Assessment of Heat Strain in Workers Wearing PPE
工人穿著個人防護裝備時的熱應變評估

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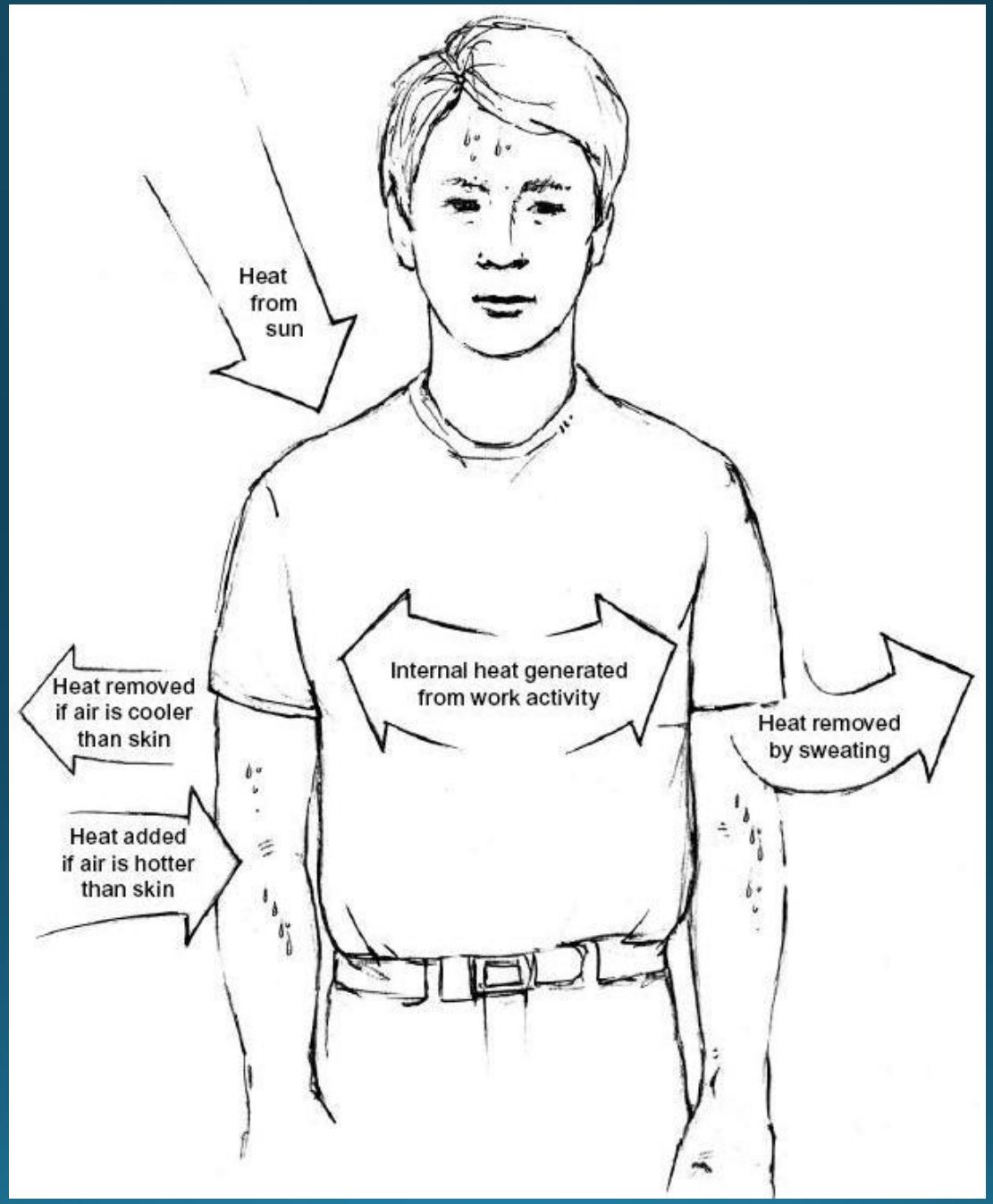
Heat balance
熱平衡



Heat balance 熱平衡

$$S = (M\text{-}W) \pm C_{res} \pm E_{res} \pm K \pm C \pm R - E$$

- S: Heat storage in body 人體蓄熱率 ($W \cdot m^{-2}$)
- M: Metabolic rate 新陳代謝率
- W: Mechanical work done by body 人對外做的機械功
- C_{res}: Respiratory convection heat flow 呼吸對流熱交換
- E_{res}: Respiratory evaporation heat flow 呼吸蒸發熱交換
- K: Conduction heat flow 傳導熱交換
- C: Convection heat flow 對流熱交換
- R: Radiation heat flow 輻射熱交換
- E: Evaporative heat loss 蒸發熱損失

Sources: EN 12515:1997

WBGT 綜合熱溫度指數

ISO 7243-1989

- For indoor 室內環境

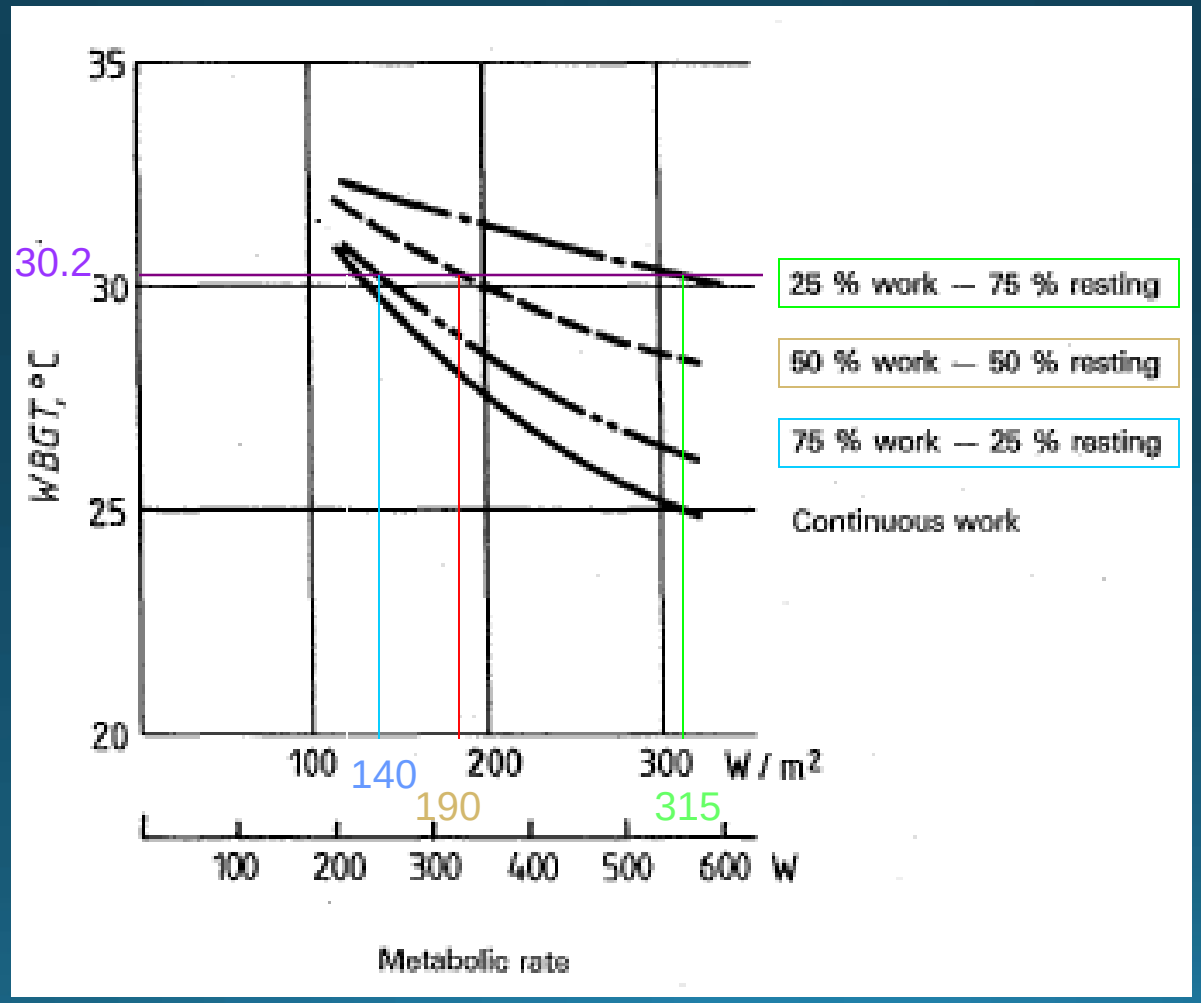
$$WBGT = 0.7NWB + 0.3GT$$

- For outdoor 戶外環境

$$WBGT = 0.7NWB + 0.2GT + 0.1DB$$

  - NWB: Nature wet bulb 自然濕球溫度
  - GT: Globe bulb 黑球溫度
  - DB: Dry bulb 乾球溫度

WBGT work resting cycles
工作休息時間參考曲線



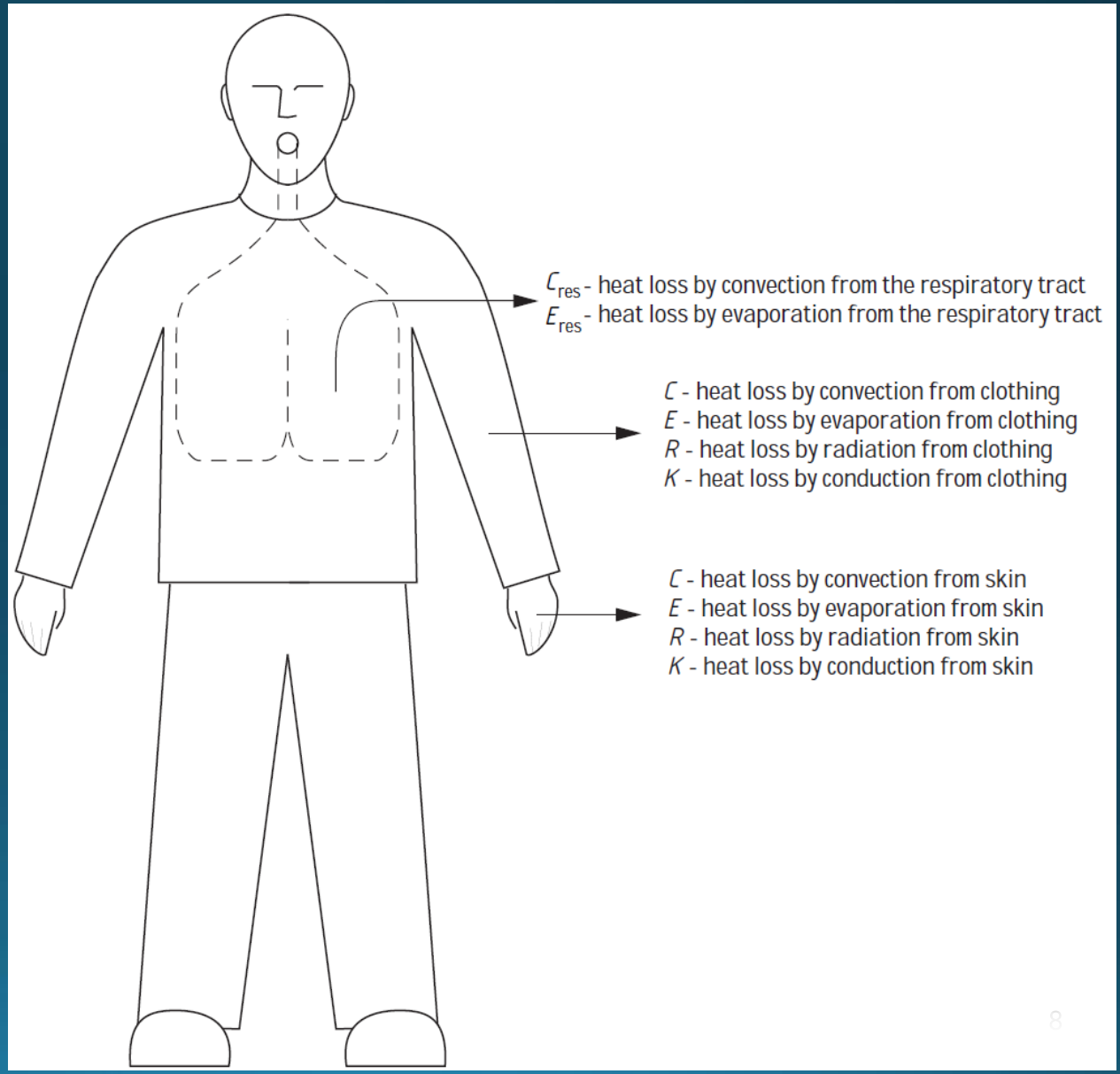
How the body cools itself
身體是如何調節溫度

- Humans loose heat primarily in 2 ways: Radiation and Evaporation (vaporization of sweat) 人體主要通過2個途徑釋放熱量：輻射和蒸發(汗水的蒸發)
- When the air temperature is 21°C or less, the body releases its heat by radiation 當氣溫在21°C或以下時，身體是通過輻射來釋放熱量
- As the air temperature rises, heat loss through radiation is greatly reduced 當氣溫升高時，輻射的熱量就會大大減少
- That leaves evaporation as the only way to effectively control body temperature 這時，蒸發就是唯一有效控制體溫的方法

Heat stress 熱壓力

- When human thermal environments cause a tendency for a rise in body heat storage, the body is in a state of heat stress. There are six basic factors that can contribute to heat stress 當人在熱環境中導致身體有儲熱的趨勢時，身體便處於熱應激狀態。有六個基本因素可導致熱應激。
  - Air temperature 空氣溫度
  - Mean radiant temperature 平均輻射溫度
  - Humidity 濕度
  - Air velocity 空氣速度
  - Thermal properties of clothing 衣服的熱特性
  - Metabolic rate 代謝率

Routes of heat loss from the body 人體熱量散失的途徑



Sources: BS 7963:2000

Effect of PPE on heat balance 個人防護裝備對熱量平衡的影響

- Metabolic rate can be increased by the weight of the PPE or by the restrictions it imposes on the movement of the wearer 個人防護裝備的重量或限制了使用者的動作都會增加代謝率。
- Convection and evaporation in the respiratory tract can be affected by the temperature and humidity of air breathed, e.g. through breathing apparatus (BA) or respiratory protective equipment (RPE) 呼吸道中的對流和蒸發會受到呼吸空氣的溫度和濕度的影響，例如通過呼吸設備（BA）或呼吸防護設備（RPE）。

Effect of PPE on heat balance 個人防護裝備對熱量平衡的影響

- Convection from the skin can be affected by the amount of the body covered by PPE and by its thermal insulation properties. In general, the greater the proportion of the body which is covered and the greater the insulation provided by the PPE, the less is the heat loss by convection 來自皮膚的對流會受到個人防護裝備覆蓋的身體的數量及其隔熱特性的影響。通常，被覆蓋的人體比例越大，個人防護裝備所提供的隔熱效果越好，對流產生的熱損失就越少。

Effect of PPE on heat balance 個人防護裝備對熱量平衡的影響

- Evaporation from the skin can be affected by the amount of the body covered by PPE, by its thermal insulation properties, and by its evaporative resistance 個人防護裝備覆蓋的皮膚面積、隔熱性能以及蒸發阻力均會影響到汗液的蒸發。
- Evaporation of sweat from the skin is usually the most effective method of cooling the body 蒸發皮膚上的汗液是冷卻身體的最有效方法。
- In general, the more of the body covered and the greater the thermal insulation and evaporative resistance of the PPE, the less is the heat loss by evaporation 當覆蓋的皮膚越多，個人防護裝備的隔熱性和蒸發阻力越大，則蒸發降溫的效果就越差。

Analysis of work situations 作業情況分析

- In any work situation in which it is thought there could be a risk of heat strain for workers wearing PPE 在任何認為PPE工人都可能存在熱應激的作業情況下
  A. Thermal environment 熱環境
  B. Metabolic rate 新陳代謝率
  C. Effect of PPE 個人防護裝備的作用

A. Thermal environment 熱環境

- Air temperature 空氣溫度
- Air velocity 氣流速度
- Humidity 濕度
- Radiant temperature 幅射溫度

B. Metabolic rate 新陳代謝率

- Heat is constantly produced by the body (metabolic heat) 人體不斷產生熱量（代謝熱）。
- The rate of metabolic heat production varies with the physical activity, and can be measured or estimated (ref EN 28996) 代謝熱產生的速率隨身體活動而變化，可以測量或估算（參考EN 28996）。

B. Metabolic rate 新陳代謝率

- Following table gives estimates of metabolic rates for physical activities typical of those carried out in industry 下表給出了作業活動中的典型代謝率估算值。
- These values assume that the worker wears a standard working garment, and are derived from those given in EN 27243:1994 這些值是假設了工人穿著EN 27243：1994中給出的標準工作服。

Metabolic rate class	Typical metabolic rate		Examples of typical industrial activities
	Rate per unit area of body surface $W \cdot m^{-2}$	Total rate of heat production (see note 1) W	
0 Resting	65	115	Resting
1 Low metabolic rate	100	180	Sitting or standing; inspecting or monitoring hot processes; walking in easily accessible areas; very light assembly operations; light control operations (e.g. buttons, hand-wheels)
2 Moderate metabolic rate	165	295	Carrying or stacking light items; operating heavy controls (e.g. opening valves); cleaning or clearing light debris, spillages etc.; walking in congested areas (e.g. limited head room); heavy welding
3 High metabolic rate	230	415	Intense arm and trunk work; pushing or pulling heavily loaded cages or pallet trucks; heavy manual handling; clearing heavy debris (e.g. cleaning and relining reactor vessels)
4 Very high metabolic rate	290	520	Very intense activities at fast to maximum pace (e.g. intense shovelling); heavy assembly or building work; climbing stairs or ladders rapidly. Work in this category can rarely be sustained for long periods without a break (see note 2)

C. Effect of PPE 個人防護裝備的作用

a. Increase in metabolic rate due to wearing PPE 穿著個人防護裝備增加了新陳代謝率
b. The thermal insulation of the material covering the body 覆蓋材料的隔熱
c. The evaporative resistance of the material covering the body 覆蓋材料的蒸發阻力
d. Closure of garments to the body 覆蓋身體的衣服
e. The proportion of the body covered 身體覆蓋的比例
f. Respiratory protective equipment 呼吸防護裝備

PPE item	Increase in metabolic rate due to wearing PPE $W \cdot m^{-2}$				
	Resting	Low metabolic rate	Moderate metabolic rate	High metabolic rate	Very high metabolic rate
Safety shoes/short boots	0	5	10	15	20
Safety boots (long)	0	10	20	30	40
Respirator (low/moderate performance, e.g. P1, P2, see note 2)	5	10	20	30	40
Respirator (high performance, e.g. P3, see note 2)	5	20	40	60	80
Self-contained breathing apparatus	10	30	60	95	125
Light, water vapour permeable chemical coverall (e.g. disposable)	5	10	20	30	40
Chemical protective water vapour impermeable ensemble [e.g. polyvinyl chloride (PVC)] with hood, gloves and boots	10	25	50	80	100
Highly insulating, water vapour semi-permeable ensemble (e.g. firefighters' gear consisting of helmet, tunic, over trousers, gloves and boots)	15	35	75	115	155

The thermal insulation of the material covering the body 覆蓋材料的隔熱

- The non-evaporative heat loss (convection, radiation and conduction) from the parts of the body covered by clothing takes place from the skin surface through the clothing and trapped air layers to the outer clothing surface 衣服所覆蓋身體各部位的非蒸發熱損失（對流、輻射和傳導）指從皮膚表面穿過衣服並被空氣層捕獲到衣服的外面。
- The resistance to this heat flow is expressed as the thermal insulation of the clothing, I_{cl}, measured in *clo* 對這種熱流的阻力為衣服的隔熱系數I_{cl}，以 *clo* 為單位。

The thermal insulation of the material covering the body 覆蓋材料的隔熱

- I_{cl} values for different types of clothing ensembles are given in ISO 9920:1995 & values for typical workwear are given in BS 7963:2000
ISO 9920：1995中給出了不同類型服裝的 I_{cl} 值，BS 7963：2000中列出了典型工作服的 *clo* 值。
- The standard working garment defined in EN 27243:1994 has a thermal insulation of 0.6 *clo* 在 EN 27243：1994中定義了標準工作服的隔熱值為 0.6 *clo*。
- Most ensembles incorporating PPE are likely to have a higher I_{cl} 大多數個人防護裝備的組合會有更高的 I_{cl}。

The proportion of the body covered 身體覆蓋的比例

- The proportion of the body that is covered by PPE affects the heat strain experienced by the individual 個人防護裝備的覆蓋比例會影響每個人的熱應變。
- Following table can be used to determine the proportion of the body covered by different garments 下表可用於確定不同衣服覆蓋的身體比例

The proportion of the body covered 身體覆蓋的比例

Garment 衣服	% of body covered 覆蓋比例
Helmet/hat 頭盔/帽子	4
Hood/balaclava/cowl 頭巾/頭套/斗篷	7
Respirator face piece 呼吸器面罩	3
Vest 背心	30
Short sleeved top 短袖上衣	35
Long sleeved top長袖上衣	45
Long sleeved top with Hood 長袖連帽上衣	60
Long sleeved top and trousers (boiler suit) 連帽工作服	80
Shorts 短褲	25
Trousers 長褲	45
Gloves 手套	5
Shoes 鞋	7

The proportion of the body covered 身體覆蓋的比例

- When multiple garments are worn, they can overlap, for example when trousers or shorts are worn with a top, the total coverage is not the sum of the individual items worn 當穿多件衣服時，它們可能會重疊，例如，穿褲子或短褲及上衣時，總覆蓋率不是所穿物品的總和。
- The overlap between a top and trousers or shorts is approximately 10 %, i.e. the total body coverage of a vest and shorts is approximately 45 %; and of a long sleeved top and trousers is approximately 80 % 上衣與褲子或短褲之間的重疊率約為10%，即背心和短褲的全身覆蓋率約為45%；長袖上衣和褲子的比例約為80%。

Respiratory protective equipment 呼吸防護裝備

- Further information on the amount of the body covered by different clothing ensembles is given in ISO 9920:1995 ISO 9920:1995 中提供了更多由不同服裝集合覆蓋的身體數量的信息。
- If there is a supply of breathing air to a worker wearing PPE, limited body cooling can be provided by evaporation of water from the lungs, and by convective heat loss from the surface of the lungs 如向使用個人防護裝備的工人提供呼吸空氣，則可利用肺部水份的蒸發和肺部的對流熱來有限度地冷卻身體。

The individual 個別因素

- The physiological response of an individual to heat stress depends on a number of factors, such as age, gender, degree of heat acclimatization, physical fitness, obesity, medical condition and treatments, previous heat illness, chronic skin disorders (rashes etc.), habitual alcohol/drug abuse, and minor illnesses. Further advice, and questionnaires for use in assessing medical fitness and details of undertaking a medical fitness assessment are given in ISO/DIS 12894 一個人對熱應激的生理反應取決於許多因素，如年齡、性別、熱適應程度、健康程度、肥胖症、醫療狀況和治療方法、之前的熱疾病、慢性皮膚病（疹子），酗酒/吸毒和輕微疾病。ISO / DIS 12894 中提供了進一步的建議以及用於評估醫療適應性的調查表以及進行醫療適應性評估的詳細信息。