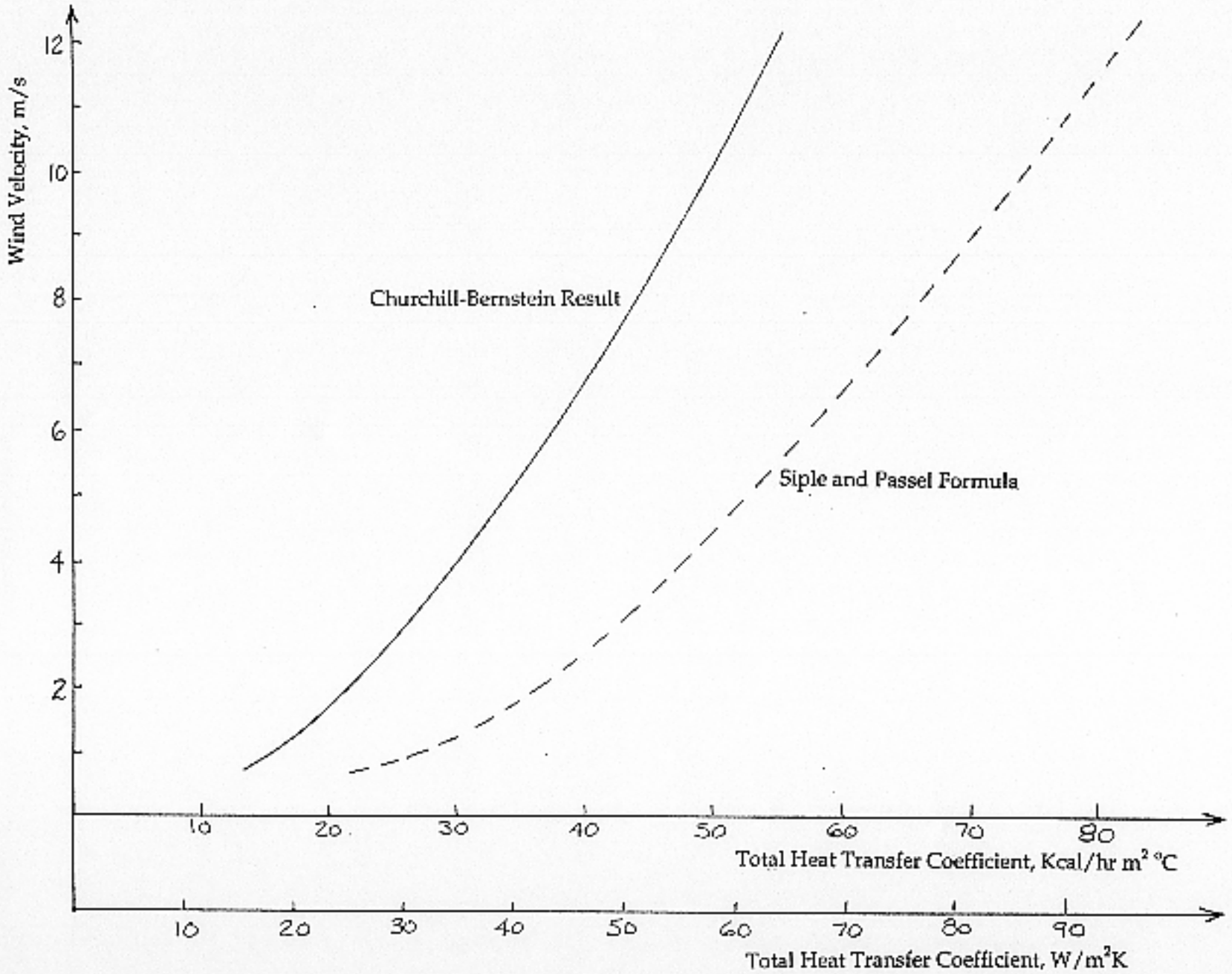
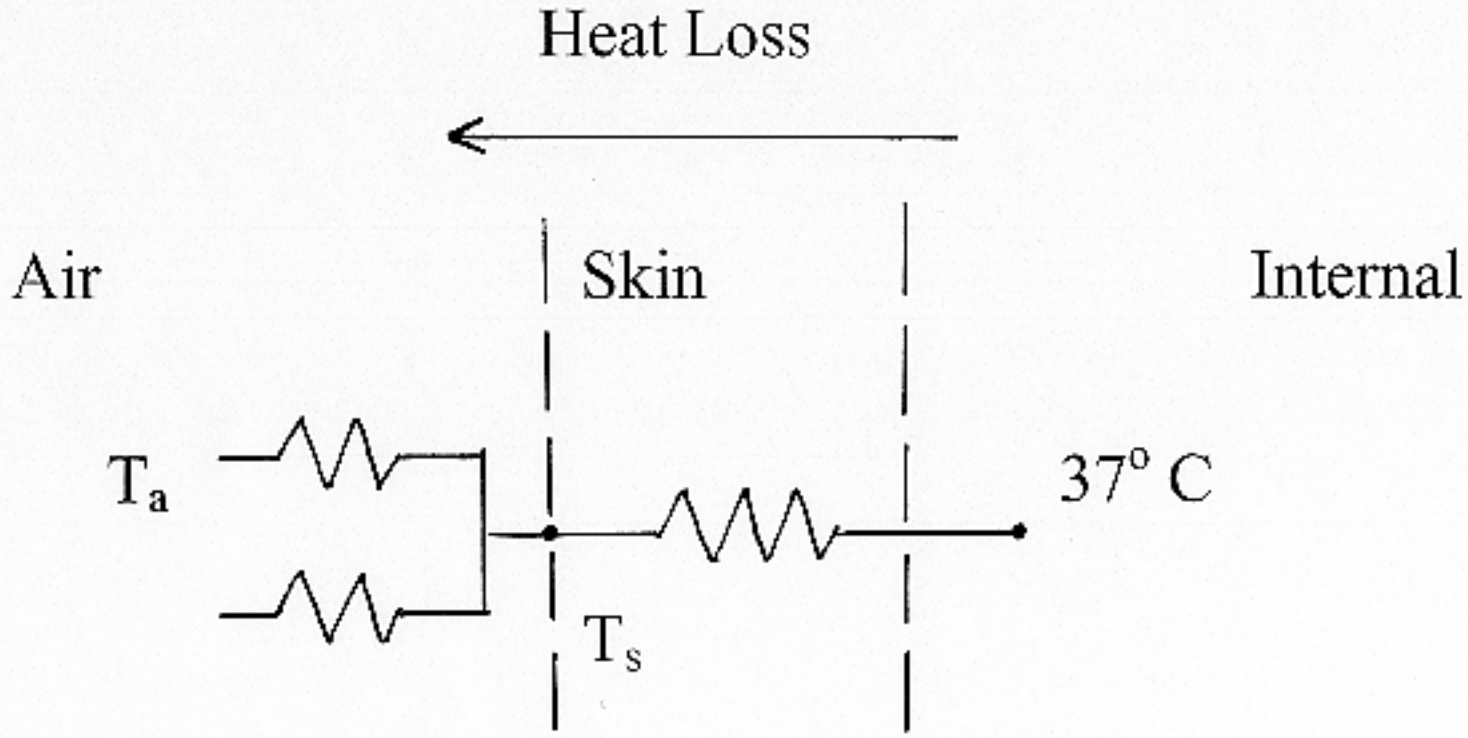


Fig. 2. Wind Velocity vs. Total Heat Transfer Coefficient
Comparison With Churchill-Bernstein Result.



$$Q = \Delta T/R = \Delta T/ [\ 0.09 + (h_c + h_r)^{-1}\ ]$$

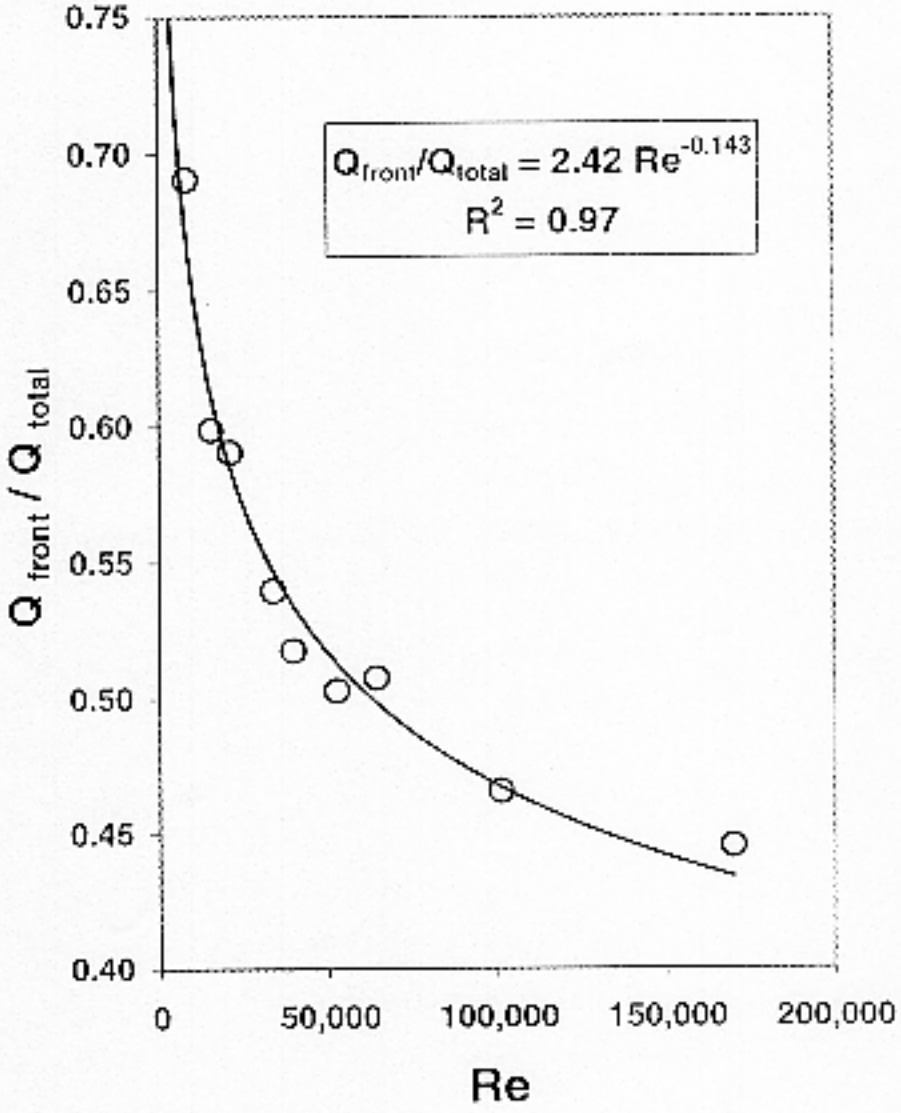
h_c a function of T_s and wind speed

$$h_r = \sigma\ \varepsilon\ (T_s + T_a)\ (T_s^{\ 2} + T_a^{\ 2}) \qquad \varepsilon = 1$$

Heat Transfer Theory Applied to Humans

Assumptions:

1. Head as a hollow cylinder, 218 mm long x 177 mm diam.
2. Only face exposed, half cylinder facing the wind.
3. Cold facial skin conduction R = 0.09 m^2K/w. Verified by human testing.
4. Interior of the cylinder at 37°C.
5. Wind at 10m height is 150% of wind at face level. Subject walking into the wind at 3 mph.
6. Calm wind speed 3 mph.



Based on the data of E. Achenbach, 1975.

Iterate the solution to $Q_{wc} = Q_{actual}$ with T_s assumed to get h

$$h_{still} (T_s - WCT) = h_{actual} (T_s - T_a)$$

h_{still} found from T_s and calm wind speed.

Solve for WCT.

Regression Equations
For Wind Chill Temperature Charts

$$\mathbf{WCT = 35.74 + 0.6215T - 35.75V^{0.16} + 0.4275TV^{0.16}}$$

T = air temperature in degrees Fahrenheit

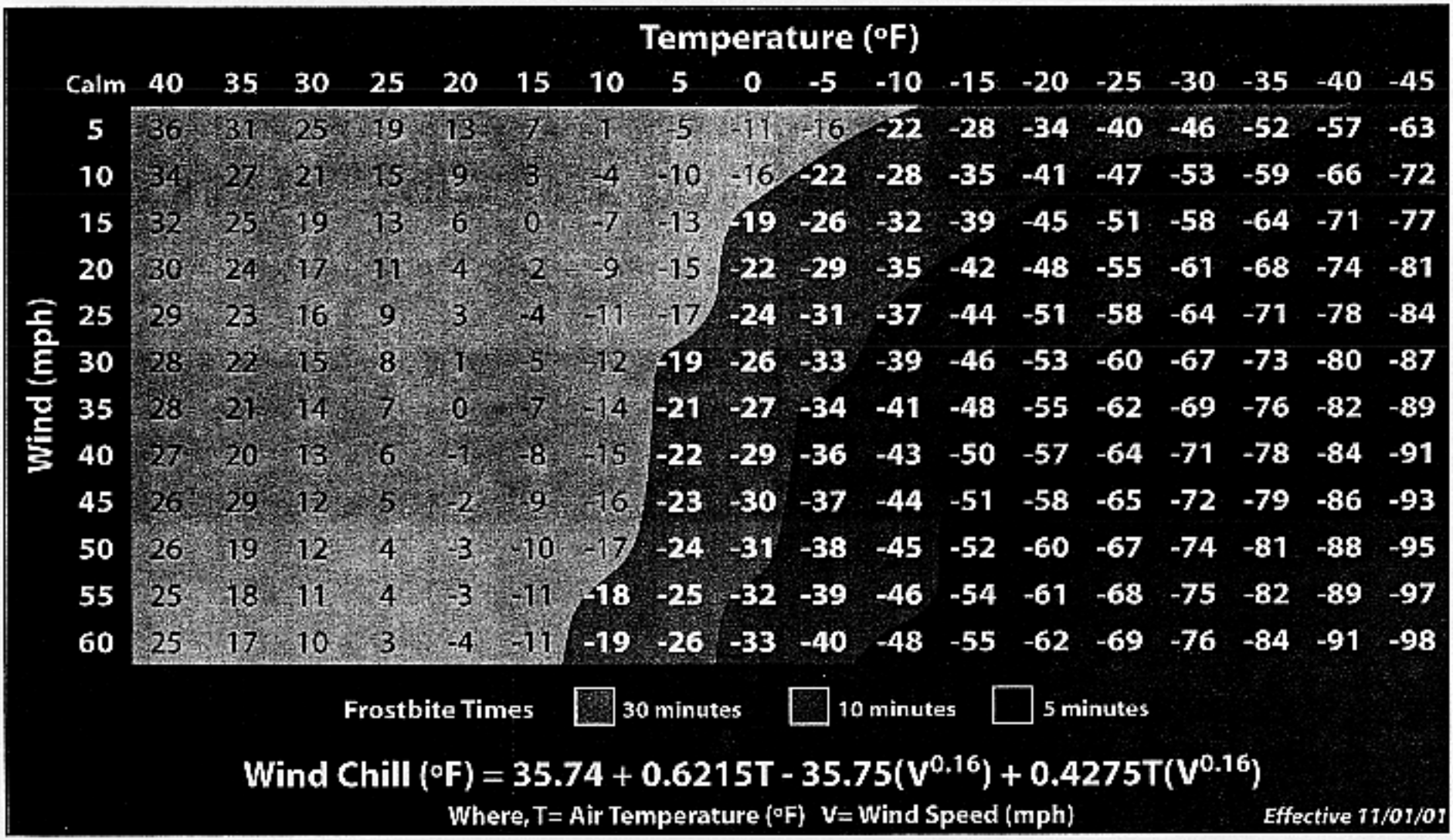
V = Wind speed in mph

$$\mathbf{WCT = 13.11 + 0.6215T - 11.37V^{0.16} + 0.3965V^{0.16}}$$

T = air temperature in degrees Celsius

V = wind speed in km/hr

Wind Chill Chart



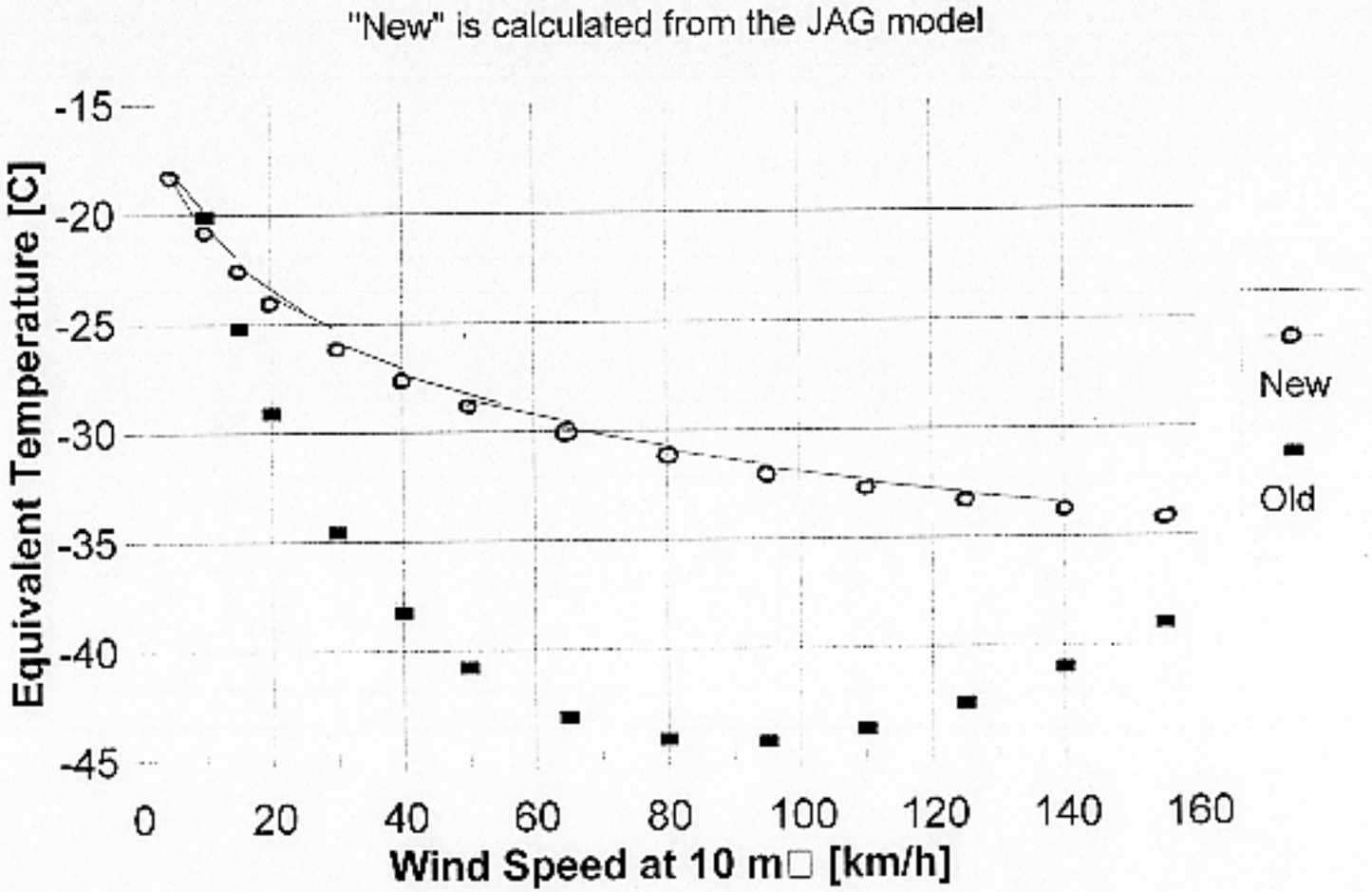
$$\text{Wind Chill (°F)} = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.4275T(V^{0.16})$$

Where, T= Air Temperature (°F) V= Wind Speed (mph)

Effective 11/01/01

TABLE 1. Wind chill equivalent temperature as a function of air temperature and wind speed (courtesy, National Climatic Center).

Wind Speed at 10m in mph	Air Temperature in °F																		
	45	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
4	45	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	43	37	32	27	22	16	11	6	0	-5	-10	-15	-21	-26	-31	-35	-42	-47	-52
10	34	28	22	16	10	3	-3	-9	-15	-22	-27	-34	-40	-46	-52	-58	-64	-71	-77
15	29	23	16	9	2	-5	-11	-18	-25	-31	-38	-45	-51	-58	-65	-72	-78	-85	-92
20	26	19	12	4	-3	-10	-17	-24	-31	-38	-46	-53	-60	-67	-74	-81	-88	-95	-103
25	23	16	8	1	-7	-15	-22	-29	-36	-44	-51	-59	-66	-74	-81	-88	-96	-103	-110
30	21	13	6	-2	-10	-18	-25	-33	-41	-49	-56	-64	-71	-79	-86	-93	-101	-109	-116
35	20	12	4	-4	-12	-20	-27	-35	-43	-52	-58	-67	-74	-82	-89	-97	-105	-113	-120
40	19	11	3	-5	-13	-21	-29	-37	-45	-53	-60	-69	-76	-84	-92	-100	-107	-115	-123
45	18	10	2	-6	-14	-22	-30	-38	-46	-54	-62	-70	-78	-85	-93	-102	-109	-117	-125


"New" is calculated from the JAG model
Equivalent Temperature [C]
-15
-20
-25
-30
-35
-40
-45
0
20
40
60
80
100
120
140
160
Wind Speed at 10 m□ [km/h]
New
Old

Regression Equations
For Time to Frostbite of Skin

Frostbite time (Ft) in minutes:

$$\mathbf{Ft = ((-24.5 \times ((0.667 \times (V \times 8/5)) + 4.8)) + 2111) \times (-4.8 - ((Tair - 32) \times 5/9))^{-1.668}}$$

Tair = air Temperature in degrees Fahrenheit

V = wind speed in mph > 16 mph measured at a height of 33 ft

$$\mathbf{Ft = ((-24.5 \times ((0.667 \times V) + 4.8)) + 2111) \times (-4.8 - Tair)^{-1.668}}$$

Tair = air Temperature in degrees Celsius

V = wind speed in km/h > 25 km/h measured at a height of 10 m

Based on 5% Frostbite Risk When Skin Reaches – 4.8 C

Time to occurrence of frostbite (5% risk of frostbite) in minutes or hours (h)

Air Temperature (°F)

WIND MPH	cal	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
	5	>2h	>2h	>2h	>2h	31	22	17	14	12	11	9	8	7
	10	>2h	>2h	>2h	28	19	15	12	10	9	7	7	6	5
	15	>2h	>2h	33	20	15	12	9	8	7	6	5	4	4
	20	>2h	>2h	23	16	12	9	8	8	6	5	4	4	3
	25	>2h	42	19	13	10	8	7	6	5	4	4	3	3
	30	>2h	28	16	12	9	7	6	5	4	4	3	3	2
	35	>2h	23	14	10	8	6	5	4	4	3	3	2	2
	40	>2h	20	13	9	7	6	5	4	3	3	2	2	2
	45	>2h	18	12	8	7	5	4	4	3	3	2	2	2
	50	>2h	16	11	8	6	5	4	3	3	2	2	2	2