CALCULATING UTCI EQUIVALENT TEMPERATURE.

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INTRODUCTION

The 'Universal Thermal Climate Index' (UTCI) (Jendritzky et al. 2007) ultimately aims at developing a one-dimensional quantity, which adequately reflects the human physiological reaction to the multi-dimensionally defined actual thermal condition. The human reaction is simulated by a multi-node model of human thermoregulation (Fiala et al. 2001, 2007), which is augmented by a clothing model. As illustrated in Figure 1, the index value will be calculated from the multivariate dynamic output of that model.

Expressing the index value in terms of an equivalent temperature constitutes a commonly applied concept (Richards and Havenith 2007, Parsons 2003). As operationalised in UTCI, the equivalent temperature (ET) is defined as the air temperature (Ta) of the reference condition causing the same model response as the actual condition. For applying this definition both the reference condition and the model response have to be identified.

The left panel of Figure 2 illustrates the derivation of ET for an actual climatic condition. The offset to air temperature (Ta) is found by comparing the actual model response to the response under reference conditions. As demonstrated in the right panel of Figure 2, it can be deduced from the definition that ET equals air temperature under reference conditions.

For explicitly performing these comparisons, the multivariate dynamic model response has to be condensed into a one-dimensional representation, which may be termed as response index.

As details on the clothing model and on the reference conditions are provided elsewhere, this paper focuses on the statistical treatment applied to the model response for implementing the calculation of the UTCI equivalent temperature (ET).

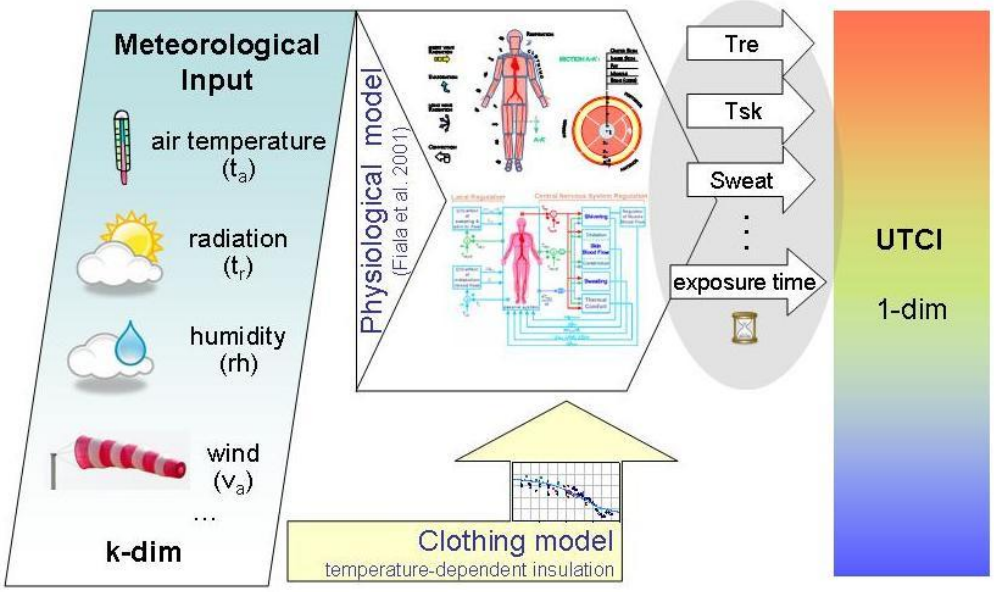

Figure 1: Scheme for the climatic assessment by UTCI calculated from the dynamic output of a thermophysiological model augmented by a clothing model.

METHODS

Simulation runs of the physiological model generated two sets of data with values of twelve output variables after simulated exposure times of 30, 60, 90 and 120 min:

- Grid data (N = 104692) with the output of the physiological model for conditions defined over a grid of meteorological input variables, for which ET values will be required. The climatic parameters were defined as:
  - Air temperature: -50 °C ≤ Ta ≤ +50 °C (1 K increment)
  - Mean radiant temperature: -30 °C ≤ Tr – Ta ≤ +70 °C (5 K increment),
  - Wind speed (10 m above ground level):
    va = 0.5, 0.8, 1.2, 1.8, 2.7, 4.0, 6.0, 9.0, 13.5, 20.2, 30.3 m/s,
  - Humidity:
    rh=5, 50, 100% (Ta ≤ 0 °C),
    rh=5, …(6 steps)…, 100% or max. vapour pressure = 5 kPa (Ta > 0 °C)
- Reference data (N = 926) containing the results of simulation runs for the reference conditions with air temperature covering the expected range of ET predictions. The climatic parameters were defined as:
  - Air temperature: -110 °C ≤ Ta ≤ +75 °C (0.2 K increment)
  - Mean radiant temperature: Tr = Ta,
  - Wind speed (10 m above ground level): va = 0.5 m/s,
  - Humidity: rh=50% (Ta ≤ 29 °C), vapour pressure = 2 kPa (Ta > 29 °C)

Two steps of multivariate analyses were applied to the grid data. Hierarchical cluster analyses were used to identify a subset of the 48 physiological variables (12 quantities at 4 time points), which shall characterize the model response adequately. Then a one dimensional response index representing the model response was calculated by principal component analysis on this subset.

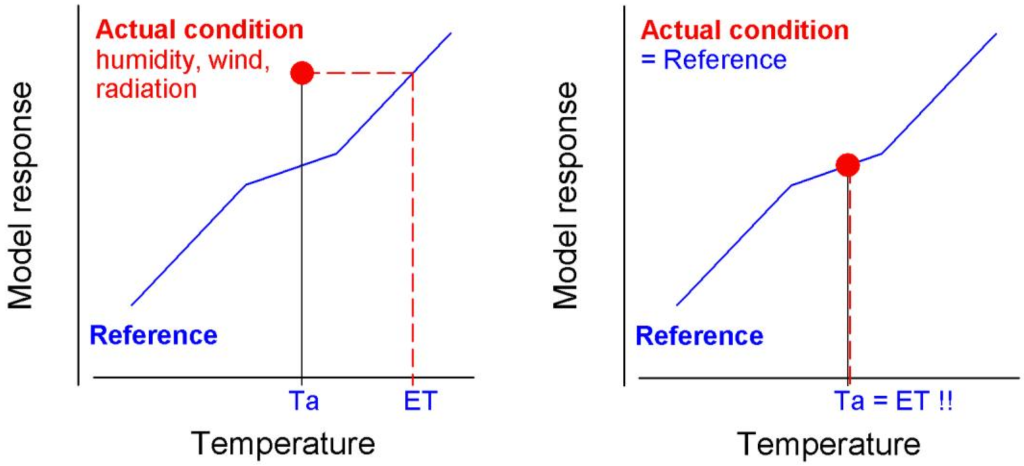

Figure 2: Concept of deriving the equivalent temperature (ET) in the general case (left) and for an actual condition coinciding with the reference (right panel).

Eventually, ET was computed by determining the air temperature of the reference data with the same value of the response index as the grid data under consideration as illustrated in Figure 2.

RESULTS

The hierarchical cluster analyses, which had shown similar outcomes in an earlier version of the reference dataset (Bröde et al. 2009, Kampmann et al. 2008), revealed that the dynamic model response was sufficiently represented by the values after 30 and 120 min of 7 parameters of thermal strain: rectal, mean skin and face temperatures, sweat rate, skin wettedness, skin blood flow, shivering.

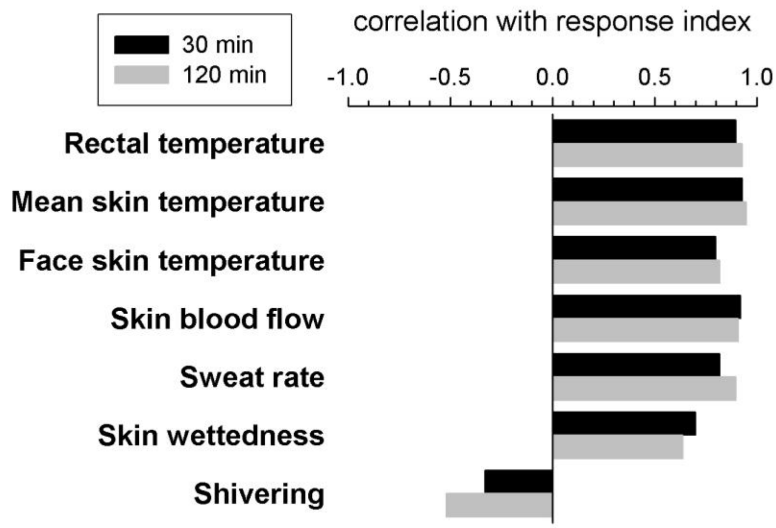

Figure 3: Correlation coefficients of the single physiological variables after 30 and 120 min with the one dimensional response index calculated by principal component analysis.

The first principal component calculated from these variables accounted for approximately two thirds of the total variation and was applied as a response index in the subsequent calculations of ET.

From the correlation coefficients of the single variables with the response index (Figure 3), it can be deduced that an increase in rectal and skin temperatures, skin blood flow, sweat rate and skin wettedness also increases the response index value, while an increase in shivering (as well as a decrease in rectal and skin temperatures and blood flow) is associated with a decrease of the response index.

Therefore the response index may be interpreted as an integrated characteristic value of thermal strain with high values pointing to heat strain, whereas low values indicate cold strain.

As different combinations of values of the single variables may lead to identical values of the response index, climatic conditions with the identical ET have, by definition, the same value of the response index, but may yield non-unique values for single variables like rectal or mean skin temperature. However, due to the high correlation of the single variables with the response index, this variation was limited, as indicated in Figure 4 for the rectal temperature after 2h.

Furthermore, the median response to ET was in good agreement with the values obtained for the reference conditions (Figure 4).

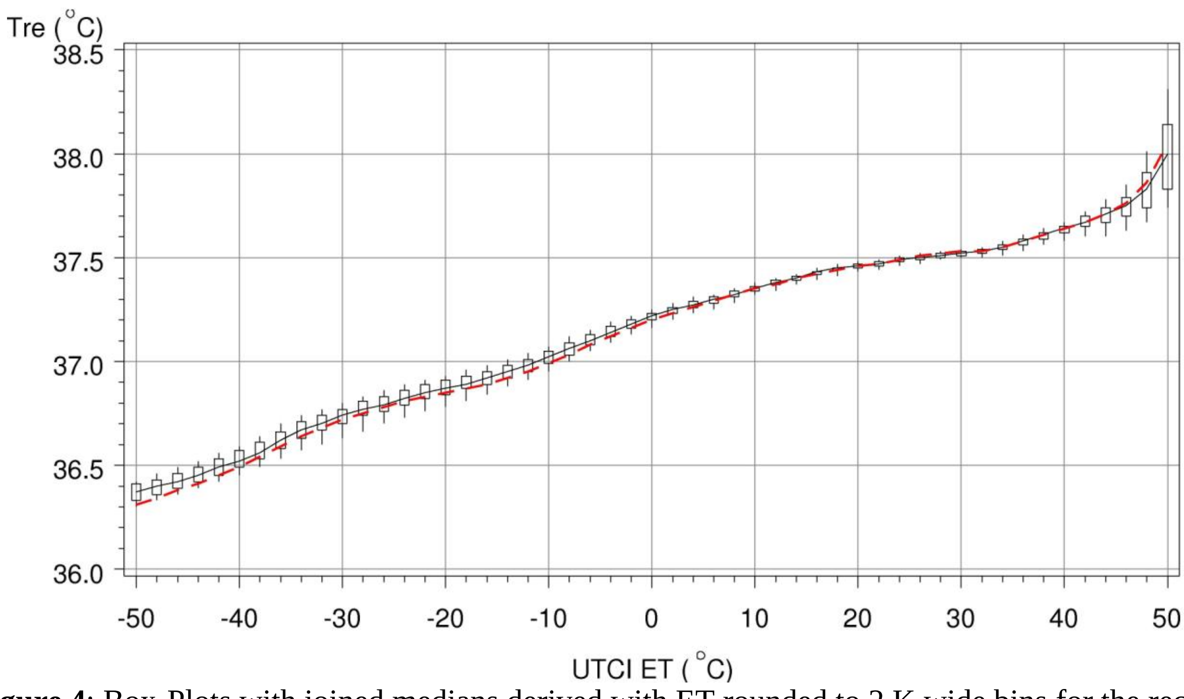

Figure 4: Box-Plots with joined medians derived with ET rounded to 2 K wide bins for the rectal temperatures (Tre) after 2h. The whiskers mark the 5th and 95th percentile, respectively. Values for the reference conditions are plotted as the red broken line.

CONCLUSIONS

The projection of the multivariate dynamic response of the physiological model into a one dimensional integrated characteristic value of thermal strain allowed for the calculation of UTCI equivalent temperatures over a wide range of relevant combinations of the meteorological parameters.

The good agreement of the median response of single variables to ET with the values obtained for the reference conditions suggests that the assessment or categorization of climatic situations into conditions of heat or cold stress can be based on the responses to the reference conditions.

First results of sensitivity analyses performed within this action indicate that UTCI ET reflects the expected effects of wind, heat radiation and humidity.

ACKNOWLEDGEMENTS

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