

M502: THERMAL ENVIRONMENT

STUDENT CALCULATION EXERCISES - ANSWERS

SECTION A – HEAT STRESS

QUESTION 1

Using the appropriate psychrometric chart use the dry bulb and wet bulb temperature to obtain the relative humidity of 40%.

The dew point temperature can be obtained directly from the psychrometric chart by reading the temperature on the wet bulb scale where the dry bulb and wet bulb scales intersect the relative humidity scale, using this approach the t_{dp} is approximately 14.7°C.

Alternatively it can be calculated using the formula on page 58 of the Student Manual.

$$\begin{aligned} P_a &= 24^* - 0.667 (30 - 20) \\ &= 17.33 \end{aligned}$$

$$\begin{aligned} t_{dp} &= \frac{4030.18}{18.956 - \ln 17.33} - 235 \\ &= \frac{4030.18}{16.106} - 235 \\ &= 15.2^{\circ}\text{C} \end{aligned}$$

The relative humidity can be calculated from

$$\begin{aligned} \text{RH} &= \frac{P_a}{P_{sa}} \times \frac{100}{1} \\ &= \frac{17.33}{43^*} \\ &= 40.3\% \end{aligned}$$

* Obtained from psychrometric chart in mb

QUESTION 2

Using the nomogram for normal corrective effective temperature, draw a line between the dry and wet bulb temperatures. Where the line crosses the appropriate velocity line (0.5 ms^{-1}) read the corrected effective temperature from the scale.

Answer = 24°C

To obtain the normal corrective effective temperature use the same nomogram but replace the dry bulb temperature with the globe temperature.

Answer = 28°C

QUESTION 3

To obtain the appropriate data to insert into the calculation, follow the steps on page 106 of the Student Manual.

Step 1: As $t_g \neq t_a$, increase the wet bulb as described:

$$\begin{aligned}\text{Wet bulb} &= 0.4 (40 - 30) \\ &= 4^{\circ}\text{C}\end{aligned}$$

$$\begin{aligned}\therefore \text{Corrected wet bulb} &= 20 + 4 \\ &= 24^{\circ}\text{C}\end{aligned}$$

Step 2: Correct the wet bulb temperature for the appropriate metabolic workrate.

As the activity is described as moderate, the approximate metabolic workrate is 192 Wm^{-2} (Table 7.1).

$$\begin{aligned}\text{Corrected wet bulb} &= 24^{\circ}\text{C} + 3.3 \\ &= 27.3\end{aligned}$$

Step 3: Correct the wet bulb temperature for clothing.

$$\begin{aligned}\text{Corrected wet bulb} &= 27.3 + 1.5 \times 0.5 \\ &= 27.3 + 0.75 \\ &= 28.1^{\circ}\text{C}\end{aligned}$$

Step 4: Using the nomogram for P4SR, obtain the “Basic 4-hour Sweat Rate (B4SR)” by drawing a line between the corrected wet bulb and the globe temperature.

$$\text{B4SR} = 1.2 \text{ litres}$$

Step 5: Calculate the P4SR using the equation on page 107 of the Student Manual.

$$\begin{aligned}\text{P4SR} &= 1.2 + 0.37 \times 0.5 + (0.012 + 0.001 \times 0.5) (192 - 63) \\ &= 1.2 + 0.185 + 1.61 \\ &= 3.0 \text{ litres}\end{aligned}$$

As the P4SR is 3.0 litres and it is assumed that this situation is one of regular exposure, the sweat rate is the maximum value of 3 litres. Consequently, measures should be taken to reduce the heat strain of the individuals involved.

QUESTION 4

Calculate the WBGT from the appropriate formula. As there is no solar load this is

$$\begin{aligned}\text{WBGT} &= 0.7 \text{ NWB} + 0.3 \text{ GT} \\ &= 0.7 \times 20 + 0.3 \times 40 \\ &= 14 + 12 \\ &= 26^{\circ}\text{C}\end{aligned}$$

Reference to the ACGIH screening criteria indicates this situation to be below the TLV for moderate work.

QUESTION 5

Calculate the HSI from the appropriate formula on page 112 of the Student Manual
($HSI = E_{req} / E_{max} \times 100$)

$$\begin{aligned} C &= 4.6 (0.5)^{0.6} (35 - 30) \\ &= 15.17 \text{ Wm}^{-2} \text{ (clothed)} \end{aligned}$$

$$\begin{aligned} R &= 4.4 (35 - 52) \\ &= 4.4 (-17) \\ &= -74.8 \text{ Wm}^{-2} \text{ (clothed)} \end{aligned}$$

$$\begin{aligned} E_{req} &= M - R - C \\ &= 192 - (-74.8) - 15.7 \\ &= 251 \text{ Wm}^{-2} \end{aligned}$$

$$\begin{aligned} E_{max} &= 7 v^{0.6} (56 - P_a) \\ &= 7 (0.5)^{0.6} (56 - 17.3) \\ &= 7 \times 0.66 \times 38.7 \\ &= 179 \text{ Wm}^{-2} \end{aligned}$$

$$\begin{aligned} \therefore HSI &= \frac{251}{179} \times \frac{100}{1} \\ &= 140 \end{aligned}$$

(Obtain water vapour pressure P_a in mb from relative humidity psychrometric chart by reading off the value equivalent to where the wet and dry bulb temperatures intersect the relative humidity chart. Alternatively use the value calculated in Question 1 as part of the calculation of the dew point)

As the HSI is >100, exposure time is limited by a rise in core body temperature.

$$\begin{aligned} \text{Allowable exposure time} &= 2440 / (E_{req} - E_{max}) \\ &= \frac{2440}{72} \\ &= 34 \text{ minutes} \end{aligned}$$

SECTION B – COLD STRESS

QUESTION 1

$$\begin{aligned}
 WCI &= 1.16 (10 \sqrt{4.2 + 10.45 - 4.2}) (33 - -30) \\
 &= 1.16 (10 \times 2.05 + 6.25) (63) \\
 &= 1.16 \times 26.75 \times 63 \\
 &= 1955 \text{ Wm}^{-2}
 \end{aligned}$$

Effect would be that exposed flesh freezes within one hour.

QUESTION 2

$$\begin{aligned}
 t_{ch} &= 33 - \frac{1955}{25.5} \\
 &= 33 - 76.7 \\
 &= -43.7^{\circ}\text{C}
 \end{aligned}$$

QUESTION 3

According to the ACGHI TLV's an air temperature of -30°C and a wind speed of 4.2 ms^{-1} (15 km/hr) would indicate that a maximum work period of 55 minutes with 3 warm up periods is appropriate.