Short-Term Heat Stress Exposure Limits Based on WBGT

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Bottom Line

\[ t_{\text{limit}} \left[ \text{min} \right] = \frac{26,000}{\text{AdjWBGT}^3 \text{TLV}} 10 \]

\[ \text{AdjWBGT} \left[ ^\circ \text{C} \right] \text{ WBGT} \text{ measured} \text{ CAF} 0.02 \text{ M[water]} 7.6 \]
Graphically

See http://personal.health.usf.edu/tbernard/thermal/
Question

How did we get there?
Some Science
and
Some Art
Acknowledgments

CDC/NIOSH 1R01 OH03983

Participants

Laboratory Staff

NIOSH support of Sunshine Education and Research Center at USF

University of South Florida
Science

Laboratory Trials
Time-Limited Protocol
Participants

Thirteen Heat Acclimatized Adults

✓ 9 Men
✓ 4 Women

Metabolic Rate of 188 W/m²
Clothing Ensemble

Work Clothes
✓ Cotton
✓ CAF = 0

NexGen®
✓ Vapor-Permeable, Water Barrier
✓ CAF = 2.5 °C

Tychem QC®
✓ Vapor Barrier
✓ CAF at 50%rh = 7.5 °C
Environmental Conditions

<table>
<thead>
<tr>
<th>Ensemble</th>
<th>L1</th>
<th>L2</th>
<th>L3</th>
<th>L4</th>
<th>L5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Clothes</td>
<td>36</td>
<td>37</td>
<td>38</td>
<td>40</td>
<td>44</td>
</tr>
<tr>
<td>NexGen</td>
<td>33</td>
<td>34</td>
<td>36</td>
<td>38</td>
<td>41</td>
</tr>
<tr>
<td>Tychem QC</td>
<td>29</td>
<td>30</td>
<td>32</td>
<td>34</td>
<td>38</td>
</tr>
</tbody>
</table>

at 50% relative humidity
Results

Time [min]

Heat Stress Level

- Work Clothes
- NexGen
- Tychem QC
First Conclusion

An Errant Data Group: NexGen-L2
✓ Statistically Significant
✓ Not Plausible

Ignoring NexGen-L2
✓ No Differences Among Ensembles
✓ Supports CAF for Short-Term Exposures
✓ $WBGT_{eff} = WBGT + CAF$
WBGT Adjustment for Metabolic Rate

Laboratory Trials Based on Normalized Rate to Body Surface Area

- Average = 188 W/m²

From previous work

- Low to High M: $\Delta \text{WBGT}_M = 0.039 \left( M_{[W/m^2]} - 188 \right)$
- $\text{AdjWBGT} = \text{WBGT}_{\text{eff}} + \Delta \text{WBGT}_M$
Data

![Graph showing data points for different work clothes: Work Clothes (red diamonds), NexGen (green crosses), Tychem QC (blue triangles). The x-axis represents Adjusted WBGT [°C], and the y-axis represents Time [min].]
Art

Professional Judgment
(aka SWAG)
Curve Fitting

Determine a Protective Limit

✓ WBGT Difference from TLV at Average M
✓ Inverse WBGT Difference with Fixed Minimum Time
✓ Visual Fitting
  ▪ 3rd Power
  ▪ Coefficient

\[ t_{\text{limit [min]}} = \frac{26,000}{\text{WBGT}^3} 27^{10} \]
Result

- Work Clothes
- NexGen
- Tychem QC

Adjusted WBGT [°C] vs Time [min]
Generalization

Total Metabolic Rate in Watts

Increase Range of Metabolic Rate

\[ \Delta \text{WBGT}_M = 0.02 (M_W - 370) \]

Limited to 120 minutes or Less
Back to the Beginning

\[
\frac{t_{\text{limit}}}{} \quad \frac{26,000}{\text{AdjWBGT}} \quad \frac{10}{\text{TLV}}
\]

\[
\text{AdjWBGT} \quad \text{WBGT}_{\text{measured}} \quad \text{CAF} \quad 0.02 (M[w] \quad 370)
\]

\[
\text{AdjWBGT} \quad \text{WBGT}_{\text{measured}} \quad \text{CAF} \quad 0.02 M[w] \quad 7.6
\]

\[
\text{TLV} \quad 56.7 \quad 11.5 \log_{10} M[w]
\]
Compare to Others

<table>
<thead>
<tr>
<th>Heat Stress Level</th>
<th>Time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 °C-WBGT</td>
<td>USF at 480 W</td>
</tr>
<tr>
<td>40 °C-WBGT</td>
<td>EPRI at 480 W</td>
</tr>
<tr>
<td>45 °C-WBGT</td>
<td>USF at 275 W</td>
</tr>
<tr>
<td></td>
<td>EPRI at 270 W</td>
</tr>
<tr>
<td></td>
<td>PHEL at 280 W</td>
</tr>
</tbody>
</table>

† 180 min
Questions

Come Visit Us

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NIOSH Sunshine ERC
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