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WBGT Forecast for Prevention of Heat Stroke in Japan

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1. Introduction

Heat Stroke caused by higher temperatures and humidity, related to Global Warming and heat island effects especially in larger cities, has become one of the hottest subjects in Japan. In Japan 200 to 300 people died because of heat strokes in one year (Nakai, 1993) [1][7] and recently the number of deaths of aged people, older than 65, has been increasing.

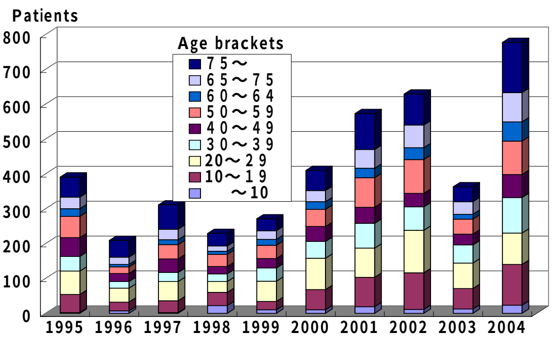

Fig.1. Age brackets of patients taken to hospitals by ambulances in Tokyo

WBGT(Wet-bulb Globe Temperature: Yaglou and Minard, 1957) [2] is a standard index to set down the rule for workers or athletes also in Japan. And the WBGT can be calculated from dry-bulb temperature, wet-bulb temperature and globe temperature.

Dry-bulb temperature is quite common and wet-bulb temperature can be calculated from dry-bulb temperature, humidity and pressure. But on globe temperature, we did not have a estimation method in Japan. So through observations of temperature, humidity, wind speed, sun radiation, globe temperature and so on, we formulate the equation to estimate globe temperature with dry-bulb temperature, sun radiation and wind speed.

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And we also tried to estimate globe temperature on the heat balance theory.

Then using numerical forecasts issued by JMA (Japan Meteorological Agency), we tried to make WBGT 3-hourly forecast for the day and the next day in order to warn of the risk of heat stroke. We experimentally provided the forecast through the web site (http://www.nies.go.jp/wbgt/) from July to September in order to alert of to the risk of heat stroke.

2. WBGT observation and data

In order to observe WBGT around Tokyo continuously, we set observation instruments on the top of the JMBSC building from Jun/06/2005 to Jul/30/2005, and then we moved these instruments to Tsukuba in order to compare the difference in WBGT between a grass ground and an asphalt ground.

Table 1. Observation parameters and instruments

Parameter	Instrument
Dry bulb temperature	Pt thermometer (Yokogawa Inc. E-734)
Dew point temperature	Li-Cl Hygrometer (Yokogawa Inc. E-771)
Globe temperature	Globe temperature probe (Kyoto electric Inc 5inch-WBGT sensor.)
Wind	Propeller anemometer (Yokokagawa Inc. WM-8841)
Sun radiation	Pyranometer (Eko Instruments, MS-402)

According to the observation at Tokyo, the average WBGT for clear days on a grass ground exceeded 25 degrees Celsius (77 degrees Fahrenheit:) from 9 am to 4pm, showing that from early morning the risk for heat stroke is high.

Fig.2. Exterior of the equipment at Tsukuba

And the maximum WBGT during the observation exceeded 30 degrees Celsius (86 degree Fahrenheit), and the peak of WBGT shifted in the morning compared with the dry bulb temperature which has its peak at around 2pm. It also warns that we have to pay attention to heat stroke from early morning, especially field athletes and workers do

In order to extend this study, we collected additional WBGT observation data as shown in Table 2.

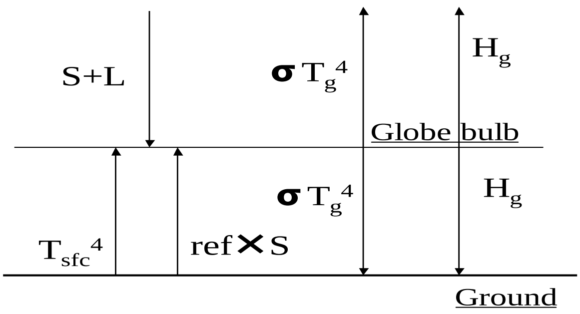
Table 2. WBGT data

City	period	Institution
Kurume	Sept. 17 – Oct. 16, 2002	Kyushu Technical and Engineering Office
Tokyo	Aug. 12 – Sept. 15, 2004	JMBSC
Hikone	Jun. 24 – Aug. 4, 2005	University of Shiga Prefecture
Kusatu	Sept. 1 – Sept. 11 2005	Kyoto Electronics Manufacturing, Co., Ltd.

3. Estimation of Globe Temperature

In Japan, at about 150 stations controlled by the Japan Meteorological Agency, temperature, humidity, wind speed and sun radiation are observed. If we can estimate the globe temperature from such well-known meteorological elements, we'll be able to estimate WBGT using common meteorological elements, helping public use WBGT index easily and regularly.

At first we considered the heat balance on a globe temperature sensor. We deemed a globe bulb as a flat plate and looked into the heat balance on a flat plate (Given cooling heat by winds, the globe bulb could be regarded as a plate).



T: Air temperature

T_g: Globe temperature

T_{sfc}: Ground surface temperature

Fig.3 Heat balance on a globe bulb

To the upper side of a plate, solar radiation (S) and atmospheric radiation(L) come in and from the lower side reflection on the ground(ref*S) and radiation from the ground(σT_{sfc}^4) come in, on the other hand, a plate radiates $2\sigma T_g^4$ from both sides and sensible heat 2Hg are ripped off by air.

On a fine day, a globe bulb is kept dry, so latent heat from the bulb is estimated to be 0. The heat balance on a plate can be determined from the following equation.

$$S + L + \sigma T_{SFC}^4 + ref \times S = 2\sigma T_g^4 + 2H_g \quad (1)$$

$$H_g = c_p \rho C_h U (T_g - T) \quad (2)$$

Where S is the amount of global solar radiation, L is the long-wave radiation from air, T_{SFC} is the surface temperature of ground, ref×S is the reflection from ground (ref is the albedo of ground), T_g is the globe temperature, T is the dry bulb temperature, H_g is the sensible heat from globe bulb, $c_p \rho$ is the heat capacity of air ($1.21 \times 10^3 JK^{-1}m^{-3}$, at 1 atmand 20 degree Celsius), C_h is the transer coefficient of heat and U is the wind velocity(m/s).

When albedo is equal 0.3, a sample of each heat factor can be estimated as Table 3. For example, at noon, the solar radiation is 42 percent, long-wave radiation is 15 percent, reflection from ground is 13 percent and radiation from ground is 30 percent of total heat income to a globe bulb.

Table 3. Rough heat balance on globe bulb

(W/m^2)

Time	S	L	σ Tsfc4	S*ref	- σ Tg4	-H
8:00	326.9	299.9	429.2	98.1	453.2	123.8
10:00	641.3	314.3	528.2	192.4	520.5	317.6
12:00	857.4	303.9	601.5	257.2	536.5	473.5
14:00	706.9	297.0	601.0	212.1	542.3	366.1
16:00	389.6	300.9	549.7	116.9	518.3	160.2

* Sept./24/2002 at Kurume (ground=asphalt)

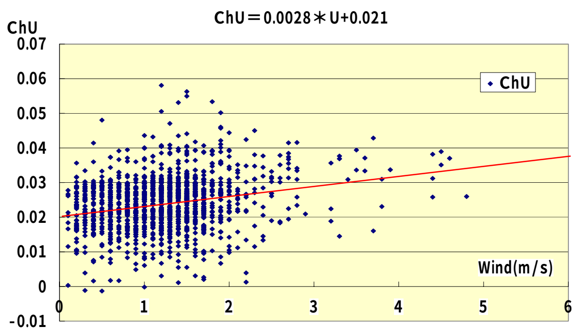


Fig.4 Heat Transfer coefficient C_hU and wind speed (Kurume, September 2002)

On the other hand, C_h (heat transfer coefficient) is statistically determined from the observation at Kurume.

$$C_h*U = 0.0028*U+0.021 \qquad (3)$$

Where U is wind velocity (m/s)

And then in order to estimate Tg-T(the difference between globe temperature and dry bulb temperature), we transform Eq.(1). Here σT_{sfc}^4 and σT_g^4 are approximated from Eqs. (5) and (6).

$$T_g - T = \frac{(1+ref)S + L + 4\sigma T^3(T_{sfc} - 5/4\times T)}{2(c_p \rho C_h U + 4\sigma T^3)} \qquad (4)$$

$$T_{sfc} \approx \sigma T^4 + 4\sigma T^3 (T_{sfc} - T) \qquad (5)$$

$$T_g \approx \sigma T^4 + 4\sigma T^3 (T_g - T) \qquad (6)$$

In the numerator, the first term is greater than the second and third terms. The first term changes greatly with solar altitude, but the second and third terms do not change greatly as the first one. T_g-T depends on solar radiation greater than long-wave radiation or air temperature. The stronger wind blows, the smaller T_g-T becomes, but as the first term in the denominator is greater than the second one, so the dependence on wind cooling is relatively small.

Table 4. Estimated T_g-T

Wind speed (m/s)	Sun radiation (W/m*m) 1050	1000	950	900	850	800	750	700
1	20.6	19.5	18.5	17.5	16.5	15.4	14.4	13.4
2	18.8	17.9	16.9	16.0	15.0	14.1	13.2	12.2
3	17.3	16.5	15.6	14.7	13.9	13.0	12.1	11.2
4	16.1	15.3	14.5	13.6	12.8	12.0	11.2	10.4
9	11.8	11.2	10.6	10.0	9.4	8.8	8.2	7.6
16	8.3	8.1	7.7	7.2	6.8	6.4	5.9	5.5

Ch=0.021+0.0023*U Dry Temperature = 30 degree Celsius

When the difference in albedo between grass and concrete is 0.1 above a concrete ground, an incoming radiation to a globe bulb will increase to 150W/m^2, greater than that to a grass ground. When a solar radiation is 900(w/m^2) and wind speed is 2(m/s), the difference between globe temperature and dry bulb temperature above a concrete ground would be by 3 degree(Celsius) higher than the difference above a grass ground.

According to the observation at Tokyo and Kusatsu, approximate expressions statistically delivered from the observed data are,

$$T_g\text{-}T = 0.0163 * S \quad \text{(Kurume, Jul/2002, asphalt)}$$
$$T_g\text{-}T = 0.0110 * S \quad \text{(Kusatsu, Sep/2005, grass)} \qquad (7)$$

The difference in T_g-T between an asphalt ground and a grass ground under 900W/m^2 of solar radiation is estimated to be 4.7 degree Celsius.

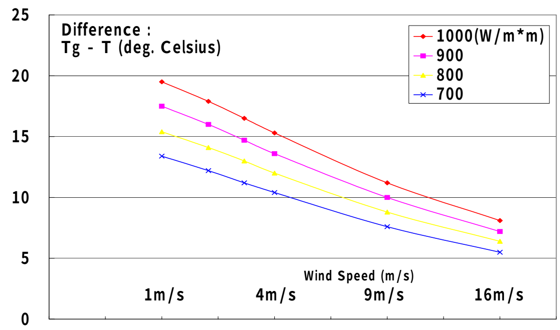


Fig.5 Estimated difference between Tg and T

On the other hand, according to the observation at Hikone (Yorimoto,2005), the difference in Tg-T between a concrete ground and a grass ground (observed from 9 a.m. to 3 p.m.) was 2.6 degree Celsius.

From Eqs. (4),(5) and (6), we can roughly estimate the globe temperature, but we cannot verify its accuracy because we don't have enough data to evaluate precisely.

4. Estimation of WBGT

In the summer 2005, in order to warn the risk of heat stroke and reduce the occurrence of heat stroke, we have experimentally tried to issue WBGT 3-hourly forecast for a day and the next day. As well-known, WBGT in the outside is estimated:

$$WBGT = 0.7*T_w+0.2*T_g+0.1*T_d \qquad (8)$$

Where T_w is wet bulb temperature (deg. C),
T_g is globe temperature (deg. C)
T_d is dry bulb temperature (deg. C)

NWP and statistical forecast made by JMA provides T_d, but T_w and T_g have to be estimated from humidity, wind speed, solar radiation and so on.

Regarding T_w, we can calculate it using the approximate calculation method established by Iribarne, J. V., and W.L. Godson(1981) [6].

On T_g, we can use the statistical equation calculated from the WBGT observation at Tokyo during the summer, 2005.

$$T_g - T_d = 0.017 * S - 0.208*U \quad (9)$$

Where T_g is globe temperature (deg.),

T_d is dry bulb temperature (deg.)

S is a solar radiation(W/m^2),

U is wind speed (m/s).

Fig. 6. An Example of WBGT forecast site

Estimated WBGT is released to the public through the web site (http://www.nies.go.jp/wbgt/) from July to September to experimentally alert people to the risk of heat stroke.

5. Conclusion

Through the observations and theoretical approaches, we roughly estimated WBGT and tried to provide WBGT information to the public. This trial encouraged people to study heat diseases and helped them understand the risk very well. But, unfortunately, we do not have enough data that has been continuously observed for the entire summer and there is no observatory where we can continuously observe globe temperature, wet bulb temperature and dry bulb temperature. Due to the shortage of continuous observation data, we cannot evaluate and improve the expressions and theory. In the summer 2006, we're going to set up permanent observatories in order to collect enough data. And if observational data on WBGT were open to the public, it would help people understand the risk of heat stroke.

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