Dependence of mean radiant temperature on 3D radiant flux densities: the example of urban quarters in a mid-size Central European city during summer heat

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problem

- main problem for urban planning in Central European cities: increasing summer heat due to regional climate change
  ➔ to develop, apply and validate mitigation methods

- relevance for citizens by methods and results from
  urban human-biometeorology

- thermal stress for citizens
  quantified by thermal indices like PET (not T_a or UHI!)
  strongest outdoors in summer

- most crucial variable: radiant exchange in terms of T_{mrt}

determination of T_{mrt}

- numeric simulation by models, e.g.
  - SOLWEIG
  - ENVI-met
  - RayMan
- experiments
  - globe thermometer
  - **six-directional method**

    measuring short- and long wave radiant flux densities
    - from the four horizontal cardinal directions (E, S, W, N)
    - as well as from the upper and the lower hemisphere

T_{mrt}

$$T_{mrt} = \left[\frac{S_{rad}}{\varepsilon \cdot \sigma} \right]^{0.25} - 273.15$$

T_{mrt}: mean radiant temperature (°C)

S_{rad}: total of all absorbed radiant flux densities ($W\ m^{-2}$)

ε: emissivity of the human body (0.97)

σ: Stefan-Boltzmann constant ($5.67 \cdot 10^{-8}\ W\ m^{-2}\ K^{-4}$)

S_{rad}

$$S_{rad} = \sum_{i=1}^{6} W_i \cdot \left(\alpha_k \cdot K_i + \alpha_l \cdot L_i\right)$$

S_{rad}: total of all absorbed radiant flux densities (W m^{-2})

K_i: short-wave radiant flux densities

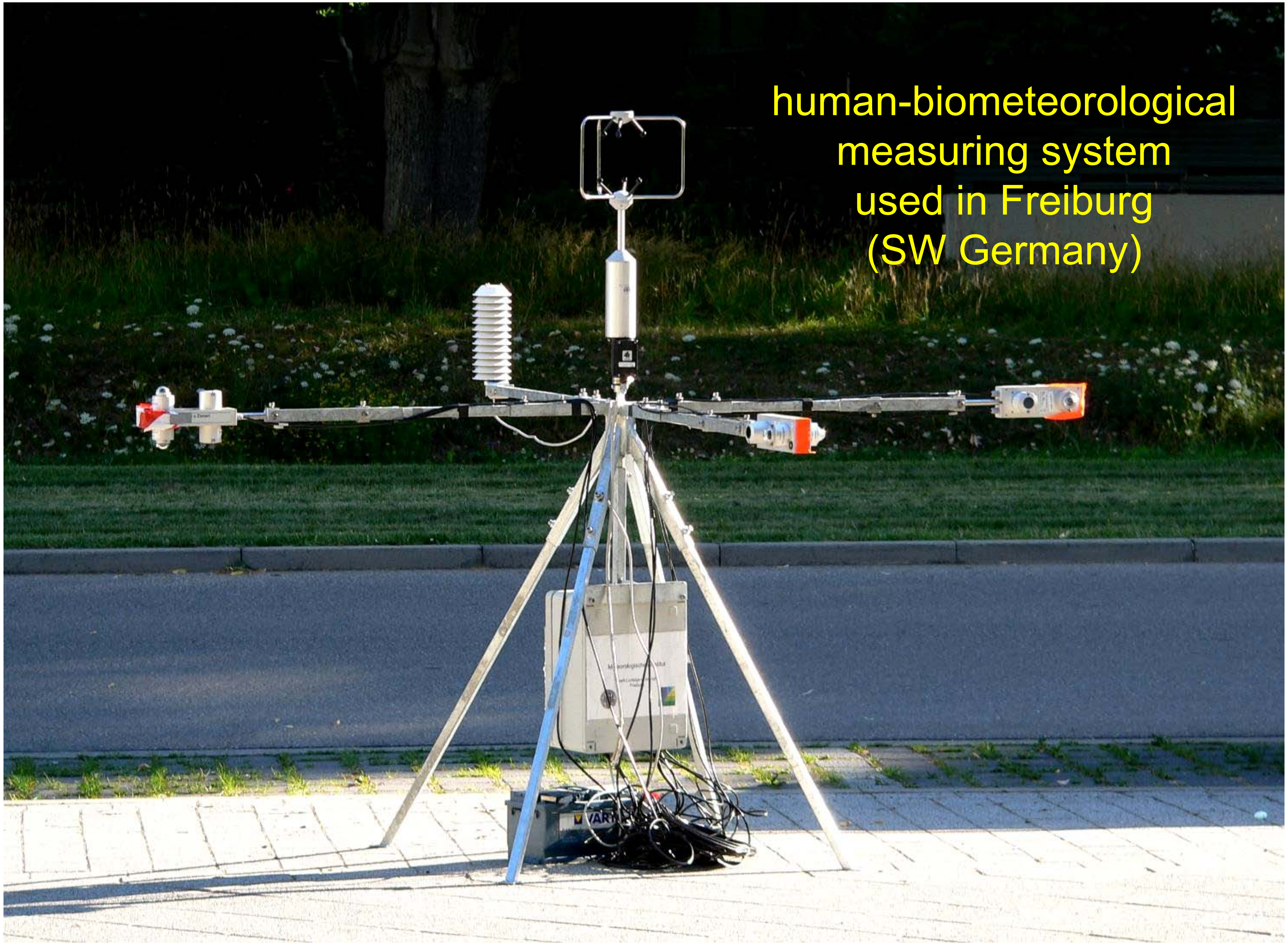
L_i: long-wave radiant flux densities

α_k: short-wave absorption coefficient (0.7)

α_l: long-wave absorption coefficient (0.97)

W_i: angle factors (percentage of K_i and L_i, received by the human body in each direction i)

six-directional method



investigation design

- 1-d experiments (7 a.m. - 9 p.m.)
  - by use of specific
    human-biometeorological measuring systems
  - at 90 different sites in Freiburg
    (mid-size city in SW Germany)
    mostly street canyons of various designs
  - during typical Central European summer weather
  - from 2007-2010

- results are aggregated to mean values over 10-16 CET
  typical timescale for daytime heat
  in Central European cities

results (I)

- linear regressions: $y = a \cdot x + b$

  x: sky view factor for the southern part of the upper half space ($SVF_{90\text{-}270}$)

y	x	R^2
T_a (°C)	$SVF_{90\text{-}270}$ (%)	0.002
T_{mrt} (°C)	$SVF_{90\text{-}270}$ (%)	**0.774**
PET (°C)	$SVF_{90\text{-}270}$ (%)	0.332

results (II)

- linear regressions: $y = a \cdot x + b$

  x: short-wave radiant flux densities

  absorbed by the human-biometeorological reference person

y	x	R^2
T_{mrt} (°C)	$K{\downarrow}_{abs}$ (W/m^2)	0.898
T_{mrt} (°C)	$K_{hor,abs}$ (W/m^2)	0.900
T_{mrt} (°C)	$K_{vert,abs}$ (W/m^2)	0.902
T_{mrt} (°C)	K^*_{abs} (W/m^2)	**0.910**

results (III)

- linear regressions: $y = a \cdot x + b$

  x: long-wave radiant flux densities

  absorbed by the human-biometeorological reference person

y	x	R^2
T_{mrt} (°C)	$L\downarrow_{abs}$ (W/m^2)	0.021
T_{mrt} (°C)	$L\uparrow_{abs}$ (W/m^2)	**0.755**
T_{mrt} (°C)	$L_{hor,abs}$ (W/m^2)	0.400
T_{mrt} (°C)	$L_{vert,abs}$ (W/m^2)	0.391
T_{mrt} (°C)	L^*_{abs} (W/m^2)	0.402

conclusions (I)

- linear regressions: $y = a \cdot x + b$
  - y: T_a, T_{mrt}, PET (averaged over 10-16 CET)
    x = $SVF_{90\text{-}270}$
    ➔ highest R^2 (0.774) for y = T_{mrt}
  - y = T_{mrt} (10-16 CET)
    x: absorbed short-wave radiant flux densities (10-16 CET)
    ➔ highest R^2 (0.910) for x = K^*_{abs}
  - y = T_{mrt} (10-16 CET)
    x: absorbed long-wave radiant flux densities (10-16 CET)
    ➔ highest R^2 (0.755) for x = $L\uparrow_{abs}$

conclusions (II)

- linear regressions: $T_{mrt} = a \cdot x + b$

  ➔ higher R^2 values for different K_{abs} flux densities (x)
  in contrast to different L_{abs} flux densities (x)

- multiple regression:

  $T_{mrt} = 0.113 \cdot K^*_{abs} + 1.535 \cdot L\uparrow_{abs} - 12.6$

  ➔ $R^2 = 0.977$

conclusions (III)

- linear regressions: $T_{mrt} = a \cdot x + b$

  ➔ higher R^2 values for different K_{abs} flux densities (x) in contrast to different L_{abs} flux densities (x)

- multiple regression:

$$T_{mrt} = 0.113 \cdot K^*_{abs} + 1.535 \cdot L\uparrow_{abs} - 12.6$$

➔ $R^2 = 0.977$

$$T_{mrt} = 0.661 \cdot K\downarrow_{abs} + 1.359 \cdot L\uparrow_{abs} - 6.7$$

➔ $R^2 = 0.941$

T_{mrt} (°C); $K\downarrow_{abs}$, K^*_{abs}, $L\uparrow_{abs}$ (W/m²): mean values over 10-16 CET


Thank you for
your attention