UTCI
The Universal Thermal Climate Index

COST Action

Gerd Jendritzky
Freiburg, Germany

ISB  WMO
Why UTCI?

- Assessment of the thermal environment: Key issue in human biometeorology
- History: >100 simple thermal indices
- Last 35 years: heat budget modelling
- Integration of new knowledge and concerns
- Need: harmonization → UTCI (ISB, WMO)
- COST Action (Example: UV-Index)
Key applications

**Daily forecasts**
- Public weather service
- Warnings (heat load (HHWS), cold stress (windchill))
- Advice (clothing, outdoor activities)

**Climate**
- Bioclimatological assessments
- Bioclimate maps in all scales (micro - macro)
- Urban design, engineering of outdoor spaces
- Consultancy for where to live
- Outdoor recreation and climatotherapy
- Epidemiology
- Climate impact research
Key applications

Examples

• Klima-Michel-model with Perceived Temperature PT
• Assessment standard of DWD for the thermal environment
• Based on Fanger‘s PMV equation and Gagge‘s PMV* correction
• Application specific treatment of the meteorological input data (Tmrt!)

• All other complete heat budget models would provide comparable results (more or less).
Key applications

**Daily forecasts**
- Public weather service
- Warnings (heat load (HHWS), cold stress (windchill))
- Advice (clothing, outdoor activities)

**Climate**
- Bioclimatological assessments
- Bioclimate maps in all scales (micro - macro)
- Urban design, engineering of outdoor spaces
- Consultancy for where to live
- Outdoor recreation and climatotherapy
- Epidemiology
- Climate impact research
Perceived Temperature PT    July 27, 2003

heat load

UTC
13:00
Perceived Temperature PT July 29, 2003

heat load

UTC
13:00
Perceived Temperature PT  July 30, 2003

Heat load
- extreme
- strong
- moderate
- slight
- comfortable

Cold stress
- slight
- moderate
- strong
- extreme

UTC
13:00
Perceived Temperature PT  August 1, 2003

heat load

UTC
13:00
Perceived Temperature PT  August 2, 2003

UTC 13:00

heat load

cold stress

UTC
13:00
Perceived Temperature PT    August 7, 2003

heat load

- extreme
- strong
- moderate
- slight
- comfortable

cold stress

UTC
13:00
Perceived Temperature PT    August 8, 2003
Perceived Temperature PT    August 10, 2003

heat load

UTC
13:00
Perceived Temperature PT  August 11, 2003

heat load

cold stress

UTC
13:00
Perceived Temperature PT  August 12, 2003

heat load

- extreme
- strong
- moderate
- slight
- comfortable
- slight
- moderate
- strong
- extreme

cold stress

UTC
13:00
Perceived Temperature PT    August 13, 2003

heat load

cold stress

UTC
13:00
Perceived Temperature PT    August 15, 2003

heat load

UTC
13:00

cold stress
Perceived Temperature PT August 16, 2003

heat load

- extreme
- strong
- moderate
- slight
- comfortable

cold stress

UTC
13:00
Perceived Temperature
• extremely hot
Sultriness
• extremely sultry

UTC
13:00

Urgent need for HHWSs based on WMO/WHO/UNEP Showcase Projects
• thermophysiologically relevant approach (PT, UTCI)
• acclimatisation to local climate
• locally adjusted intervention measures
• operationally based on services of NMSs

Incease in Mortality
France: ~+15,000
Paris: +90 %

Increase in Mortality
France: ~+15,000
Paris: +90 %
DWD thresholds

Lisbon 2003

Perceived Temperature (°C)

- slight
- moderate
- strong
- extreme
- PT12

1.3.03 15.3.03 29.3.03 12.4.03 26.4.03 10.5.03 24.5.03 7.6.03 21.6.03 5.7.03 19.7.03 2.8.03 16.8.03 30.8.03 13.9.03 27.9.03

-s5 5 15 25 35 45 55
Stepwise Watch/Warning Procedure

- numerical weather forecast NWF
- watch criteria fulfilled?
  - yes: watch is issued → early warning to emergency response decision maker
  - no: no further action required
- warning criteria fulfilled?
  - yes: alert is issued to emergency response decision maker
  - no: watch criteria fulfilled?
    - yes: maintain watch
    - no: terminate watch

response action
Key applications

**Daily forecasts**
- Public weather service
- Warnings (heat load (HHWS), cold stress (windchill))
- Advice (clothing, outdoor activities)

**Climate**
- Bioclimatological assessments
- Bioclimate maps in all scales (micro - macro)
- Urban design, engineering of outdoor spaces
- Consultancy for where to live
- Outdoor recreation and climatotherapy
- Epidemiology
- Climate impact research
Bioclimatic map of Germany
Frequency of heat load in summer and cold stress in winter
1971-2000
Bioklima
-Winter-

Naturpark Südschwarzwald

Auftreten von Kältereizen
- selten
- gelegentlich
- vermehrt
- häufig
- sehr häufig
- überwiegend
Heilklimapark Hochtaunus

Gefühlte Temperatur in °C

127 - 140
141 - 150
151 - 160
161 - 170
171 - 180
181 - 190
191 - 200
201 - 210
211 - 220
221 - 230
231 - 240
241 - 250
251 - 260
261 - 270
271 - 280
281 - 290
291 - 300
301 - 310
311 - 330
Deutscher Wetterdienst

Human Biometeorology

cold

37°C
36°C
32°C
28°C
34°C
31°C

warm
Key applications

Daily forecasts
- Public weather service
- Warnings (heat load (HHWS), cold stress (windchill))
- Advice (clothing, outdoor activities)

Climate
- Bioclimatological assessments
- Bioclimate maps in all scales (micro - macro)
- Urban design, engineering of outdoor spaces
- Consultancy for where to live
- Outdoor recreation and climatotherapy
- Epidemiology
- Climate impact research

gerd.jendritzky@dwd.de DWD 2004
RayMan – http://www.mif.uni-freiburg.de/rayman

(A. Matzarakis, 2001)
Cross section street canyon

height

width
Deutscher Wetterdienst
Human Biometeorology

Berlin

frequency of heat load
Key applications

Daily forecasts
- Public weather service
- Warnings (heat load (HHWS), cold stress (windchill))
- Advice (clothing, outdoor activities)

Climate
- Bioclimatological assessments
- Bioclimatic maps in all scales (micro - macro)
- Urban design, engineering of outdoor spaces
- Consultancy for where to live
- Outdoor recreation and climatotherapy
- Epidemiology
- Climate impact research

gerd.jendritzky@dwd.de
DWD 2004
Total Mortality $M{R_{TOT}}$ and Perceived Temperature $PT$
Hypothetical heat warnings in 2003
Mortality in relation to the expected value


Lisbon (1981 - 1998)

SW Germany (1968 - 2003)

Budapest (1972 - 2001)

Thermal stress category

Thermal stress category

Thermal stress category

Thermal stress category
The heat wave 2003 in Europe: A unique feature?

IPCC WGI, 2001:

“Higher maximum temperatures and more hot days over nearly all land areas are very likely”

Beniston, 2004
Deutscher Wetterdienst
Human Biometeorology

△ Perceived Temperature PT (July) 2041-50 and 1971-80, „business-as-usual“ (IS92a)

ECHAM4/T106
DKRZ Hamburg
July Delta Perceived Temperature (K), IS92a-CTL

data: Deutsches Klimarechenzentrum Hamburg; ECHAM4/T106

birger.tinz@dwd.de

DWD 2000
Why UTCI?

- Assessment of the thermal environment: Key issue in human biometeorology
- History: >100 simple thermal indices
- Last 35 years: heat budget modelling
- Integration of new knowledge and concerns
- Need: harmonization → UTCI (ISB, WMO)
- COST Action (Example: UV-Index)
I  \[ M + W + Q^* + Q_H + Q_L + Q_{SW} + Q_{Re} = 0 \]

II  Simple indices

III  Heat budget modelling

IV  Multi-node models

V  UTCI
Avenues of Heat Exchange

- Sun or other radiation source
  - Direct radiation
  - Reflected radiation
- Infra-red radiation
- Conduction
- Convection
- Respiration
- Sweat evaporation
- External work
The human heat budget

\[ M + W + Q^* + Q_H + Q_L + Q_{SW} + Q_{Re} = 0 \]

- **M**: metabolic rate
- **W**: mechanical power
- **Q^***: radiation budget
- **Q_H**: turbulent flux of sensible heat
- **Q_L**: turbulent flux of latent heat (diffusion of water vapour)
- **Q_{SW}**: turbulent flux of latent heat (sweat evaporation)
- **Q_{Re}**: respiratory heat flux (sensible and latent)
Principle

Each index value must result in the same thermophysiological effect regardless of the combinations the meteorological input values.

No simple index is able to fulfill this requirement!
Why UTCI?

- Assessment of the thermal environment: Key issue in human biometeorology
- History: >100 simple thermal indices
- Last 35 years: heat budget modelling
- Integration of new knowledge and concerns
- Need: harmonization $\rightarrow$ UTCI (ISB, WMO)
- COST Action  (Example: UV-Index)
I \quad M + W + Q^* + Q_H + Q_L + Q_{SW} + Q_{Re} = 0

II \quad Simple indices

III \quad Heat budget modelling

IV \quad Multi-node models

V \quad UTCI
Thermophysiological Assessment of the Thermal Environment

<table>
<thead>
<tr>
<th>Descriptive term</th>
<th>Thermophysiology</th>
<th>Meteorology</th>
</tr>
</thead>
<tbody>
<tr>
<td>PMV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT*</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>PET</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>OUT_SET*</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>AT 1,2,3</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>(WCT)</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>T_{sk}</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>SR</td>
<td>kgs⁻¹</td>
<td></td>
</tr>
<tr>
<td>E_{SK}</td>
<td>Wm⁻²</td>
<td></td>
</tr>
<tr>
<td>W_{sk}</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>I_{cl}</td>
<td>clo</td>
<td></td>
</tr>
</tbody>
</table>

Heat budget models
(one or two nodes)

- Fanger (1970)
- Jendritzky et al. (1979, 1991)
- Steadman (1984, 1994)
- Hoeppe (1984, 1999)
- Gagge et al. (1986)
- Blazejczyk (1994)
- Horikoshi et al. (1995, 1997)
- Pickup & de Dear (2000)
- Bluestein & Osczevski (2002)
- etc.
**Tmrt**

Uniform temperature of a black body enclosure that results in the same radiant heat exchange as under actual conditions

- Direct solar radiation
- Diffuse solar radiation
- Reflected solar radiation
- Infrared radiation from the sky
- Infrared radiation from the surroundings
### Human Biometeorology

<table>
<thead>
<tr>
<th>Azimuth</th>
<th>0°</th>
<th>30°</th>
<th>63°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>![0° Figure]</td>
<td>![30° Figure]</td>
<td>![63° Figure]</td>
<td>![90° Figure]</td>
</tr>
</tbody>
</table>

- **Azimuth**: 0°, 30°, 63°, 90°
- **Elevation**: Images of human figures at different azimuths and elevations.
Deutscher Wetterdienst
Human Biometeorology

Mean Radiant Temperature
\text{t_{25^\circ C}, s=15.9 \, hPa, ff=5 \, m/s}

VDI 3789/2

\Delta T_{\text{met}} \, K

S + D(0)_{\text{ext}}

S(0)

D(N)_{\text{ext}}

N=4

N=6

N=2

N=8

N=0

sun altitude

henning.staiger@dwd.de

DWD 2004
Why UTCI?

- Assessment of the thermal environment: Key issue in human biometeorology
- History: >100 simple thermal indices
- Last 35 years: heat budget modelling
- Integration of new knowledge and concerns
- Need: harmonization → UTCI (ISB, WMO)
- COST Action (Example: UV-Index)
I \[ M + W + Q^* + Q_H + Q_L + Q_{SW} + Q_{Re} = 0 \]
II Simple indices
III Heat budget modelling
IV Multi-node models
V UTCI
Deutscher Wetterdienst
Human Biometeorology

Fiala et al. 2001

SECTION A-A':

OUTER SKIN
INNER SKIN
FAT
MUSCLE
BONE (CORE)

SHORT WAVE RADIATION

EVAPORATION

LONG WAVE RADIATION

CONVECTION

Respiration
Clothing

A-A'

gerd.jendritzky@dwd.de
DWD 2004
Simulated whole body and local thermophysiological variables

- Mean skin temperature, $T_{sk,m}$
- Head core temperature (hypothalamus), $T_{hy}$
- Total evaporative heat loss from the skin, $E_{sk}$
- Skin wettedness, $w_{sk}$
- Local skin temperatures of face and hands, $T_{sk,f,h}$
- Cooling time for $T_{sk,f,h} < 0°C$

Assessment problem!
Variables for multi-node model simulations

Meteorological input

Air temperature ($T_a$): $-40^\circ$C < $T_a$ < $+45^\circ$C 5K

Mean radiant temperature ($T_{mrt}$): $-10K < T_{mrt} - T_a < +40K$ 10K

Relative humidity (rh): 5% < rh < 95% 15%

Relative wind speed ($v_r$): 1.1, 2.2, 4.4, 8.8, 17.6 m/s (*2)

Intrinsic clothing (Icl): 0.4, 0.6, 0.9, 1.3, 1.8, 2.6 clo

22680 combinations (partially unrealistic, but which?)
Perceived Temperature $PT^*$, °C

-50 to 50

very hot
hot
warm
slightly warm
comfortable
slightly cool
cool
cold
very cold

PMV (work performance 172 W, clo = 0.5-1.75)
1 \quad M + W + Q^* + Q_H + Q_L + Q_{SW} + Q_{Re} = 0

II \quad Simple indices

III \quad Heat budget modelling

IV \quad Multi-node models

V \quad UTCI
Human Biometeorology

Reference conditions for UTCI temperature*

- Activity walking 4 km/h = 2.3 MET (135 Wm$^{-2}$)
- Calm wind, i.e. only wind induced by walking (1.1 m/s)
- $T_{mrt} = T_a$
- $\text{rh} = 50\%$
- $I_{cl}$: variable (0.5 - 2.0 clo)

*Temperature of a reference environment that provides the same heat exchange as under the actual thermal conditions
Summary: Basic features of UTCI

- Thermophysiologically significant in the whole range of heat exchange conditions
- Valid in all climates, seasons and scales
- Useful for key applications in human biometeorology
- Steady-state conditions \( \Rightarrow \) practically useful results
- Independent of individual characteristics
- Prediction of whole body and local thermal effects
- Based on the most advanced multi-node models
- Temperature scale index
Selected subproblems

- Heat budget modelling
- Assessment of physiological variables
- Acclimatisation
- Meteorological input, in particular radiation $\Rightarrow T_{mrt}$
- Definition of areas of validity, requirements
- Applications
- ?
Why UTCI?

- Assessment of the thermal environment: Key issue in human biometeorology
- History: >100 simple thermal indices
- Last 35 years: heat budget modelling
- Integration of new knowledge and concerns
- Need: harmonization → UTCI (ISB, WMO)
- COST Action (Example: UV-Index)
Why UTCI?

• Assessment of the thermal environment: Key issue in human biometeorology
• History: >100 simple thermal indices
• Last 35 years: heat budget modelling
• Integration of new knowledge and concerns
• Need: harmonization → UTCI (ISB, WMO)
• COST Action  (Example: UV-Index)