The Black Globe Thermometer Hacking Challenge

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HeatHack and University of Edinburgh

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Heating Control
Thermal Comfort

- Temperature
- Mean Radiant Temp.
- Air velocity
- Humidity
- Clothing Insulation
- Human activity level
Thermal Comfort

How do we know?
Fanger’s Virtual Climate Chamber

Quantifying subjective ratings (Solomon Islands study)

## Table 3: Insulating Value of Clothing Elements

<table>
<thead>
<tr>
<th>Man</th>
<th>clo</th>
<th>Women</th>
<th>clo</th>
</tr>
</thead>
<tbody>
<tr>
<td>underwear</td>
<td></td>
<td>underwear</td>
<td>bra + panties</td>
</tr>
<tr>
<td>T-shirt</td>
<td>0.09</td>
<td>half slip</td>
<td>0.13</td>
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<tr>
<td>briefs</td>
<td>0.05</td>
<td>full slip</td>
<td>0.19</td>
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<tr>
<td>long, upper</td>
<td>0.35</td>
<td>long, upper</td>
<td>0.35</td>
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<tr>
<td>long, lower</td>
<td>0.35</td>
<td>long, lower</td>
<td>0.35</td>
</tr>
<tr>
<td>shirt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>light, short sleeve</td>
<td>0.14</td>
<td>blouse</td>
<td>light</td>
</tr>
<tr>
<td>light, long sleeve</td>
<td>0.22</td>
<td></td>
<td>heavy</td>
</tr>
<tr>
<td>heavy, short sleeve</td>
<td>0.25</td>
<td>dress</td>
<td>light</td>
</tr>
<tr>
<td>heavy, long sleeve</td>
<td>0.29</td>
<td></td>
<td>heavy</td>
</tr>
<tr>
<td>+5% fortie or turtle-neck)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>vest:</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>light</td>
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<td>skirt</td>
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<td>0.22</td>
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<td>slacks</td>
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<td>pullover</td>
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<td>0.37</td>
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<tr>
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<tr>
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<td>0.49</td>
<td>heavy</td>
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<td>socks</td>
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<td>stockings</td>
<td>any length</td>
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<td>panty-hose</td>
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<tr>
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<tr>
<td>boots</td>
<td>0.08</td>
<td>boots</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Based on ASHRAE 1985
Thermal Comfort

- Temperature
- Mean Radiant Temp.
- Air velocity
- Clothing Insulation
- Humidity
- Human activity level
Mean Radiant Temperature (MRT)

- Area weighted mean temperature of all the objects surrounding the body
- Angle factor matters
Comfort model

Source: http://smap.cbe.berkeley.edu/comforttool
What temperature?

- the science is about climate controlled spaces with low thermal mass, where dry bulb (air) is close enough
- really “operative temperature” (about radiant and convective heat exchange)
- Approximated as the average of mean radiant temperature and air temperature
Thermal mass
Vernon’s globe (1930)

1. black globe
2. one-hole rubber stopper
3. dry bulb thermometer

Getting MRT from globe temperature

\[
MRT = \left[(GT + 273)^4 + \frac{1.1 \times 10^8 \cdot v_a^{0.6}}{\varepsilon \cdot D^{0.4}}(GT - T_a)\right]^{1/4} - 273
\]

**MRT** mean radiant temperature (C)

**GT** globe temperature (C)

\(v_a\) air velocity at the level of the globe (m/s)

\(\varepsilon\) is the emissivity of the globe (no dimension)

**D** diameter of the globe (m)

**\(T_a\)** air temperature (C)
Nova Lynx model - $345

- 6 inch diameter copper sphere
- Black matte paint
- Thermometer inserted through rubber stopper
- Sturdy stand
- Weight 2.3 kg
Classic materials
Does it have to be a 6 inch copper sphere?

- smaller globes more susceptible to air temperature and air velocity
- globes approximate people sitting down
- what's special about copper?? metal??
Formula again

\[ MRT = \left[ (GT + 273)^4 + \frac{1.1 \times 10^8 \cdot v_a^{0.6}}{\varepsilon \cdot D^{0.4}} (GT - T_a) \right]^{1/4} - 273 \]

- **MRT** mean radiant temperature (C)
- **GT** globe temperature (C)
- **\( v_a \)** air velocity at the level of the globe (m/s)
- **\( \varepsilon \)** is the emissivity of the globe (no dimension)
- **D** diameter of the globe (m)
- **\( T_a \)** air temperature (C)
Spot measurements
When two heated spheres, one black and one bright, but otherwise identical, are kept at the same temperature, they lose an equal amount of heat by conduction and convection. Any difference in heat input is due to the difference in radiational exchange.

Unless I am missing something, I struggle to see why the two globe must be at the same temperature?! All I see is two equations (one for each globe) and two unknowns (draught velocity and mean radiant temperature) (assuming that we can get the emissivities estimated, e.g. from measurement in a draught proof enclosure of known wall temperature!)
Globes
Electronics
Supporting materials
Cheapskate ground truth?
Friday, 1:30-5, City of Edinburgh Methodist
Please bring

- laptop, if you can
- useful junk: alternative globes, bases, hangers, ...
Q: Who cares if it’s cold?
A: Community groups
Risk
Important Criteria

- completeness
- truthfulness
- robustness
- aesthetics
Right shape, wrong religion?

Marie-Lan Nguyen / Wikimedia Commons / CC-BY 2.5
Not robust enough for spaces with children!
Close, but nope