Heat Stress Standard for Hot Work Environments in Japan

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Abstract: Threshold limit values (TLVs) are intended to protect workers from the severest effects of thermal stress and to establish the exposures to heat in working conditions. Earlier, acute heat strokes often occurred as a result of working in hot environments in Japan. However, acute heat strokes recently sometimes occurred in outdoor work environments such as industrial constructions and agriculture. Seasonal variations in weather are significant and the climatic conditions vary. The criteria are mainly set for working in mines, factories, and so on. WBGT is a useful evaluation index for hot environments; however, it is not commonly used for work practices. WBGT could be calculated and should be commonly used as a standard during summer. Japan mainly has a very hot and humid climate during summer. With regard to the thermal standard for offices, humidity also creates a problem in the indoor thermal conditions. Therefore, it is better to decide the TLVs of the thermal conditions according to seasons and activity levels. Inadequate thermal stress may cause discomfort and adversely affect the performance, safety, and harm to health. Further, thermal factors in the work environment must be measured and evaluated under light workload conditions like deskwork for safety and work efficiency.

Key words: Heat stress, Thermal standard, Work efficiency, Indoor thermal condition

Occurrences of Heat Strokes during Work in Japan

Earlier, acute heat strokes often occurred as a result of working in hot environments in Japan. The number of heat stroke occurrences, according to the statistics provided by the Ministry of Health, Labor and Welfare, categorized as on-the-job diseases was annually reported to be above 100 in 1955; most of these occurrences were diagnosed in the mining industry. In 1965, this number decreased rapidly with closing mines and coal mines and improvements in the workplace environment, such as air conditioning. However, after these events, acute heat strokes sometimes occurred in outdoor work environments such as industrial constructions and agriculture¹⁾.

The occurrences of heat strokes during outdoor work were related to the weather conditions such as heat waves and geographical features such as inland areas or basins; the influences of these features on the climate were significant.

During intensely hot or cool summers, agriculture production or electricity consumption had a considerable social influence throughout Japan.

Based on newspaper reports regarding the heat stroke situation in Japan, the percentage of occurrences of heat strokes during work was 28.9%; daily life activities, 38.4%; and exercising, 32.7%. Occurrences of heat strokes during outdoor work such as agriculture were observed mostly in persons older than 65 years and during daily life activities^{2,3)}.

According to the database of the Fire Defense Agencies in the Fukushima prefecture regarding the emergency transportation records from 1991 to 1995, a total of 435 cases of heat strokes and dehydrations were recorded; 193 of these cases (44.4%) were recorded in August and 155 of these cases (35.6%) in July. 18.6% of these heat disorders occurred during labor activities (outdoor work, agriculture, etc.), 26.9% during daily life activities, 33.5% during sports activities, and so on. A number of heat disorders in the elderly—in the seventies [67 cases (15%)] and eighties [78

cases (18%)—were diagnosed in rural areas; however, the number of cases diagnosed for children under 10 years of age and people in their fifties were fewer in the rural areas: 20 cases (4.6%) and 34 cases (7.8%) were reported, respectively (Fig. 1). The discomfort index is calculated from the air temperature and wet-bulb temperature. A large number of heat disorder cases at discomfort indexes of 80–84 and above 85 ranges were recorded: 169 (39%) and 134 (31%), respectively.

A number of midsummer days—days with a maximum daily temperature of above 30°C—occurred from May to September; they occurred frequently in July and August⁴. A significant positive correlation was found between the number of midsummer days and the cases of heat disorders in each month.

The typical workplaces that involve hot environments are blast furnaces, cupolas, and indoor workshops used for melting glass. Usually, a workshop environment is considered significantly hot when it has a dry-bulb air temperature exceeding 40°C, wet-bulb air temperature exceeding 32.5°C, glove temperature exceeding 50°C, or effective temperature exceeding 32.5°C⁵.

Based on the data that related the thermal conditions with deaths due to heat strokes, an air temperature of around 40°C is considered to be safe for dry conditions such as those with humidity less than 10%. However, the conditions become severe for work even for an air temperature of around 27°C in humid conditions with a relative humidity of near 100%⁶. Therefore, a correlation is evident between the occurrence of heat strokes and humidity in hot work environments.

Natural or Artificial Thermal Conditions

Japan is an island country with the following main islands: Hokkaido is the northern island, Honshu is the main island, Shikoku is in the Inland Sea, and Kyushu is the southern island. From Hokkaido to Okinawa islands, Japan stretches from the latitudes 46° to 24°. In Japan, seasonal variations in weather are significant and the climatic conditions vary.

Figure 2 shows the climograph of the selected cities in Japan and the world: Tokyo in Honshu, Sapporo in Hokkaido, Naha in Okinawa Island, London in U.K., Montreal in Canada, and San Jose in Costa Rica. In the figure, the number indicates the month. In Naha, the average annual air temperature was 22.7°C and the monthly average air temperatures ranged from 16.6°C in January to 28.5°C in July. The average annual humidity was 75% and the monthly average humidity ranged from 68% in December to 84% in

Fig. 1. Occurrences of heat strokes from 1991 to 1995 in Fukushima prefecture⁴.

Fig. 2. Climograph of Tokyo, Sapporo, Naha, London, Montreal and San Jose.

June. In Sapporo, the average annual air temperature was 8.5°C and the monthly average air temperatures ranged from -4.1°C in January to 22.0°C in August. The average annual humidity was 70% and the monthly average humidity ranged from 63% in April to 77% in July and August. In Tokyo, the average annual air temperature was 15.9°C and the monthly average air temperatures ranged from -4.1°C in January to 27.1°C in August. The average annual humidity was 63% and the monthly average humidity ranged from 50% in January to 75% in July. Generally, the climate of Japan is hot and humid during summer and cool and dry during winter. Further, the climate of London is generally

humid and has a neutral temperature. The climate of San Jose is constantly warm throughout the year and has dry and wet seasons. The climate of Montreal is cold and moderately humid during winter^{7,8)}.

Hot climatic conditions in summer directly influence the occurrence of diseases such as heat strokes and dehydration. Further, seasonal climatic conditions are indirectly related to the risk factors of diseases such as Japanese encephalitis and malaria. People living in rural areas are accustomed with the natural conditions, and they are sometimes exposed to severe weather conditions. On the other hand, most people in urban areas are accustomed with artificial conditions; they have access to air-conditioning systems during hot seasons, resulting in frequent occurrences of cooling disorders.

Using the vital statistics of the seasonality of monthly deaths in Japan, the death rate due to infectious diseases showed two peaks earlier—one in summer and one in winter. Also, a second peak was observed in summer (August and July). In 1950, a similar tendency to that in 1947 was observed. In summer, gastrointestinal diseases, infectious diseases, Japanese encephalitis, and so on were commonly diagnosed. According to the seasonal disease calendar from 1906 to 1910, the death rates due to digestive diseases such as dysentery, diarrhea, and inflammation of the intestine and other diseases such as beriberi, tuberculosis, and whooping cough were higher in summer. After 50 yr, from 1957 to 1961, the death rate only from dysentery was high in summer. In recent year, deaths from many diseases were common in winter, with the exception of malignant neoplasm, infectious diseases and suicide. The death rate from suicide was higher from March to July and lower in winter. There were many suicides in the generation over 45 yr old, especially males^{9,10)}.

Overexposure to a certain range of ultraviolet rays is one of the undisputed causes of skin cancer. In this case, people have an increased chance of being exposed to cancer-inducing ultraviolet irradiation during summer. Ultraviolet radiation is beneficial to life in moderation, but harmful in excess¹¹⁾.

Mortalities from seasonal diseases or meteorological factors are associated with the environmental conditions. Physical conditions such as light, temperature, pressure in natural or artificial climates, and mental and social conditions such as culture and economy can be associated in the form of a single factor or a complex set of factors.

Thermal Standards for Work Environment

In Japan, the heat and cold stress threshold limit values (TLVs) are decided by the Society for Occupational Health and the thermal standard for offices is decided by the Ministry

of Health, Labor and Welfare.

TLVs are intended to protect workers from the severest effects of thermal stress and to establish the exposures to heat in working conditions under which nearly all the workers can be repeatedly exposed to without any adverse health effects.

Table 1 shows the criteria for the occupational exposure limits for heat stress in Japan¹²⁾. These criteria are described for healthy male workers, who were acclimatized and wore normal working clothes for summer as well as drank adequate salt water with a salt concentration of around 0.1%. The working period was either continuous for one hour or intermittent for two hours. These criteria are mainly set for working in mines, factories, and so on. The assessment of heat stress can be used for evaluating the risk to workers with regard to safety and health. As the heat stress approaches the human tolerance limits, the risk of heat-related disorders increases.

At high environmental temperatures, the addition of a vapor-impermeable clothing barrier may significantly increase the heat stress for the individual wearer and heat exhaustion may rapidly occur.

The wet bulb glove temperature index (WBGT) provides a useful, first-order index of the environmental contribution to heat stress; it is influenced by air temperature, radiant heat, and humidity^{13,14)}.

WBGT values are calculated using one of the following equations:

- Direct exposure to sunlight:

$$\text{WBGT out} = 0.7\text{Tnwb} + 0.2\text{Tg} + 0.1\text{Tdb}$$
- Without direct exposure to sunlight:

$$\text{WBGT in} = 0.7\text{Tnwb} + 0.3\text{Tg}$$

In the above equations, Tnwb denotes the natural wet-bulb temperature; Tg, the glove Temperature; and Tdb, the dry-bulb air temperature.

Generally, the relative metabolic rate (RMR) is used as the workload unit for occupational health in Japan¹²⁾. RMR is calculated as follows:

$$\text{RMR} = \frac{\text{Energy at work} - \text{Energy at rest}}{\text{Basal metabolic energy}}$$

Where, the basal metabolic energy is calculated using the body surface area (m²), which is calculated using the body weight (kg) and body height (cm). The “very light” workload categories are those categorized as RMR 1 and below. Examples of activities in this category are car driving and

Table 1. Occupational exposure limits (OELs) for heat stress in Japan¹²⁾

Work Load	OELs	
	WBGT (°C)	CET** (°C)
RMR*-1 (Very light, -130 kcal/h)	32.5	31.6
RMR -2 (Light, -190 kcal/h)	30.5	30.0
RMR -3 (Moderate, -250 kcal/h)	29.0	28.8
RMR -4 (Moderate, -310 kcal/h)	27.5	27.6
RMR -5 (Heavy, -370 kcal/h)	26.5	27.0

*: Relative Metabolic Rate (RMR) = (Metabolic energy expenditure during work—Metabolic energy expenditure at rest)/Basal metabolic rate corresponding to the work period.

**: Corrected effective temperature.

deskwork such as writing. The “light” workload categories are those categorized as RMR 1–2. Examples of activities in this category are those that involve standing work during like a watching operation or walking at about 45 m/min. The “moderate” workload categories are those categorized as RMR 2–3. Examples of activities in this category are walking at 70–95 m/min or cleaning a floor. The “slight heavy” workload categories are those categorized as RMR 3–4. Examples of activities in this category involve cycling at about 170 m/min or using a grinder. The “heavy” workload categories are those categorized as RMR 4–5. Examples of activities in this category are sawing by hand or riveting.

In Japan, the workload is mostly categorized as RMR 1–2 with regard to automation or mechanization. A worker with a workload of RMR 4 can work continuously for one hour, whereas that with a workload of above RMR 4 may work intermittently. For example, the TLVs indicate that a “light” workload categorized as RMR 1–2 requires an environment with a WBGT of 30.5°C (Table 1).

Table 2 shows the criteria with regard to environmental conditions for office buildings in Japan. The thermal standard for offices is intended for office workers to work safely and comfortably. The air temperature in office buildings is 17–28°C. The relative humidity is 40–70% and the air velocity is below 0.5 m/s^{15, 16)}.

Japan mainly has a very hot and humid climate during summer. With regard to the thermal standard for offices, humidity also creates a problem in the indoor thermal conditions. Therefore, it is better to decide the TLVs of the thermal conditions according to seasons and activity levels.

WBGT is a useful evaluation index for hot environments; however, it is not commonly used for work practices in Japan. The air and wet-bulb temperatures were commonly used in Japan; therefore, the effective temperature was introduced along with these factors. Further, the glove temperature

was useful in radiant heat environments; therefore, the corrected effective temperature (CET) was introduced along with the glove and wet-bulb temperatures¹²⁾. CET is calculated from the following equation:

$$\text{CET} = 0.786\text{WBGT} + 6.0 \text{ (°C)}$$

The meteorological observatories and weather stations in Japan record the air temperature, wet-bulb temperature, and wind velocity as the thermal factors. It is preferable to measure the glove temperature. Therefore, the WBGT value could be calculated and should be commonly used as a standard during summer in Japan.

Weather information is useful in summer in order to prevent heat disorders. In this case, the weather is variable; it can be temporarily sunny, cloudy, or rainy. Therefore, only one equation may be sufficient for the calculation of WBGT values, that is, $\text{WBGT} = 0.7T_{\text{nw}} + 0.2T_{\text{g}} + 0.1T_{\text{db}}$. Without any direct exposure to sunlight, the glove temperature almost becomes the same as the dry-bulb air temperature. Further, the wind velocity should be included for the evaluation of the environment.

Safety, Work Efficiency, and Thermal Environment

Thermal stress during work is the net thermal load that a worker may be exposed to the combined contribution of metabolic cost of work, environmental factors (air temperature, humidity, air velocity, and radiant heat exchange), and clothing requirements. Inadequate thermal stress may cause discomfort and adversely affect the performance, safety, and harm to health. Occupational exposure to hot and cold environments may have an adverse effect on the performance, health, and comfort of the workers. Such thermal conditions are observed in several outdoor jobs and indoor works. Hot working conditions are regarded as one of the main causes of accidents, illnesses, and other health problems.

Hard work or training under hot conditions has led to a marked increase in heat casualties and heat disorders, such as heat exhaustion, heat stroke, and heat syncope, often in combination with dehydration. The most serious consequence of exposure to intense heat is heat stroke, which may be fatal. It is caused by a sudden collapse in temperature regulation, leading to a marked increase in the heat content of the body. The rectal temperature may be 40°C or higher^{17, 18)}.

The relationships between the heart rate and core body temperature were discussed, and the regression lines for body

Table 2. Threshold limit values of environmental condition at office building in Japan¹⁶⁾

Item	Standard at present	Comfort standard (propose)		
Air temperature	17–28°C	summer	sitting work	24–27°C
		winter	standing work	20–25°C
Air velocity	<0.5 m/s			18–20°C
Humidity	40–70%			<0.5 m/s
CO ₂	office with central air conditioning system <0.1%			50–60%
	office without central air conditioning system <0.5%			<0.1%
CO	10 ppm, 50 ppm			<10ppm
Ambient dust	<0.15 mg/m ³			<0.15 mg/m ³
Air volume	10 m ³ /person			10–13 m ³ /person
Ventilation air volume	–			30 m ³ /person/h

Fig. 3. The mean values of scores and errors of the one-digit-addition test at 5 min and 90 min according to different vertical air temperatures (N = 6)²⁰⁾.

temperature on the heart rate were formulated for work safety^{19, 20)}.

At high environmental temperatures, the addition of a vapor-impermeable clothing barrier significantly increases the heat stress for the individual wears and heat exhaustion occurs rapidly²⁰⁾.

Heart disorders, resulting due to thermal stress would occur during transit, where the workers move from the hot workplace to a cool place for relaxation. Workers suffering from heart diseases, abnormalities in the ECG, hypertension, and so on require to consider the thermal conditions,

particularly elderly people who would have heart disorders or blood circulation problems. Workers must undergo regularly health checkups.

During deskwork, with regard to the relationship of peak performance at a certain level of arousal, deterioration in performance either at low or high arousal levels occurred; the arousal levels reduced comfort and the hot temperatures affected the performance. The paradox of improving instead of deteriorating the mental performance under certain thermal stress levels is explained by the inverted U-shaped relationship between arousal and performance. Comfortable conditions reduced the arousal level. Slightly uncomfortable air temperature or humidity elevated arousal, which improved the performance. This has been observed in many task performances such as arithmetic visual judgments, auditory performance, skill, and reaction time. Increasing or decreasing the ambient temperature eventually increased the arousal level beyond its optimum value to a range where the performance deteriorated. The strain of increasing or decreasing the body temperature, which became over-arousing after a period of time, resulted in a reduction in the performance¹⁹⁾.

The upper body of the subject was exposed to air temperatures of 15°C, 20°C, 25°C, 30°C, or 35°C, whereas the lower part was subjected to a constant air temperature of 30°C. Slight differences were observed between the values at 5 min and 90 min in the scores of the one-digit-addition test for the upper-body air temperatures of 15°C and 20°C. However, the values at 90 min were lower than those at 5 min at the upper-body air temperatures of 25°C, 30°C, and 35°C. The scores decreased with an increase in the upper-body air temperature, particularly at 90 min. The number of errors was slightly greater at 5 min at an upper-body air temperature of 25°C (Fig. 3). The values of discomfort

sensation at 5 min and 90 min at the upper-body air temperatures of 20°C, 25°C, and 30°C were similar; however, the values at 90 min at the upper-body air temperatures of 15°C and 35°C were greater than that at 5 min; in other words, there was an increase in the amount of discomfort. Mildly uncomfortable ambient conditions, where the upper-body air temperatures were cool and lower-body air temperatures were warm, improved the performance; however, at an upper-body air temperature of 35°C, the performance deteriorated as the subjects felt uncomfortable and hot²¹⁾.

With regard to work practices in severe conditions, the workers should be under protective observation such as a buddy system or supervision, and the workers should be instructed with regard to safety and health procedures. Further, thermal factors in the work environment must be measured and evaluated under light workload conditions like deskwork for safety and work efficiency.

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