Heat Stress Equation Development and Usage for Dryden Flight Research Center (DFRC)

Franzeska Houtas
TYBRIN Corporation

Edward H. Teets Jr.
NASA Dryden Flight Research Center
Outline

• Heat Stress Intro
• Background
• Development
• Implementation/Automation
Leading causes of weather fatalities
Heat Stress

• Net heat load of metabolic and environmental factors

• Four methods of heat loss: conduction, convection, radiation, evaporation
  – Normal: convection and radiation
  – Heat stress: evaporation (up to 80%)
Illnesses

- Heat rash
- Heat Syncope
- Heat cramps
- Heat exhaustion
- Heat stroke
Predisposing Factors

- Certain Medications
- Very small body size
- Poor nutrition
- Overweight
- Over 40 years old (the older the more sensitive)
- Previous heat illness
- Heart disease
- High blood pressure
- Diabetes
- Skin disease
- Liver, kidney, and lung problems
Predisposing Factors (cont.)

• Physical activity
• Poor physical condition
• Fatigue
• Excessive clothing
• Dehydration
• Being female
• Being pregnant
• Alcohol, caffeine, nicotine intake
• Sunbathing
Vehicle Temperatures

- Previous studies have examined the internal environment of motor vehicles.
- One study showed that with an outdoor ambient temperature of 98.2°F, 75% of the maximum temperature rise in the vehicle occurred within 5 minutes of closing the doors and maximized within 15 minutes to 124 –153°F.
- Opening the windows 20 cm (8 inches) had minimal effect on the temperature rise and maximum temperature attained.
Vehicle Temperatures
Vehicle Temperatures

- A study done at Dryden has shown that using a sunshade and having windows cracked is the best method of reducing the temperature inside a parked vehicle.
- [Legend: NS – No sun shade, SS – sun shade]
Vehicle Temperatures

- Maximum Ambient Temperature 106 °F
- Inside Vehicle Max temp: 157.6 °F
- WBGT: 117.32 °C
### Measured Surface Temperature of Vehicles at Dryden (Direct Sunlight)

<table>
<thead>
<tr>
<th>Time (PDT)</th>
<th>1145</th>
<th>1300</th>
<th>1330</th>
<th>1400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Air Temp (°F)</td>
<td>100</td>
<td>102-104</td>
<td>107</td>
<td>109</td>
</tr>
<tr>
<td>Wind (Knots)</td>
<td>&lt;10</td>
<td>10+</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Black Car (2 cars) °F</td>
<td>175</td>
<td>166-172</td>
<td>185</td>
<td></td>
</tr>
<tr>
<td>White Car °F</td>
<td>136</td>
<td>129</td>
<td>138</td>
<td></td>
</tr>
<tr>
<td>Red Car °F</td>
<td>153</td>
<td>151-154</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charcoal Grey Car °F</td>
<td>161</td>
<td>165</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Conclusion: Black surfaces, when exposed to direct sunlight typical at Dryden, will exceed 180°F on a hot summer day. This is true for graphite/epoxy laminates, either gloss or flat finish. White surfaces are typically 40+°F cooler than black.
Heat Stress Indices

- Principles of heat exchange
  - HIS (‘Belding and Hatch’)
- Subjective impressions (comfort)
  - HI (NWS Heat Index)
- Empirical observations/Physiological Experiments
  - Wet Bulb Globe Temperature (WBGT)
WBGT

- Three temperature measurements
  - Natural Wet-Bulb Temperature
    - Not ‘Wet-bulb’
  - Globe Temperature
  - Shielded Dry-Bulb Temperature
WBGT Equations

• Direct Sunlight Exposure

\[ \text{WBGT} = 0.7T_{\text{NWB}} + 0.2T_{G} + 0.1T_{DB} \]

• Indoor or Shaded Environments

\[ \text{WBGT} = 0.7T_{\text{NWB}} + 0.3T_{G} \]

• \( T_{\text{NWB}} \) = Natural Wet Bulb Temperature
• \( T_{G} \) = Globe Temperature
• \( T_{DB} \) = Dry Bulb Temperature.
### WBGT Flag Definitions (°F)

<table>
<thead>
<tr>
<th>Flag</th>
<th>WBGT Index Range</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No Flag</strong></td>
<td>81.9 or below</td>
<td>Wet Bulb Globe Thermometer (WBGT) index 81.9 or below. Normal activity can proceed.</td>
</tr>
<tr>
<td><strong>Green</strong></td>
<td>82 - 84.9</td>
<td>Discretion is required in planning heavy exercise for non-acclimatized personnel. This is a marginal heat stress limit for all personnel. Water intake: 1 quart per hour.</td>
</tr>
<tr>
<td><strong>Yellow</strong></td>
<td>85 - 87.9</td>
<td>Strenuous activity must be curtailed for new and non-acclimatized personnel during the first 3 weeks of heat exposure. Avoid work in direct sunlight, if possible. Rest periods of 15 minutes per hour. Encourage water consumption at least every 30 minutes, 1 quart in an hour.</td>
</tr>
<tr>
<td><strong>Red</strong></td>
<td>88 - 89.90</td>
<td>Avoid work in direct sunlight, if possible. Rest periods of 30 minutes per hour. Encourage water consumption at least every 15 minutes, 1 quart in an hour.</td>
</tr>
<tr>
<td><strong>Black</strong></td>
<td>90 or Above</td>
<td>Terminate all outdoor tasks. Where termination is not immediately feasible, move quickly to safety after finishing activity. Avoid work in direct sunlight. Rest periods of 45 minutes per hour. Water intake: 1 quart per hour.</td>
</tr>
</tbody>
</table>
Reasons for Other Equations

• Absence of thermal environment monitoring system (Direct WBGT instrument)
• Large area not well enough covered by instrument
• Equations developed
  – American College of Sports Medicine (ACSM)
  – Westinghouse Savannah River Company (WSRC)
• DFRC found ACSM to be good basis for desert environment
DFRC Development

- ACSM – Equation 1
  \[ \text{WBGT} = 0.567T_{DB} + 0.393e + 3.94 \]
  - \( T_{DB} \) = ambient temperature
  - \( e \) = vapor pressure calculated from RH
DFRC Development

- Direct relationship between wind speed and the reduction in the WBGT
- As the wind increases the difference between the two independent WBGT temperature increases
  - Slope = 0.16°C/kt
  - Y-intercept = -0.54 deg C
DFRC Development

- Equation 2

\[ WBGT = 0.567T_{DB} + 0.393e + 4.48 - (0.16*WS) \]

\[ T_{DB} = \text{Dry-bulb temperature} \]
Dryden WBGT Heat Stress Equation

\[ WBGT = 0.567T_{DB} + 0.393\left(\frac{RH}{100}\right) \times \left(6.112 \times \exp\left(\frac{17.67 \times T_{DB}}{T_{DB} + 243.5}\right)\right) + 5.05 - (0.207 \times WS) \]

- \( T_{DB} \) = Dry Bulb Temperature
- \( RH \) = Relative Humidity
- \( WS \) = Wind Speed
DFRC Heat Stress History

• Safety, Health, and Environmental Branch
  – Quest Technologies® QuesTemp°10/34
  – One employee assigned to take measurements
  – Infrequent data collection
  – Not accurate for entire center
DFRC Automation

• Data
  – Official measurements made by Edwards AFB FMQ-19
  – Transferred every minute to DFRC FTP site

• Computation
  – Ingested to program every 5 minutes
  – WBGT computed
  – Values sent to DFRC intranet (Xnet)

• Display
  • Date/Time stamp
  • Flag
  • Temperature
  • Wind Direction
  • Wind Speed
  • Relative Humidity
  • WBGT
DFRC Automation (cont.)

• Dissemination
  – Frequency (three iterations/15 minutes)
  – E-mail to key personnel
  – Center-wide announcement
  – X-net banner color change

• Archive
  – DFRC archives incoming and outgoing data on FTP site for continued analysis
Xnet
Heat Stress Banner on Xnet

Current Conditions

Heat Stress Index →

Last Update: 10/05/2011 1219
Flag: None
Temp (F): 61°
Relative Humidity (%): 67%
WBGT Value (F): 58.1°
Wind: 252° @ 21 kts–gusts to 27
Heat Stress Page

The Dryden Intranet

Employee Information  Dryden Management  Organizations  Communications  Transportation

Home  Heat Stress

Heat Stress Flag Definitions

**No Flag** - Wet Bulb Globe Thermometer (WBGT) index 81.9 or below. Normal activity can proceed.

**Green** - WBGT index of 82 - 94.9. Discretion is required in planning heavy exercise for non-acclimatized personnel. This is a marginal heat stress limit for all personnel. Water intake: 1 quart per hour.

**Yellow** - WBGT index of 95 - 97.9. Strenuous activity must be curtailed for new and non-acclimatized personnel during the first 3 weeks of heat exposure. Avoid work in direct sunlight, if possible. Rest periods of 15 minutes per hour. Encourage water consumption at least every 30 minutes, 1 quart in an hour.

**Red** - WBGT index of 88 - 99.9. Avoid work in direct sunlight, if possible. Rest periods of 30 minutes per hour. Encourage water consumption at least every 15 minutes, 1 quart in an hour.

**Black** - WBGT index of 90 or Above. Terminate all outdoor tasks. Where termination is not immediately feasible, move quickly to safety after finishing activity. Avoid work in direct sunlight. Rest periods of 45 minutes per hour. Water intake: 1 quart per hour.

**Note:** numbers are Wet Bulb Globe Temperature Index – not Temperature

- 24 Hour History
- Three Day Forecast
- Heat Illnesses
- Prevention
- Work Load Requirements
- Heat Stress Measurements
Graph History/Forecasts
References

• American Conference of Governmental Industrial Hygienists (ACGIH) (2003). Threshold limit values and biological exposure indices for 2003. *Cincinnati: ACGIH.*
Contact Info

• Franzeska Houtas
  – Franzeska.F.Houtas@NASA.gov

• Ed Teets
  – Edward.H.Teets@NASA.gov