

# The Application of a Rational Heat Stress Index (Thermal Work Limit) to Sports Medicine

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# Heat Transfer

- Conduction: solid to solid
- Radiation: bodies at different temperatures
- Convection: solid to fluid (liquid or gas)
- Evaporation: heat and mass transfer



# Environmental Factors Governing Human Heat Transfer

- Dry bulb (DB) temperature
- Wet bulb (WB) temperature
  - Natural Wet bulb (NWB)
- Wind speed (WS)
  - True versus Relative wind speed
- Mean radiant temperature (MRT)
  - Globe temperature (GT)
- Barometric pressure



# Human thermal comfort / thermal stress

- Thermal *comfort* related more to DB
  - Heat exchange is mostly convection
  - Convection is dry (sensible) heat exchange
- Thermal *stress* related more to WB and WS
  - Heat exchange is mostly evaporation
  - Evaporation is latent (insensible) heat exchange
- Evaporation of sweat not sweating *per se* results in cooling



# Clothing & Posture Factors Governing Human Heat Transfer

- Thermal insulation
  - Most quoted values are dry clothing
  - Heat stress results in saturated clothing
- Clothing vapour permeation
- Posture factor (View factor) affects radiation heat transfer

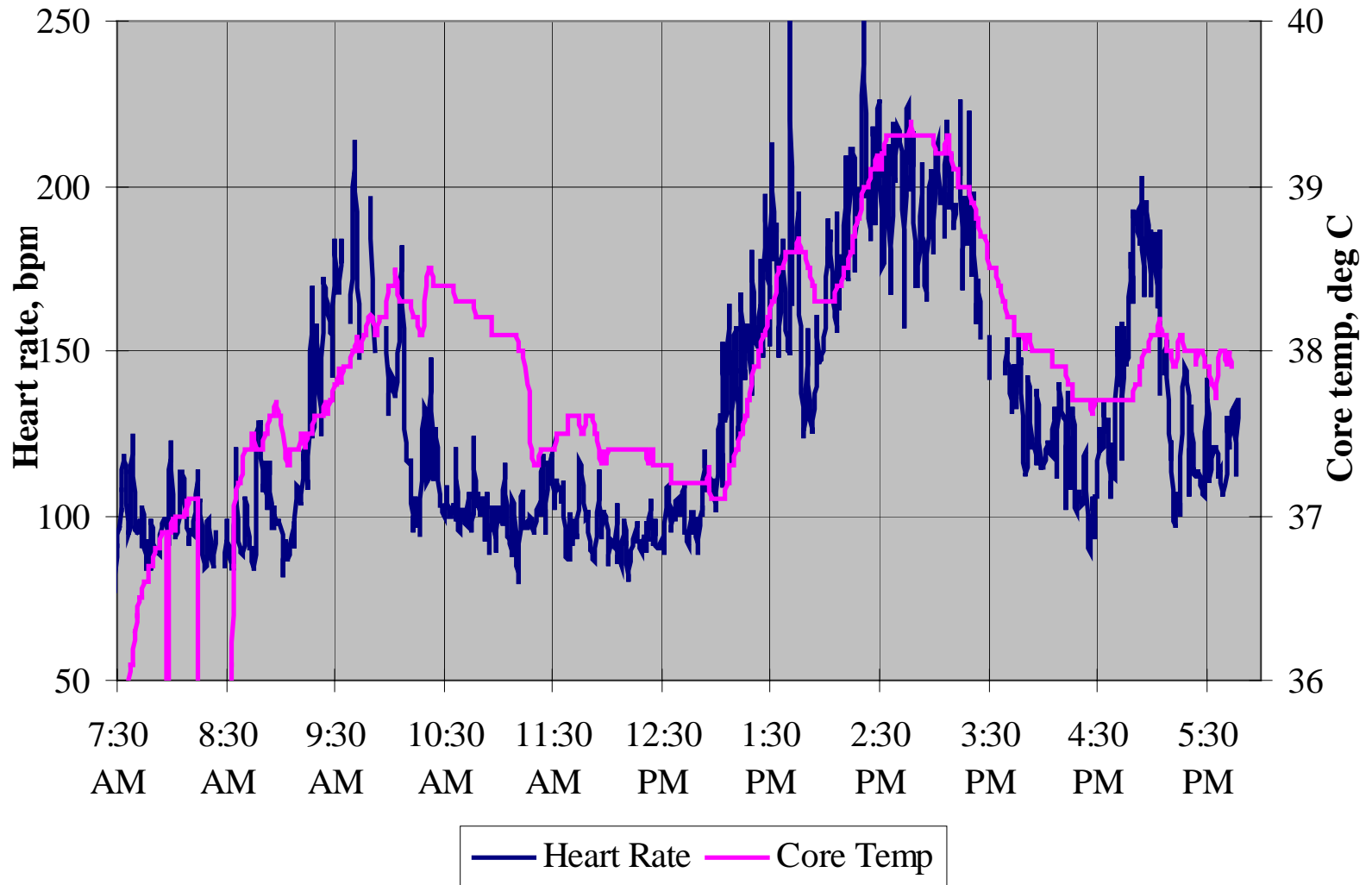


# Physiological Parameters Related to Heat Stress

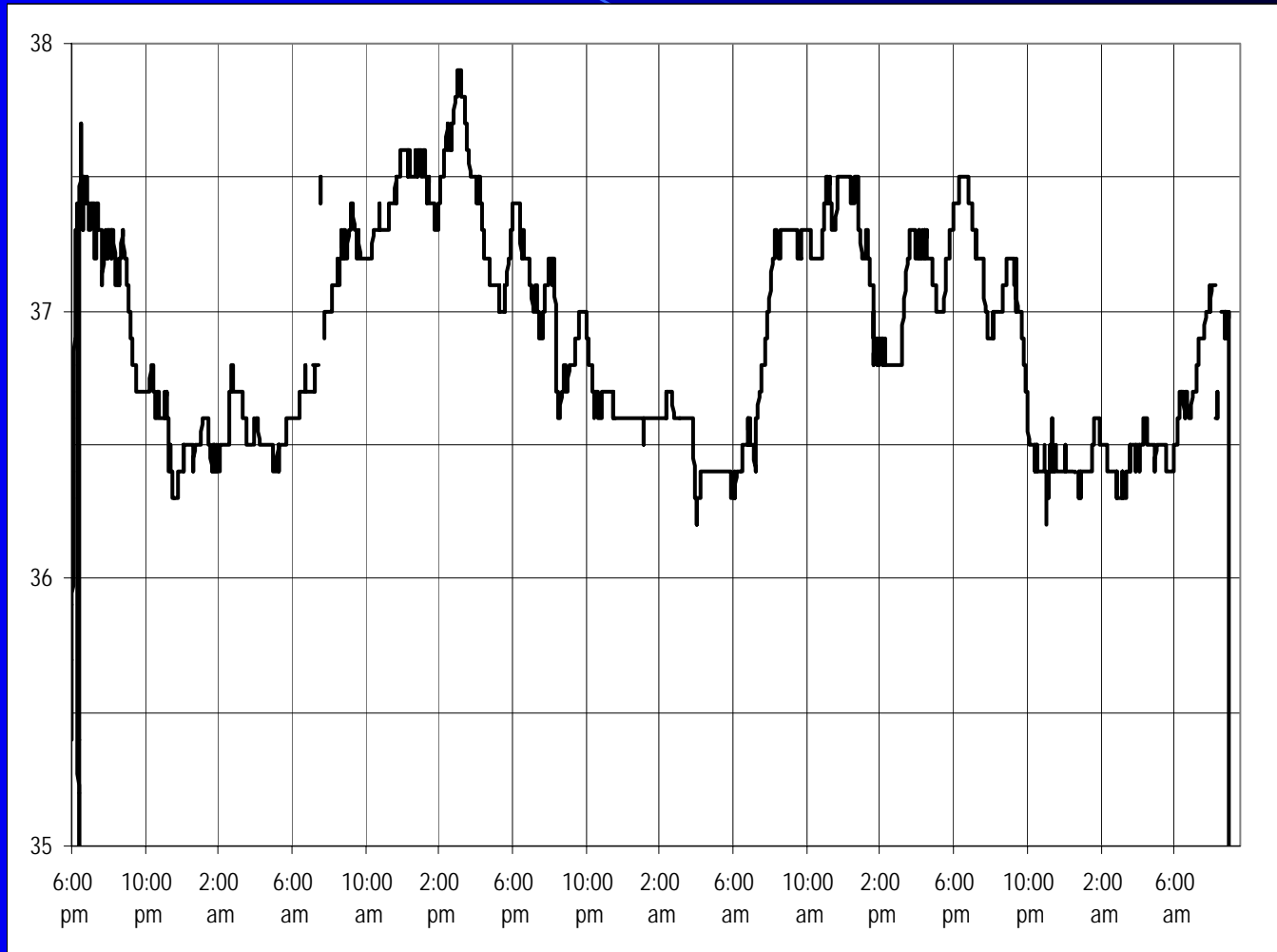
- Deep body core temperature
- Sweat rate
- Skin Wettedness
- Respiration



# Responses to thermal stress



# “Baseline” core temperature

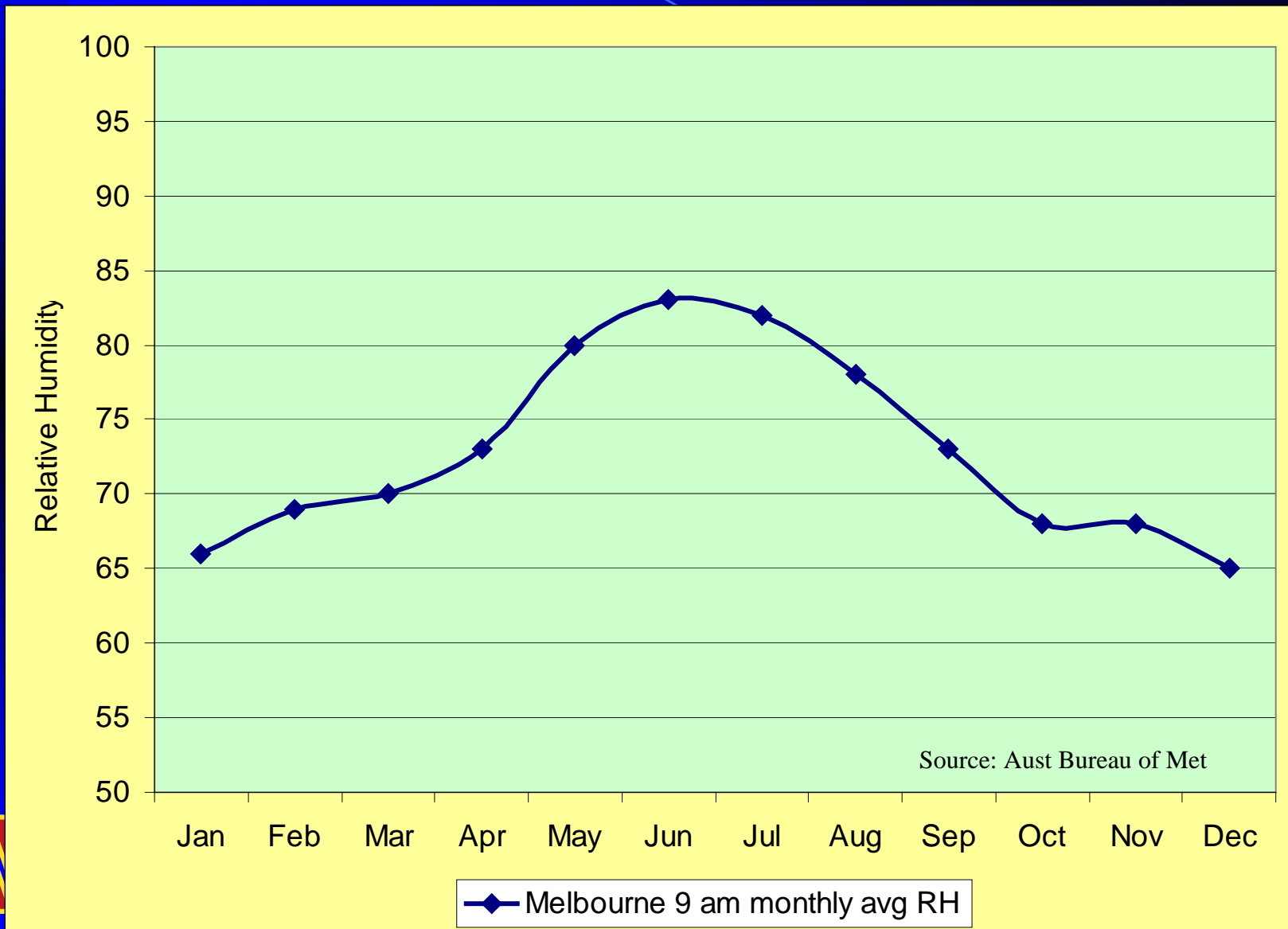


# Types of Heat Stress Indices

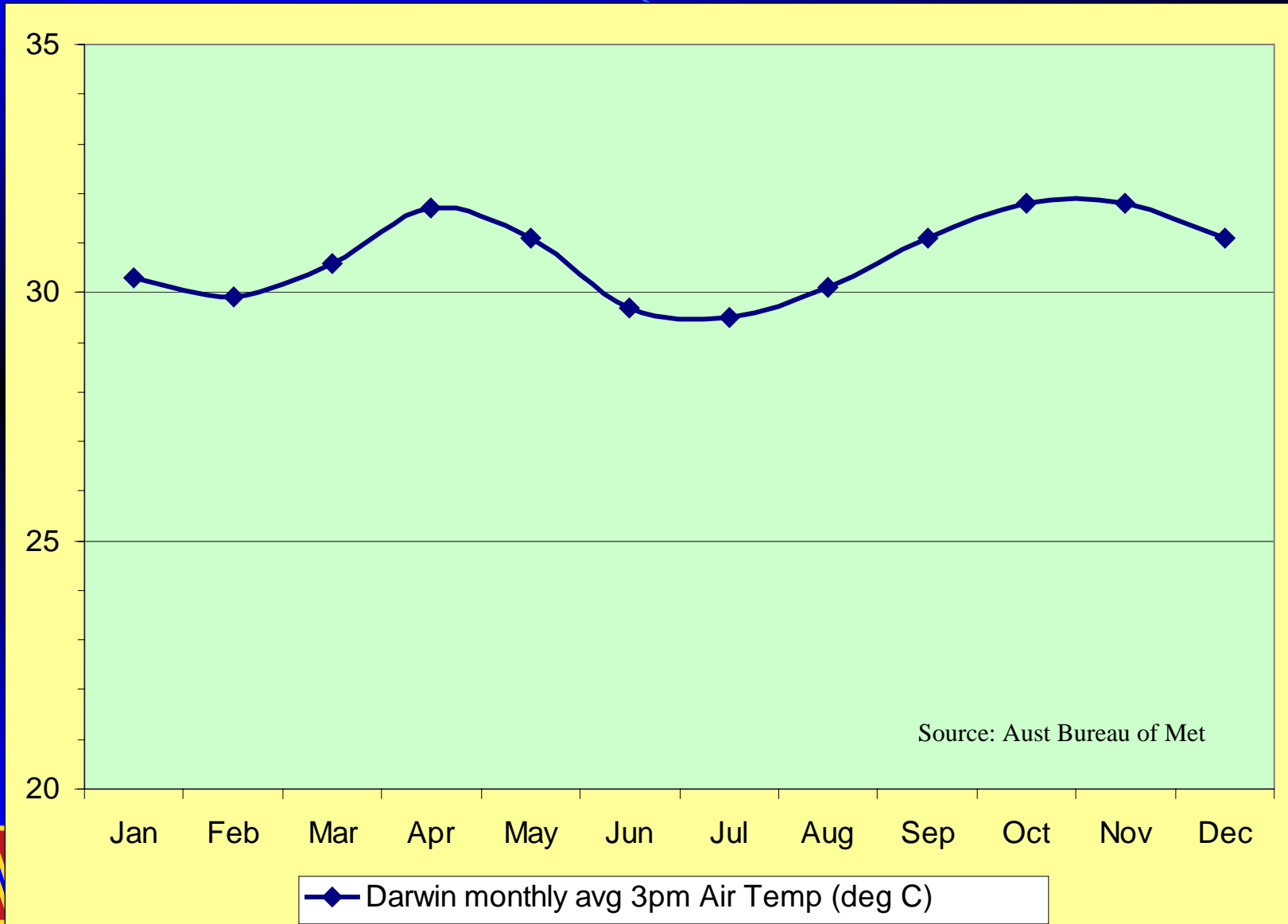
- Empirical (e.g. WBGT)
- Rational (e.g. USARIEM, ISO7933, TWL)
- Over 80 heat stress indices developed in past 100 years



# Is Heat stress related to humidity?

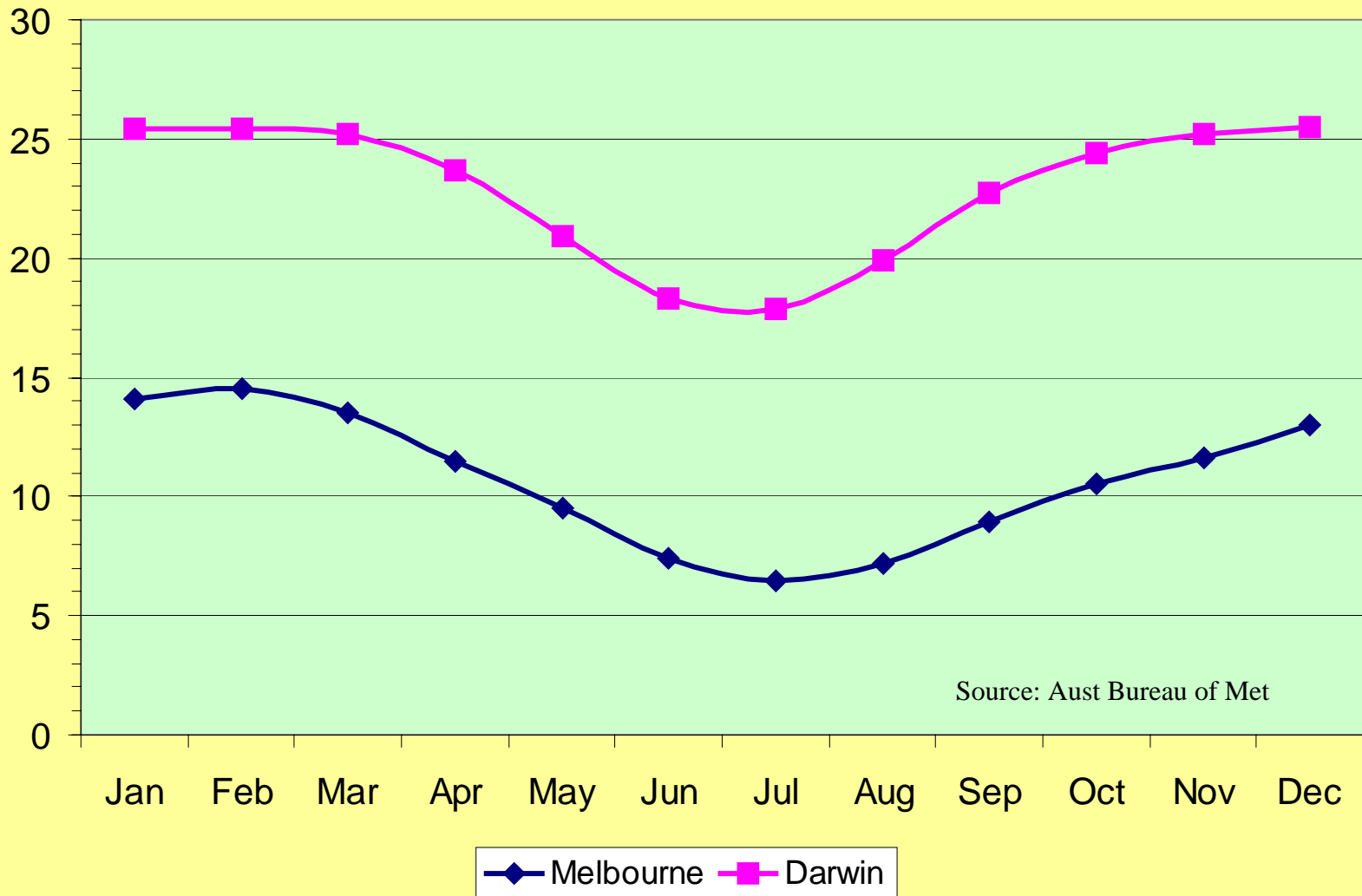


# Is Heat stress related to air temp?



# Is Heat stress related to WB?

Monthly avg 9 am WB temperature



# Is heat stress related to wind speed (V)?

- Human convective heat transfer coefficient
  - $h_c = 0.608 P^{0.6} V^{0.6}$ ,  $W.m^2.K^{-1}$
- Human evaporative heat transfer coefficient
  - $h_e = 1587 h_c P / (P - p_a)^2$ ,  $W.m^2.K^{-1}$
- In typical conditions:
  - Heat loss is strongly related to wind speed
  - Heat loss via evaporation is approx 16 times loss by convection

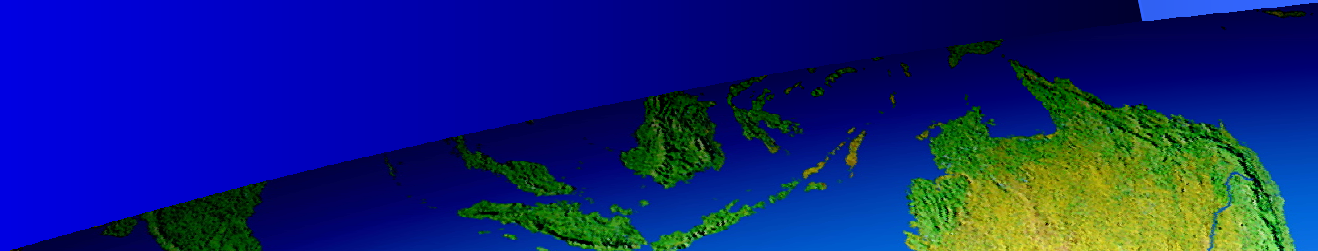
# WBGT



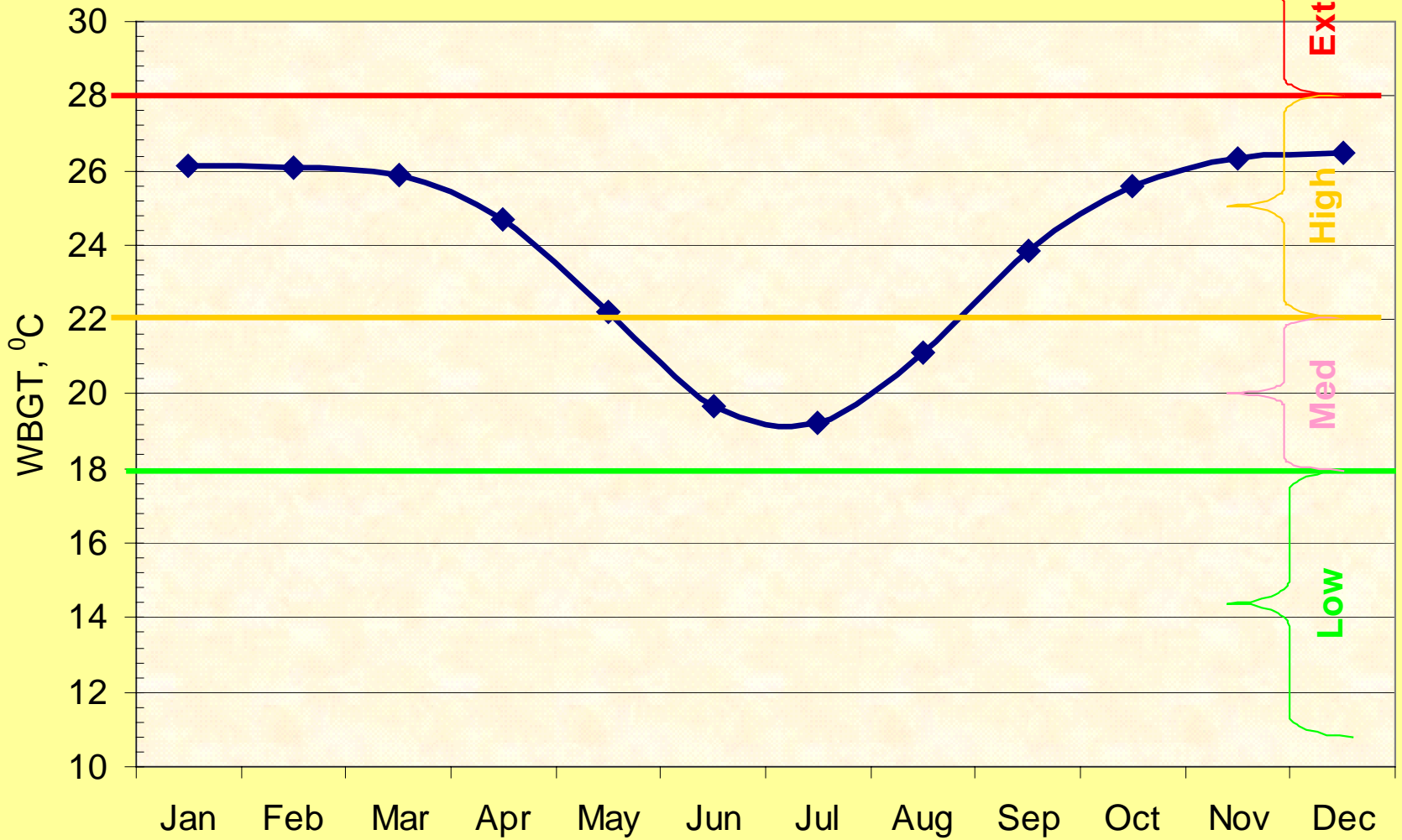
- “Wet bulb globe temperature”
- US Navy in 1957 (almost 50 years ago)
- Simplification of Effective Temperature (1923)
- (Outdoors with Solar) =  $0.7 \text{ NWB} + 0.2 \text{ GT} + 0.1 \text{ DB}$
- (No solar) =  $0.7 \text{ NWB} + 0.3 \text{ GT}$
- Numerous studies have found poor correlation between WBGT and heat stress
  - NWB almost insensitive to wind speed
  - GT completely insensitive to WS if no radiation

# SMA: Hot Weather Policy

- Risk of heat injury
- WBGT < 18<sup>0</sup> C Minimal risk
- 18 < WBGT < 22<sup>0</sup> C Moderate risk
- 22 < WBGT < 28<sup>0</sup> C High risk
- WBGT > 28<sup>0</sup> C Extreme risk

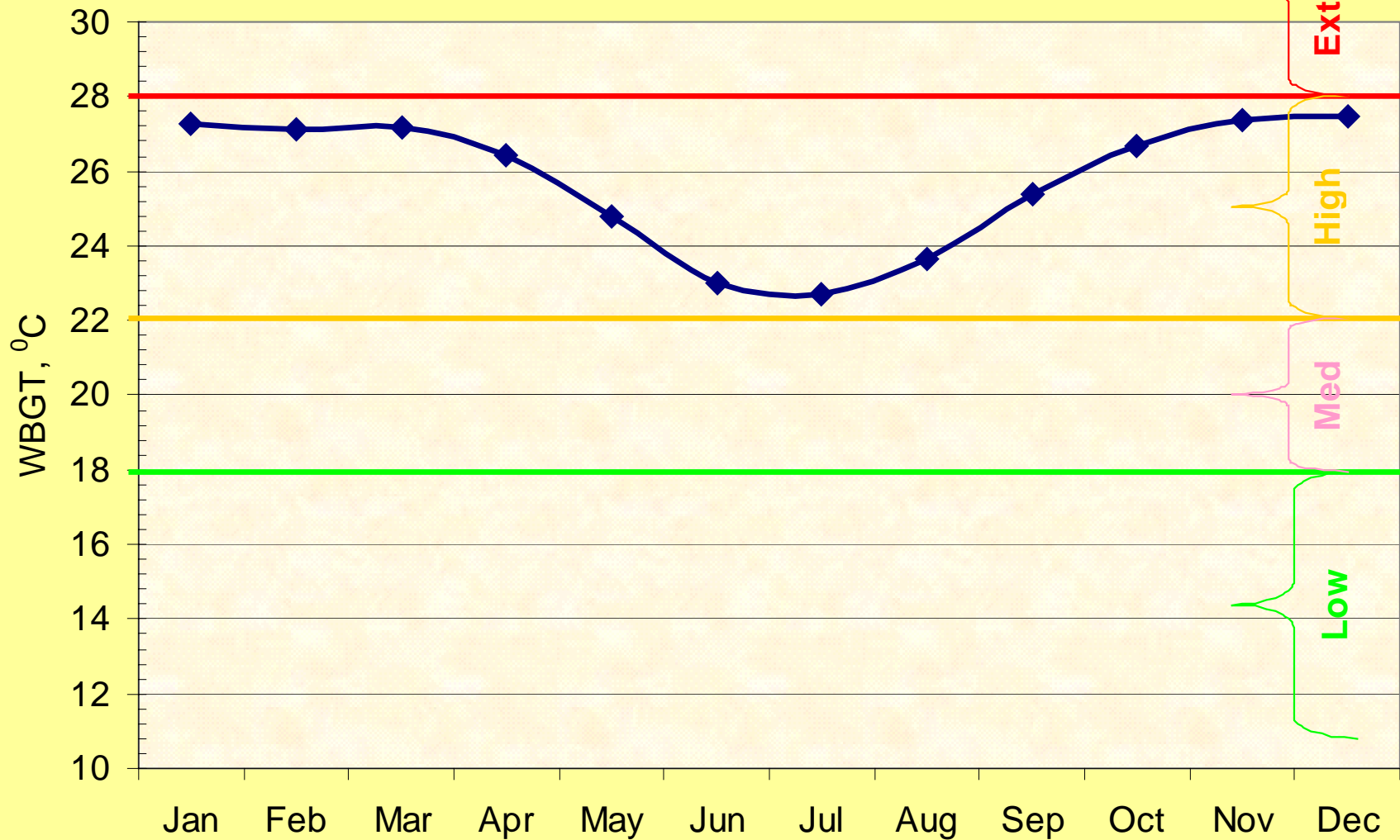


# 9 am monthly avg values, Darwin (indoors)



◆ WBGT (no solar)

# 3 pm monthly avg values, Darwin (indoors)



◆ WBGT (no solar)

# Human Heat Stress Equation

$$\text{Heat from Environment} + \text{Metabolic Heat} < \text{Cooling due to evaporation \& other means}$$

The work rate that acclimatised persons can safely maintain in a particular environment wearing a particular ensemble is called the **Thermal Work Limit**

# Thermal storage in body and time to reach thermal equilibrium

- Average thermal capacity body is  $3.49 \text{ kJ} \cdot ^\circ\text{C}^{-1} \cdot \text{kg}^{-1}$
- Assuming no cooling at all:
  - 500 W means 75 kg person will increase core temperature by  $0.1^\circ\text{C}$  per min or  $1^\circ\text{C}$  in 10 mins
  - $39^\circ\text{C}$  ‘steady-state’ body temp reached in 20 mins at 500 W or 10 mins at 1000 W



# Thermal Work Limit

- The Work Rate ( $W/m^2$  body surface area) that nearly all healthy, well-hydrated, acclimatised persons can sustain in a particular thermal environment with a particular clothing ensemble
- Notes:
  - Most Australian adult males  $\pm 2 m^2$  so that work rate in  $W$  is approximately equal to  $2 \times$  work rate in  $W/m^2$
  - TWL is now accepted under the 2004 revised AOHS Heat Stress Standard as a valid assessment tool for heat stress



# TWL limits

- Core temperature: variable  $37.6^{\circ}$  to  $39.5^{\circ}$  C
  - Std value  $38.2^{\circ}$  C
- Sweat rate: variable 0.6 to 1.5 kg/hr (l/hr)
  - Std value 1.2 kg/hr
- Sustainable work rate: variable 60 to 800  $W/m^2$  (about 120 W to 1600 W)



# Clothing parameters

- Clothing insulation (units are 'clo')
  - 0 for nude
  - 1 for typical office ensemble (dry)
  - 2+ for arctic ensemble (dry)
  - Std TWL value is 0.35 (wet)
- Clothing vapour permeation (dimensionless)
  - 0 for vapour impermeable suit
  - 1 if no impediment to vapour permeation
  - Std TWL value is 0.45



## INPUTS

<b>WB temperature, °C</b>		
<b>Relative Humidity, %</b>	<b>55.0</b>	
<b>Air temperature (DB), °C</b>	<b>28.0</b>	
<b>Globe temp (0 if using MRT), °C</b>	<b>32.0</b>	
<b>Barometric pressure, kPa</b>	<b>101.0</b>	
<b>Relative wind speed, m/s</b>	<b>3.0</b>	
<b>Mean radiant temp, °C</b>		Std values
<b>Clothing insulation, clo</b>	<b>0.35</b>	<b>0.35</b>
<b>Vapour permeation, d'less</b>	<b>0.45</b>	<b>0.45</b>
<b>Posture factor, d'less</b>	<b>0.73</b>	<b>0.73</b>
<b>Max sweat rate, kg/hr</b>	<b>1.2</b>	<b>1.2</b>
<b>Max T<sub>core</sub>, °C</b>	<b>38.2</b>	<b>38.2</b>

## OUTPUTS

<b>TWL<sub>phy</sub>, W/m<sup>2</sup></b>	<b>379</b>	<b>1</b>
<b>TWL<sub>eng</sub>, W/m<sup>2</sup></b>	<b>379</b>	<b>2</b>
<b>Actual sweat rate, kg/hr</b>	<b>0.88</b>	<b>3</b>
<b>T<sub>skin</sub>, °C</b>	<b>31.5</b>	<b>4</b>
<b>T<sub>core</sub>, °C</b>	<b>38.2</b>	<b>5</b>
<b>T<sub>H</sub>, °C</b>	<b>37.5</b>	<b>6</b>
<b>Sweat efficiency, %</b>	<b>60%</b>	<b>7</b>
<b>Wet bulb temperature, °C</b>	<b>15.7</b>	
<b>Relative humidity, %</b>	<b>55.0%</b>	

# Thermal Work Limit (TWL) Calculator

Version 6.5 Copyright MVA 2000-04. For a full or free evaluation version of HotWork™, the software to evaluate heat stress in the workplace, contact [mvamail@mvaust.com.au](mailto:mvamail@mvaust.com.au).

COMMENTS: Input values in BLUE only. Calculated values are in RED.

1. Enter WB (or RH, but not both), DB, GT (0 if using MRT), BaroP (kPa), Wind speed. If using RH, enter as a number between 0 and 100, not as a fraction. If both GT and MRT are 0, program assumes these are = DB.

2. Remaining values should not be altered if finding the standard TWL formulation (summer work uniform).

For nude condition, use 0 for clo (vapour permeation is irrelevant for nude person). TWL<sub>phy</sub> means the TWL value when the core temperature and sweat rate are limited to the values you have supplied, and DB≤44 and WB≤32. If no TWL solution is possible, or cannot meet constraints, returns 0.

TWL<sub>eng</sub> means TWL where core temperature and sweat rate are not limited to the values you have supplied, nor are DB or WB restricted to 44/32 resp, but the calculated TWL is still limited to the valid range of experimental data.

If TWL = -1, then means no solution possible within experimental data or you have supplied insufficient information to calculate TWL.

NOTE: Program calculates TWL by increasing T<sub>core</sub> (in increments of 0.05° C) until a valid solution is found.

To find TWL values using data in another spreadsheet, use this formula:

=TWL calculator v 6.5.xls!fHstTWL(WB, DB, GlobeT, BaroP, WindSpeed, MRT, Clo, VapPerm, Posture, SrMaxkgperhr, TcMax, CalcType)

This spreadsheet must be 'open' (but can be minimised) to reference the TWL function.

Note: MRT, Clo, VapPerm, Posture, SrMaxkgperhr, TcTarget, CalcType are all optional values. If not provided, they default to the standard TWL values in the table above. CalcType is the integer value shown in the Outputs table.

All units are as per the table.



# Thermal Work Limit Model

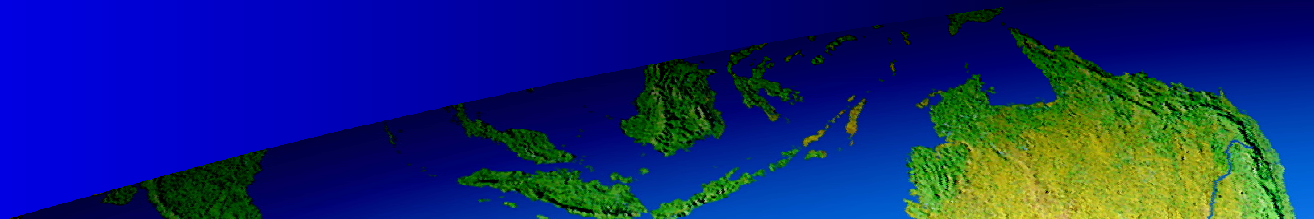
Copyright MVA, 2000-2004. All rights reserved.

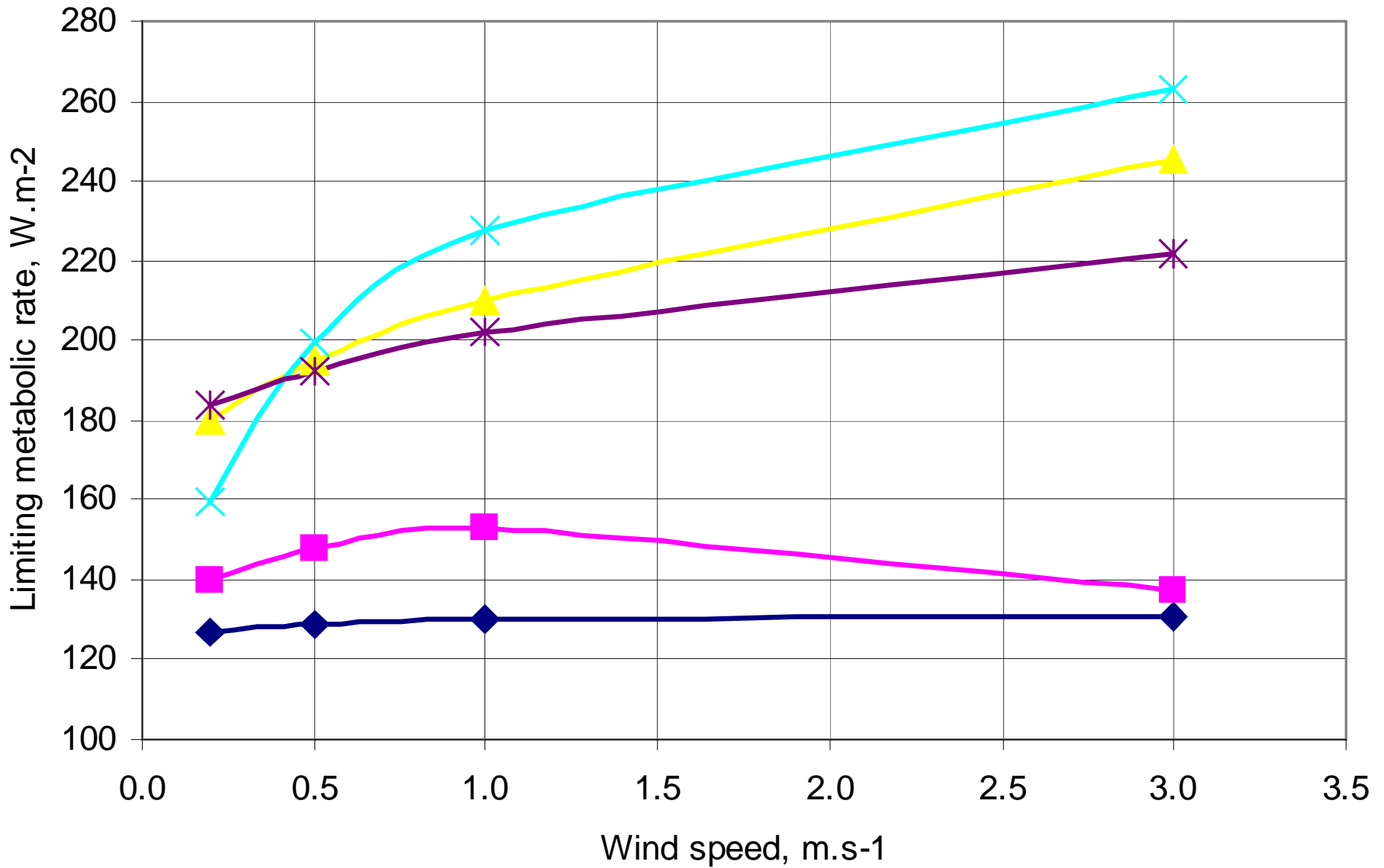
Solve  
TWL

Note: The author and the supplier have no liability to the licensee or any other person or entity for any damage or loss, including special, incidental or consequential damages caused by this product directly or indirectly. This software is provided "as is" without warranty of any kind, either expressed or implied. Warranties of merchantability or of fitness for any purpose are specifically excluded.

INPUTS & CONSTRAINTS					INTERMEDIATE & SUPPLEMENTARY CALCULATIONS						OUTPUTS		
Parameter	Value	Units	Low limit	High limit	Parameter	Value	Units	Parameter	Value	Units	Parameter	Value	Units
Barometric Pressure	95.0	kPa	80	120	Rel Wind speed	3.5	m/s	Convect'n+Rad'n	20	W/m <sup>2</sup>	Sweat rate	1.13	kg/hr
Wet bulb T	22.0	deg C	20	32	Mean Radiant T	45.0	deg C	Evap from skin	314	W/m <sup>2</sup>	T <sub>skin</sub>	34.04	deg C
Dry bulb T	29.0	deg C	20	45	Relative Hum	55%	%	Respiration	25	W/m <sup>2</sup>	T <sub>core</sub>	38.27	deg C
Wind speed	3.50	m/s	0.2	4	Dew Point T	19.1	deg C	Q <sub>coretoskin</sub>	333	W/m <sup>2</sup>	TWL <sub>constrained</sub>	359	W/m <sup>2</sup>
Globe T	32.0	deg C	20	75	h <sub>r</sub>	5.0	W/(m <sup>2</sup> .K)	Q <sub>skintoenv</sub>	333	W/m <sup>2</sup>	TWL <sub>unconstrained</sub>	340	W/m <sup>2</sup>
Latent Heat Sweat	2 430	kJ/kg	2400	2750	h <sub>c</sub>	19.8	W/(m <sup>2</sup> .K)	P <sub>satskin</sub>	5.33	kPa	Tc <sub>unconstrained</sub>	38.20	deg C
i <sub>cl</sub> , clothing conduct.	0.35	clo	0	1	h	24.9	W/(m <sup>2</sup> .K)	P <sub>air</sub>	2.22	kPa	Sr <sub>unconstrained</sub>	1.06	kg/hr
i <sub>cl</sub> , vapour perm ratio	0.45	d'less	0.1	1	h <sub>e</sub>	347.0	W/(m <sup>2</sup> .K)	K, conductance	78.79	W/(m <sup>2</sup> .K)	INSTRUCTIONS: Only change values in BLUE. Values in PURPLE can be changed if using model for other purposes.		
Sweat rate	litre/hr	0.00	1.50	t <sub>oper</sub>	32.25	deg C	Dripping sweat	0.67	kg/hr	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
Deep body core temp	deg C	37.00	39.00	f <sub>cl</sub>	1.105	d'less	Sweat efficiency	41%	d'less	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
Mean skin temp	deg C	22.00	38.27	R <sub>cl</sub>	0.05425	m <sup>2</sup> .K/W	E <sub>max, actual</sub>	314	W/m <sup>2</sup>	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
Thermoregulatory signal, T <sub>sigma</sub>	deg C	35.00	39.50	F <sub>cl</sub>	0.40154	d'less	E <sub>max, if nude</sub>	1080	W/m <sup>3</sup>	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
Skin wettedness	fraction	0.00	1.00	F <sub>cle</sub>	0.44370	d'less	□Sr/E <sub>max</sub>	2.43	d'less	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
Metabolic rate	W/m <sup>2</sup>	80	800	R <sub>ecl</sub>	0.00731	m <sup>2</sup> .kPa/W	Evaporation rate	314	W/m <sup>2</sup>	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
				F <sub>pcl</sub>	0.263	d'less	T <sub>sigma</sub>	37.84	deg C	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
				i <sub>m</sub>	0.522	d'less	Wettedness	1.00	d'less	The standard TWL values for summer, cotton work uniform, including long trousers, T-shirt, hard hat and safety boots are: i <sub>cl</sub> =0.35, i <sub>cl</sub> =0.45, Tc=38.2 <sup>o</sup> , Sr=1.2 kg/hr, Met Rate max = 800 W/m <sup>2</sup> and skin wetness max = 1.0. Assumes wet clothing due to excess of sweat at limiting met rate. This may not be true where the efficiency of sweating is high and little sweat drips. For typical dry summer work uniform i <sub>cl</sub> =0.55 (see Data sheet). Program will endeavour to highlight situations where a solution is not valid and will issue warnings and highlight "problem" cells. Typical problems include impossible input data (e.g. DB<WB) or constraints that do not allow a solution within the range of physiological relationships used to define TWL. Program will also highlight which constraint is the limiting constraint. 'Unconstrained' values is an acceptable solution to the model with fully wet skin, and Tc>=38.2. Note: this model does <u>not</u> automatically limit WB, DB and wind speed to 32 deg, 45 deg and 4 m/s respectively, as recommended in the technical paper. However, cells failing these criteria are highlighted.			
					Model can be used in several modes:								
					1. To predict limiting met rate (TWL) at maximum (or specific) Tc and Sr. To use a specific Tc or Sr, set the high and low limits to a very narrow value. Note that this will usually mean relaxing another constraint as well (e.g. if Tc is fixed at more than 38.2deg, then Sr may need to be relaxed to 1.5 l/hr, etc)								
					2. To predict Tc and Sr at a fixed met rate(TWL). To do this, set Metabolic rate to a very narrow value. Again, this may require both Tc and Sr to be relaxed.								
					3. To iteratively find the WB (or DB or wind etc) for a given met rate (TWL) and Tc/Sr.								
					For further comments, hold mouse over any cell with a red flag in its corner.								

For recommended TWL limits refer to attached sheet.

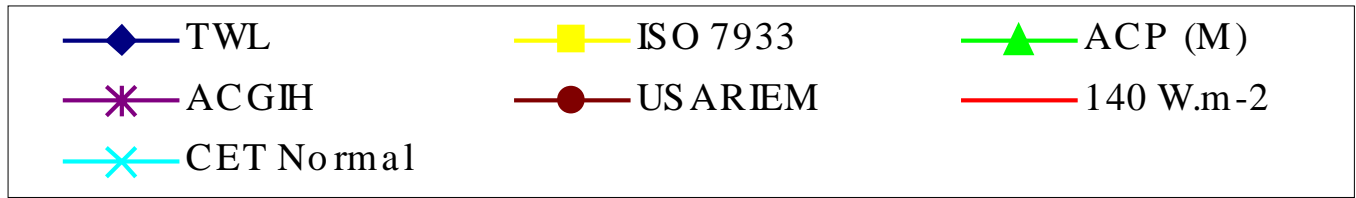
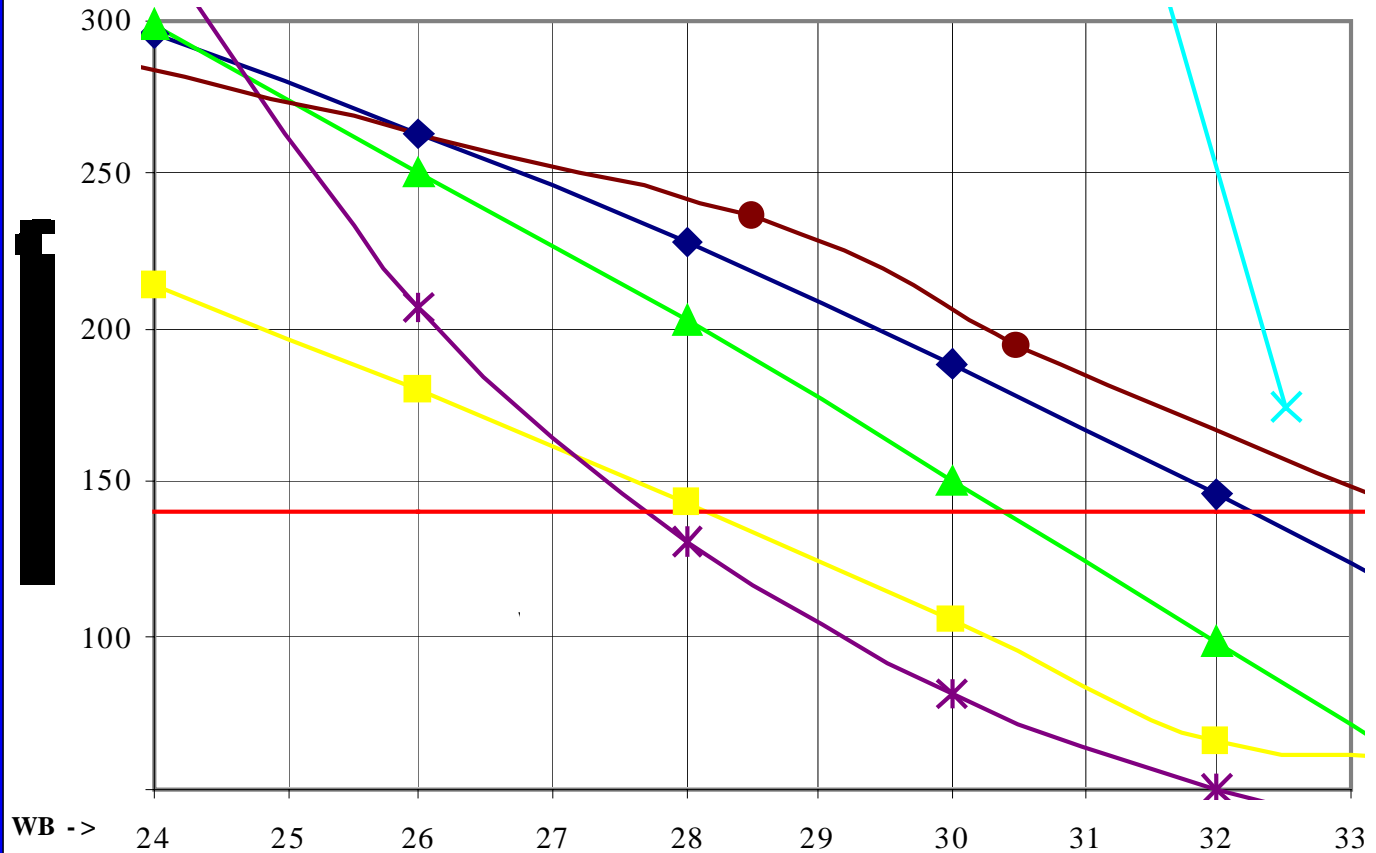




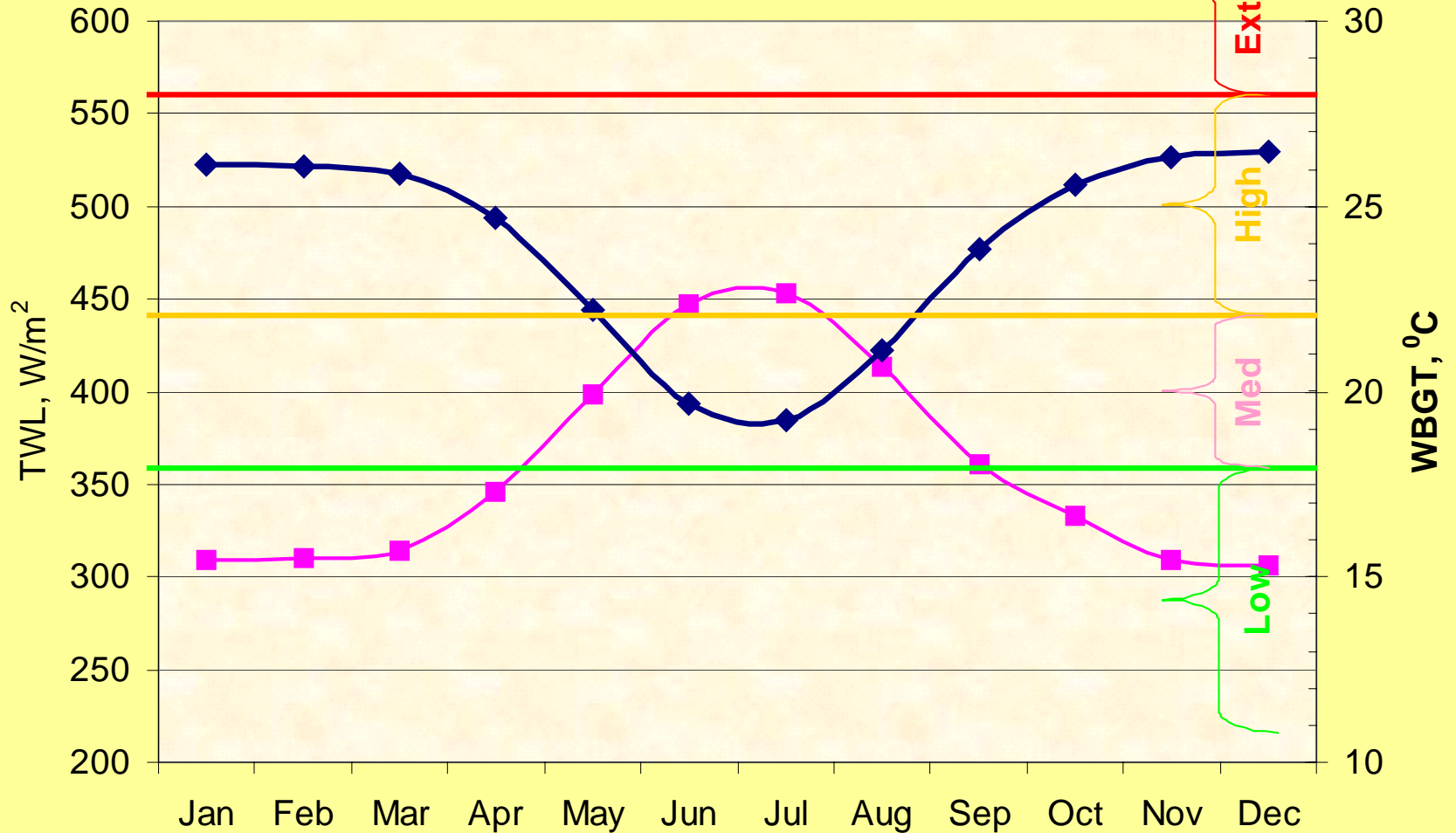
ACGIH
  ISO
  USARIEM
 
x
 TWL
 
\*
 ACP



### Heat Stress Index Comparison Hot, Humid conditions, for DB=MRT=WB+3, 1.0 m.s<sup>-1</sup> wind

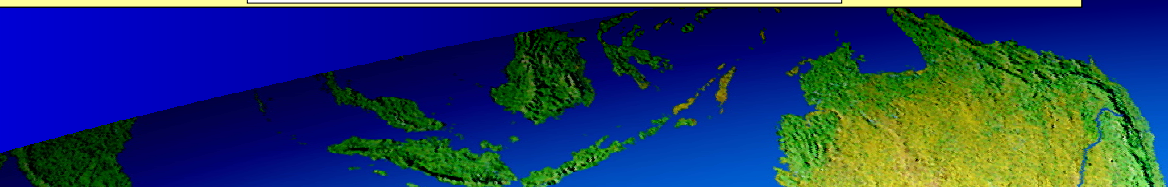


# 9 am monthly avg values, Darwin (indoors)



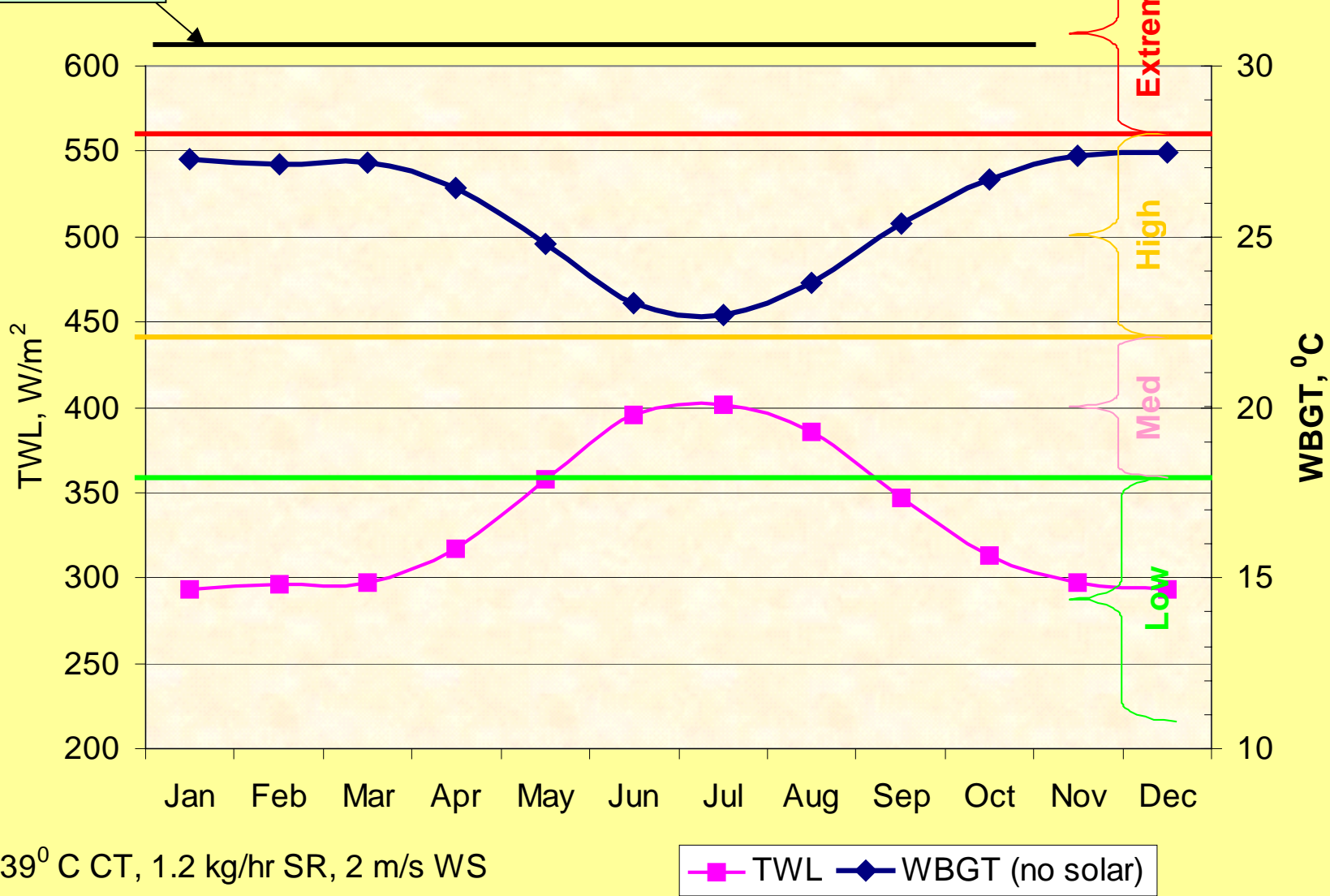
39° C CT, 1.2 kg/hr SR, 2 m/s WS

—■— TWL —◆— WBGT (no solar)



10 million manshifts

### 3 pm monthly avg values, Darwin (indoors)

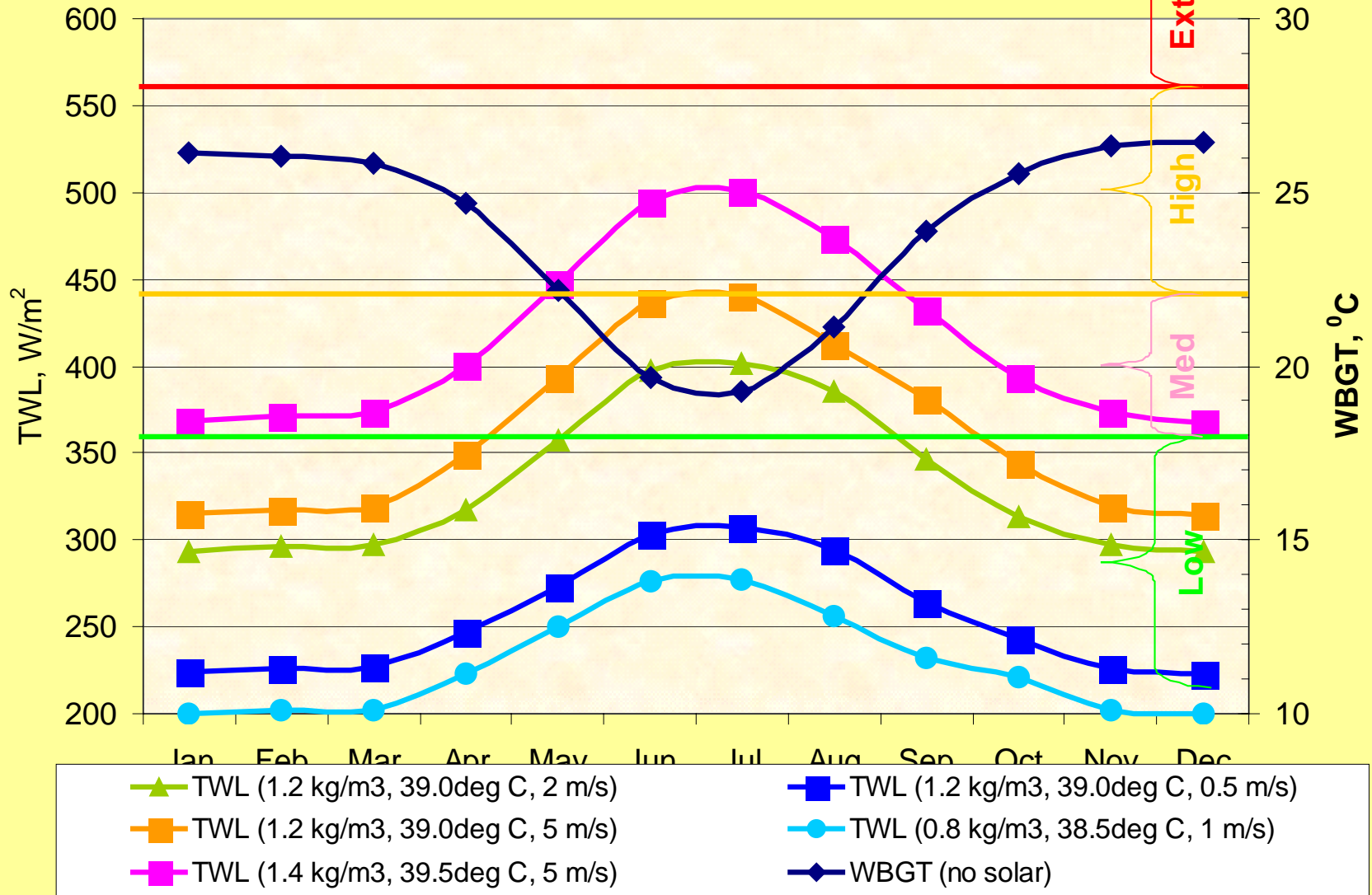


39° C CT, 1.2 kg/hr SR, 2 m/s WS

—■— TWL —◆— WBGT (no solar)



# 3 pm monthly avg values, Darwin (indoors)

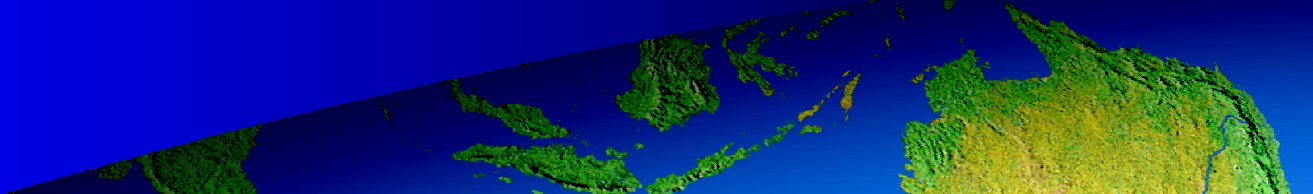
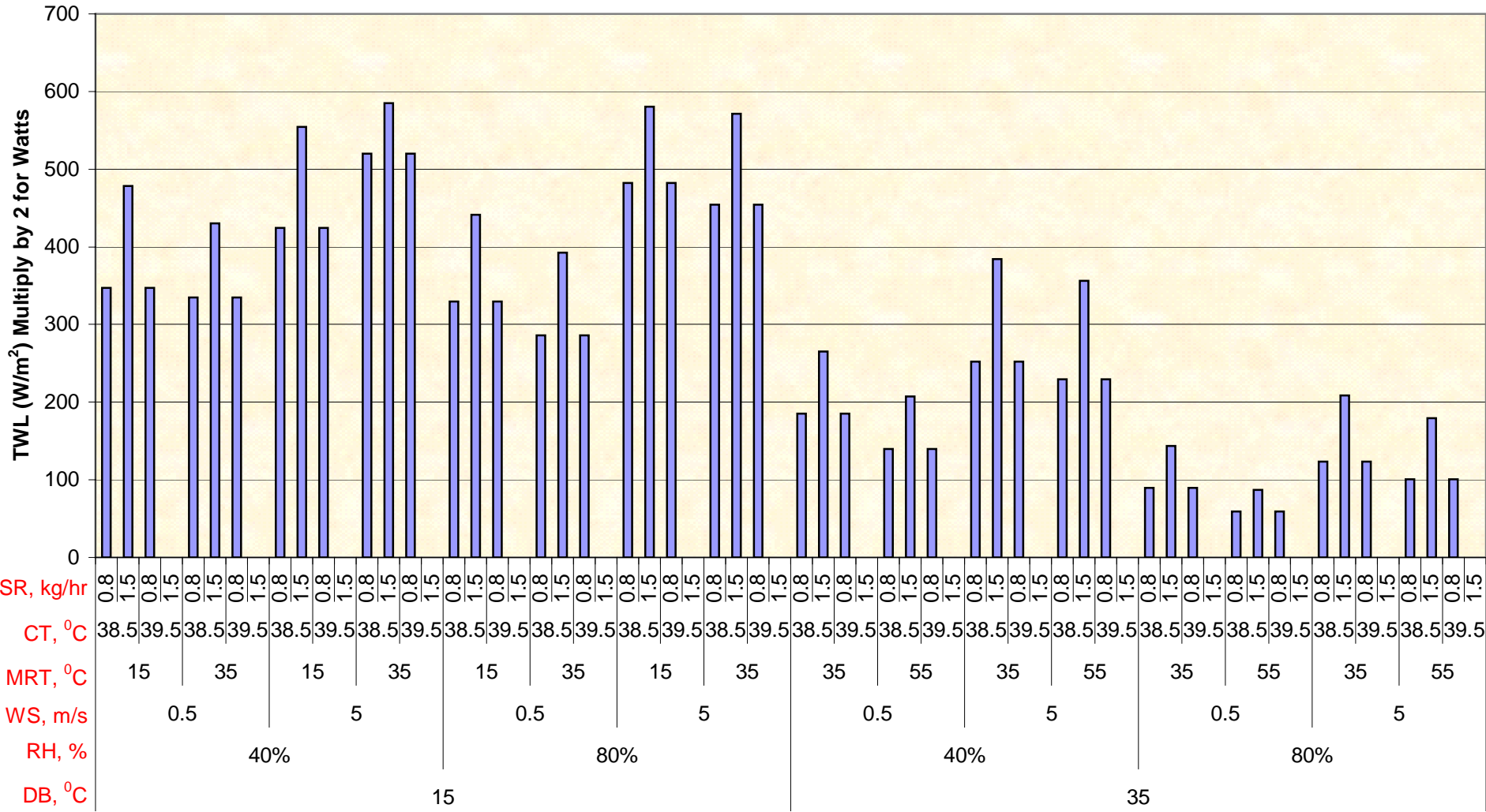


# Example of using TWL: Cycling

- Temperature and humidity
  - Cold (15<sup>0</sup> C) & dry (40% RH)
  - Cold(15<sup>0</sup> C) & humid (80% RH)
  - Hot (35<sup>0</sup> C) & dry (40% RH)
  - Hot (35<sup>0</sup> C) & humid (80% RH)
- Wind: High (5 m/s,18 kph) OR low (0.5 m/s) rel WS
- MRT: High (=DB+20<sup>0</sup> C) OR neutral (=DB)
- Core Temp: Medium OR high (38.5, 39.5<sup>0</sup> C)
- Sweat Rate: Medium OR high (0.8, 1.4 kg/hr)
- Shorts & T-shirt, good vapour permeation

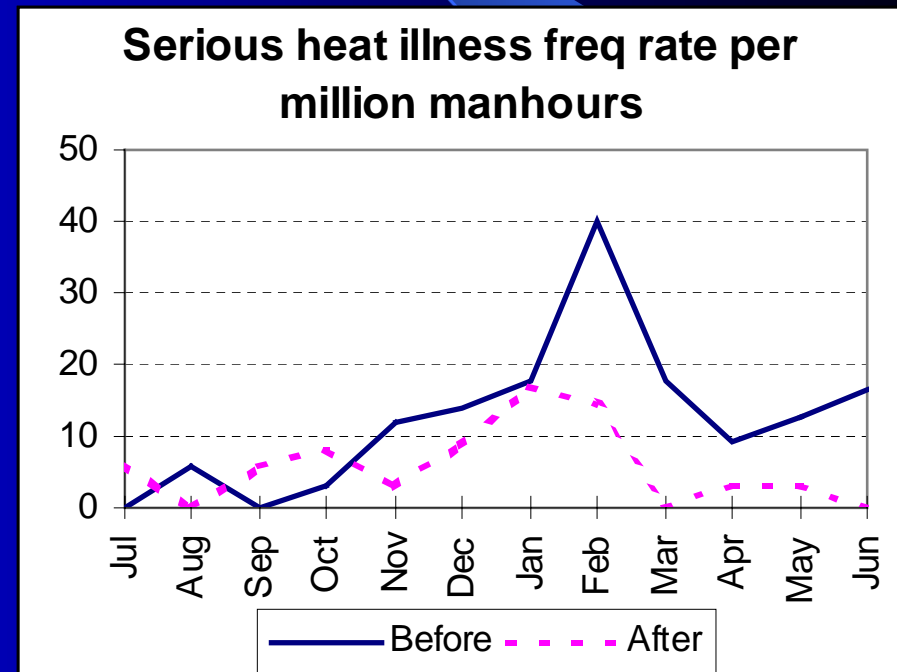
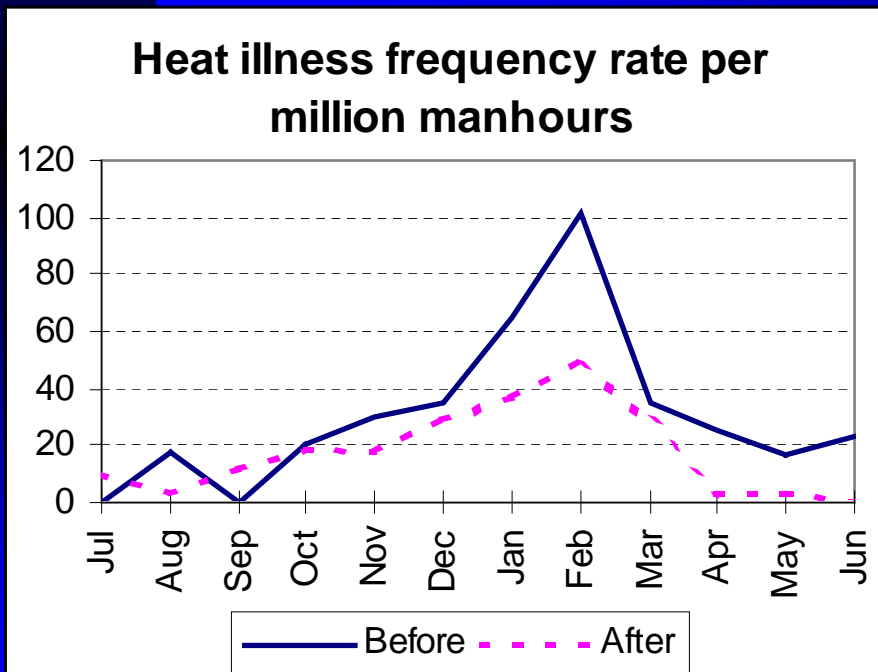


### TWL values (W/m<sup>2</sup>)



# Occupational settings

*Increased* allowable WBGT and  
*decreased* incidence of heat illness



# Work-Rest Cycling

## Work-Rest Cycle Calculator

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Note: The author and the supplier have no liability to the licensee or any other person or entity for any damage or loss, including special, incidental or consequential

Enter data (TWL, ACP, WBGT or ISO) but MUST be consistent.

Work-Rest cycle is displayed

Parameter	Units	Value	Target or ?
Limiting metabolic rate when working	W/m <sup>2</sup>	150	
Required work rate	W/m <sup>2</sup>	183	?
Limiting metabolic rate when resting	W/m <sup>2</sup>	110	
Resting metabolic rate	W/m <sup>2</sup>	60	
Allowable core temp increase	deg C	1.20	
Maximum Work Time before Rest	minutes	81	
Required Rest (Recovery) Time	minutes	54	
Work Time Ratio	% (work + rest)	60%	60%
Working Time per hour (overall)	minutes	36	

Calculate  
Unknown

### INSTRUCTIONS:

1. If you know the primary parameters (blue values), then input these and the derived parameters in purple are calculated automatically
2. If you are missing one blue value (e.g. Reqd work rate), but you have an alternate purple value (e.g. Work cycle) then:
  - \* Enter -1 in the 'Target or ?' column next to the blue value you want to calculate,
  - \* Enter the target (known) value in the 'Target or ?' column next to the purple value you know.
  - \* Press "Calculate Unknown".

NOTE: This calculation is based on 1.8 m<sup>2</sup> person weighing 70 kg and thermal capacity of body of 3.49 kJ/kg/deg C. However, as both work rate and evaporative cooling increase with size, the calculations above are applicable to most healthy individuals.

If using TWL, program assumes that during rest portion, the skin remains wet.

The work/rest cycles suggested in this program are provided for you to examine options, and to obtain guidance. They are a starting point only and MUST be confirmed by actual measurements of physiological strain in the field.

If using the "Calculate unknown" button, then BEFORE you press the button ensure that "no limit" is NOT next to "Maximum work time before rest".



# Uses for TWL

- Estimating sustainable work rate and/or work rate reduction for specific environment and clothing
  - Impact of different clothing (types, fabrics, amount)
  - Impact of different DB or RH/WB
  - Impact of different radiant heat loads (e.g. transfer an event indoors)
  - Impact of different wind speeds
  - Impact of different sweat rates or core temperatures
- Estimating refrigeration requirements, increased wind speeds, or reduced temperatures or humidity to provide for specific work rate in specific environment
- Estimating deep body core temp & sweat rate at specific work rate in specific environment



# Heat Stress Meter



# Conclusions

- WGBT
  - fundamentally & seriously flawed as assessment tool
  - over-estimates risk
- TWL
  - validated heat stress index
  - estimates sustainable met rates for healthy, well-hydrated, acclimatised persons under thermal stress
  - can take variable clothing ensembles, sweat rates and core temperatures
- Management of heat illness in sport?
  - Combination of TWL assessment (perhaps with different CT/SR limits for different categories of athletes) and different clothing parameters, suitable protocols and education of athletes, event organisers & other stakeholders



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# Other information

- Free copy of TWL calculator (needs Excel™):
  - [www.mvaust.com.au](http://www.mvaust.com.au)
- Copies of technical papers or these slides:  
email me
  - [rick.brake@mvaust.com.au](mailto:rick.brake@mvaust.com.au)

