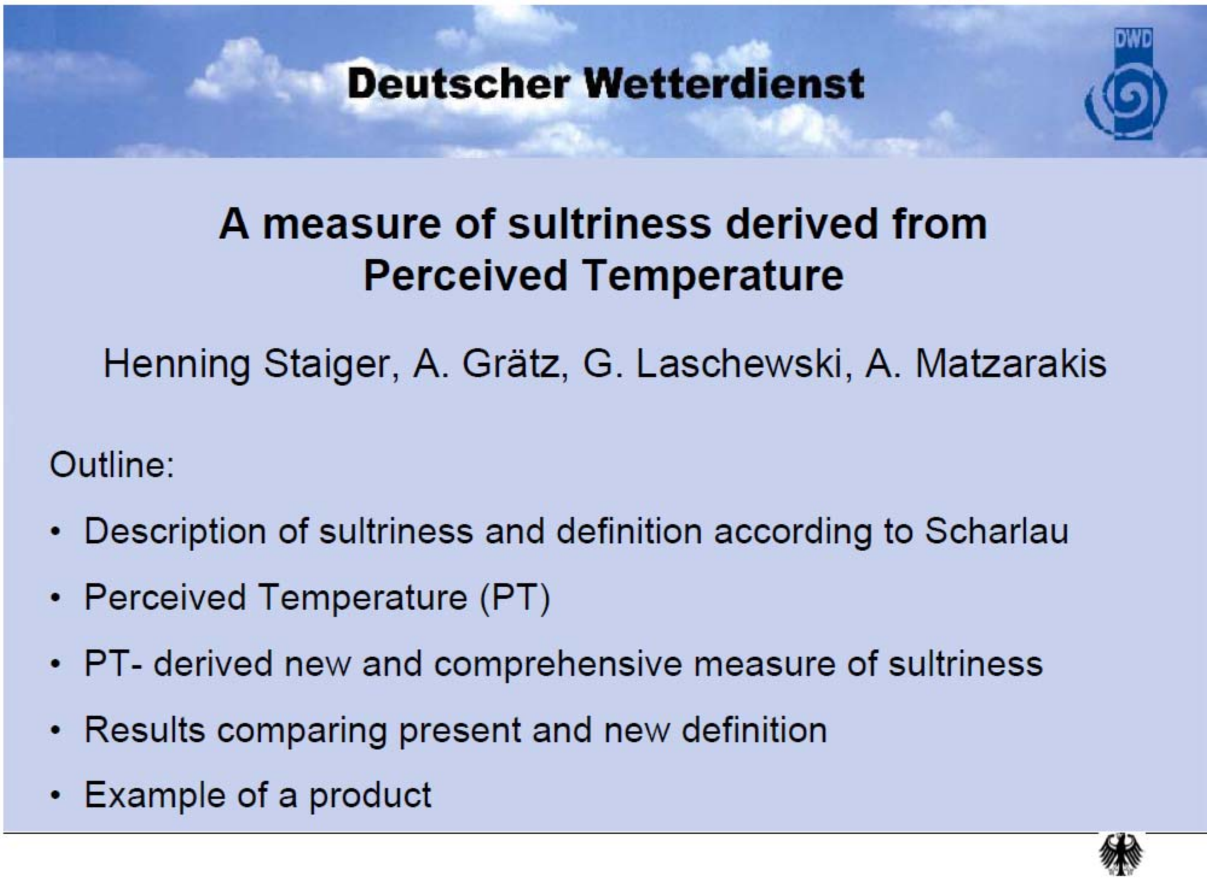
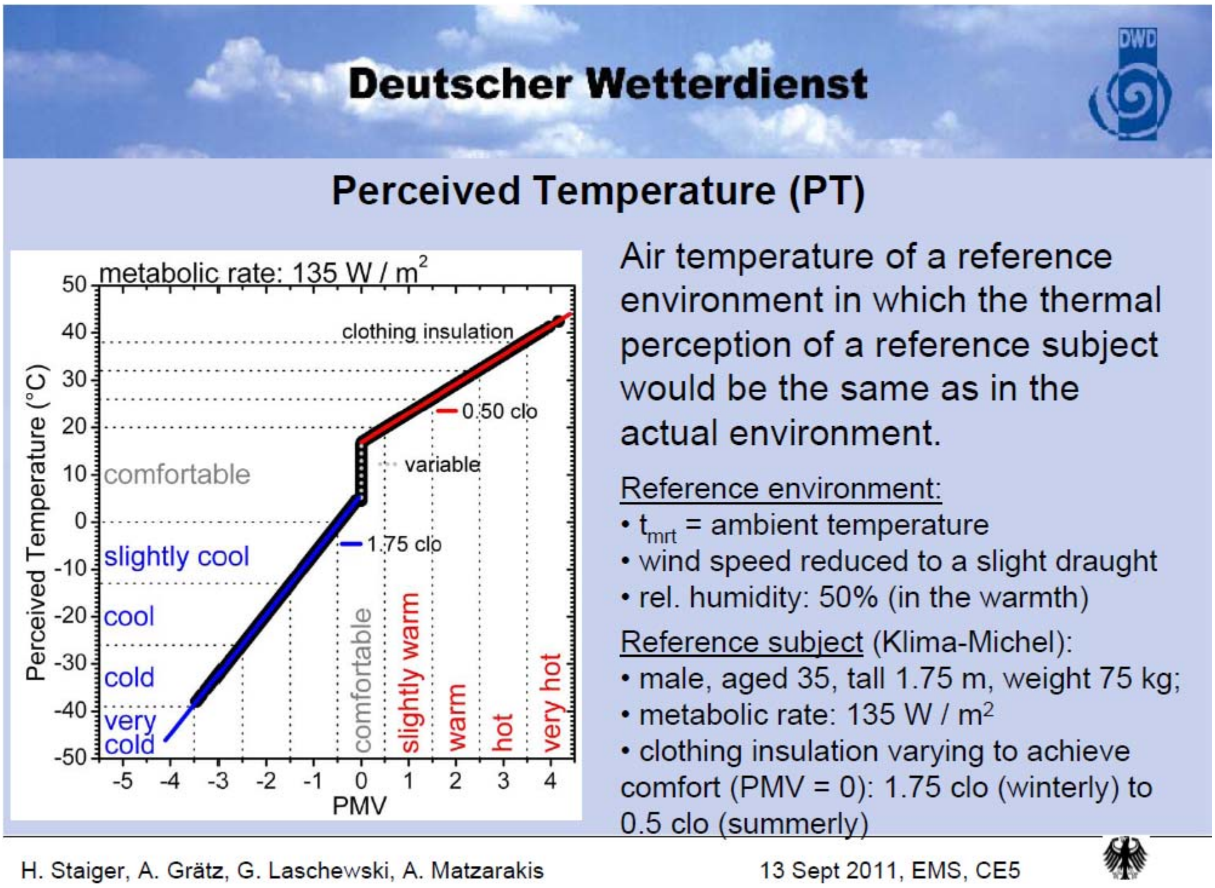


Ladies and Gentlemen!

In the summer half year German public weather forecasts frequently apply the term sultriness (in German Schwüle) in conjunction with warm and moist air masses advected from the South-West, and with thunderstorms developing under unstable air-layering. Sultriness is currently classified based on a meteorological definition that was strongly discussed in the first five to six decades of the last century. My presentation will introduce a new and comprehensive measure of sultriness. It is based on the Perceived Temperature (PT) applied by the German Meteorological Service (DWD) in evaluation of heat load and cold stress.

Hentschel describes sultriness as a sluggish, humid-warm milieu that is formed at the body surface. It epitomises thermal uncomfortable feeling. Sultriness is a special case in thermal perception, which is not subdivided into the usual scale between warm and hot neither from the physiological state nor from the climatological characterisation. It extends over a wide range of ambient temperatures and diminishes for temperatures above 32 degrees centigrade.

At present, sultriness is defined according to Scharlau at dewpoint temperatures that exceed 16.5 degrees centigrade. Forty years ago, Hentschel establishes a threshold of 14.5 degrees valid for Eastern Germany. This uncertainty in the threshold clarifies the conclusion of the last century discussions that the perception of sultriness depends on all variables influencing the human heat budget. These are ambient temperature and humidity, wind speed, short- and long-wave radiation as well as metabolic rate and insulation of clothing worn by a subject.



DWD evaluates heat load and cold stress on the human body by the Perceived Temperature (PT).

PT is defined as the ambient temperature of a reference environment in which the thermal perception of a reference subject would be the same as in the actual environment. The assessment of thermal perception is based on Fanger's Predicted Mean Vote (PMV).

PT is adapted to the assessment of outdoor conditions by enabling the clothing insulation worn to be varied to achieve comfort that means PMV equals zero. The range is restricted to 1.75 clo for cold through 0.5 clo for warm conditions. In this region PT depends on the clothing insulation only. In the adjacent cold and warm regions the clothing insulation is fixed and PMV is a measure for cold stress and heat load, respectively.

Stronger deviations from thermal neutrality are not sufficiently covered by Fanger's comfort equation. Hence, for an improved thermoregulatory performance the model is extended for these regions according to a proposal of Gagge using the ASHRAE standard "2-node-model".

Deutscher Wetterdienst

Stronger deviations from thermal neutrality: PT - extensions

$$PMV^* = PMV_{Fanger} + \Delta PMV$$

$$\Delta PMV = \alpha \times h' \times \left\{ \left(et^* - t_o\right) + \Delta t_{sk} \right\}$$

$$\Delta PMV = \alpha \times h' \times \left\{ LR \times i_m \times w_{rsw} \times \left(p_a - 0.5 \times p_{s,et^*}\right) + \Delta t_{sk} \right\}$$

$$h' = 1/\left(R_{cl} + \left((1 + 0.15 \times I_{cl}) \times (h_c + h_r)\right)^{-1}\right) \text{ (overall heat transfer coefficient)}$$

$$h_c = 12.1 \times \sqrt{v_{1m} \times \frac{p_b}{1013.25}} \qquad h_r = \frac{\partial\, \sigma \times T_{mrt}^4}{\partial\, T_{cl}} \text{ (conv. + rad. heat transfer coef.)}$$

$$R_{cl} = I_{cl} \times 0.155 \left[m^2 \times K \times W^{-1}\right] \text{ (clothing insulation)}$$

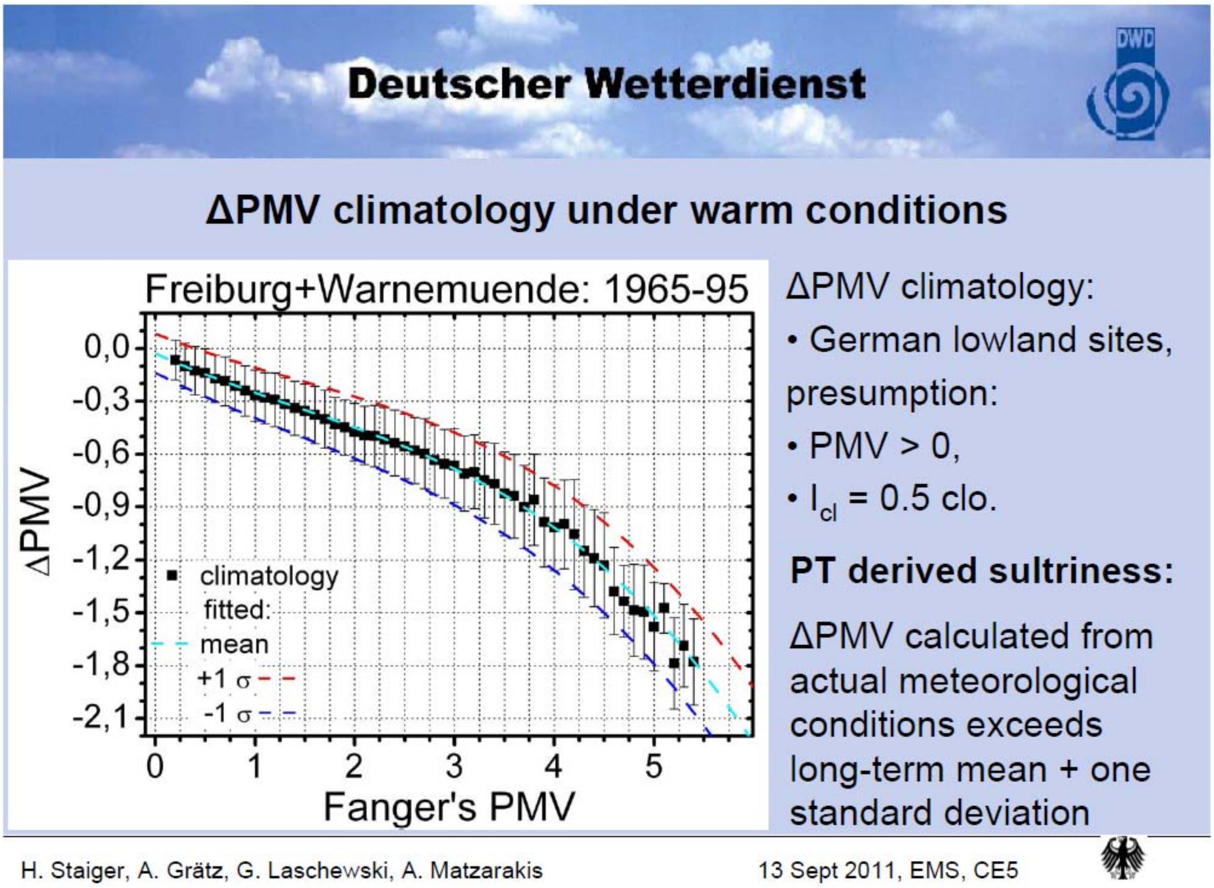
H. Staiger, A. Grätz, G. Laschewski, A. Matzarakis 13 Sept 2011, EMS, CE5

The extension is achieved by substitution of the operative temperature in Fanger's comfort equation by the rational effective temperature et*. The difference to Fanger's comfort equation is described by a term ΔPMV and the sum results in a rational PMV* that is applied in deriving the Perceived Temperature.

In the warmth, ΔPMV assesses via the difference between the rational effective and the operational temperature the enthalpy of sweat-moistened skin and of wet clothes and, thus, it can markedly deviate from Fanger's sweat evaporation under comfort.

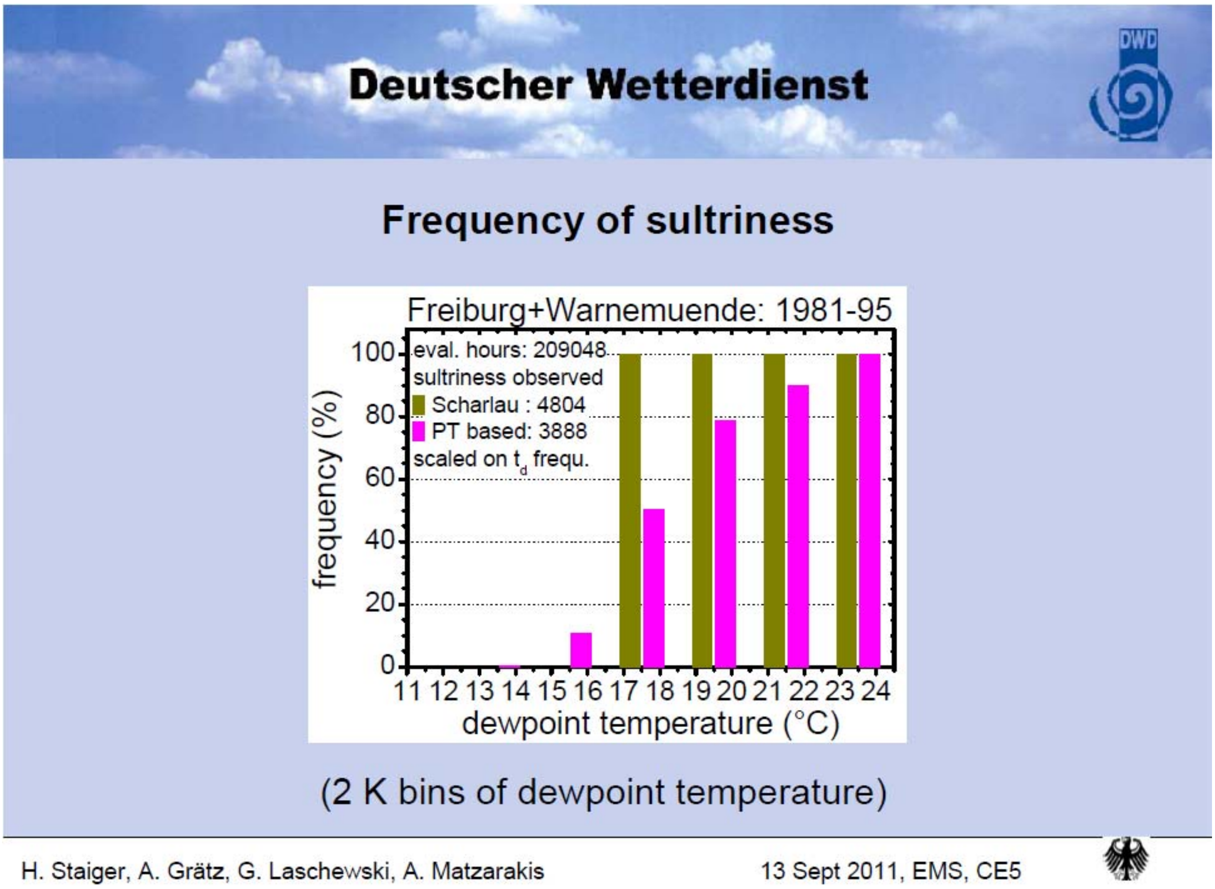
In the cold, the effective temperature equals the operative temperature and the difference is only due to skin temperature differing from Fanger's value for comfort.

ΔPMV is a function of required skin wettedness to balance the heat budget, of ambient water vapour pressure, and of saturation water vapour pressure at the rational effective temperature. Because the rational effective depends amongst others on the operative temperature, ΔPMV is implicitly also a function of Fanger's PMV.

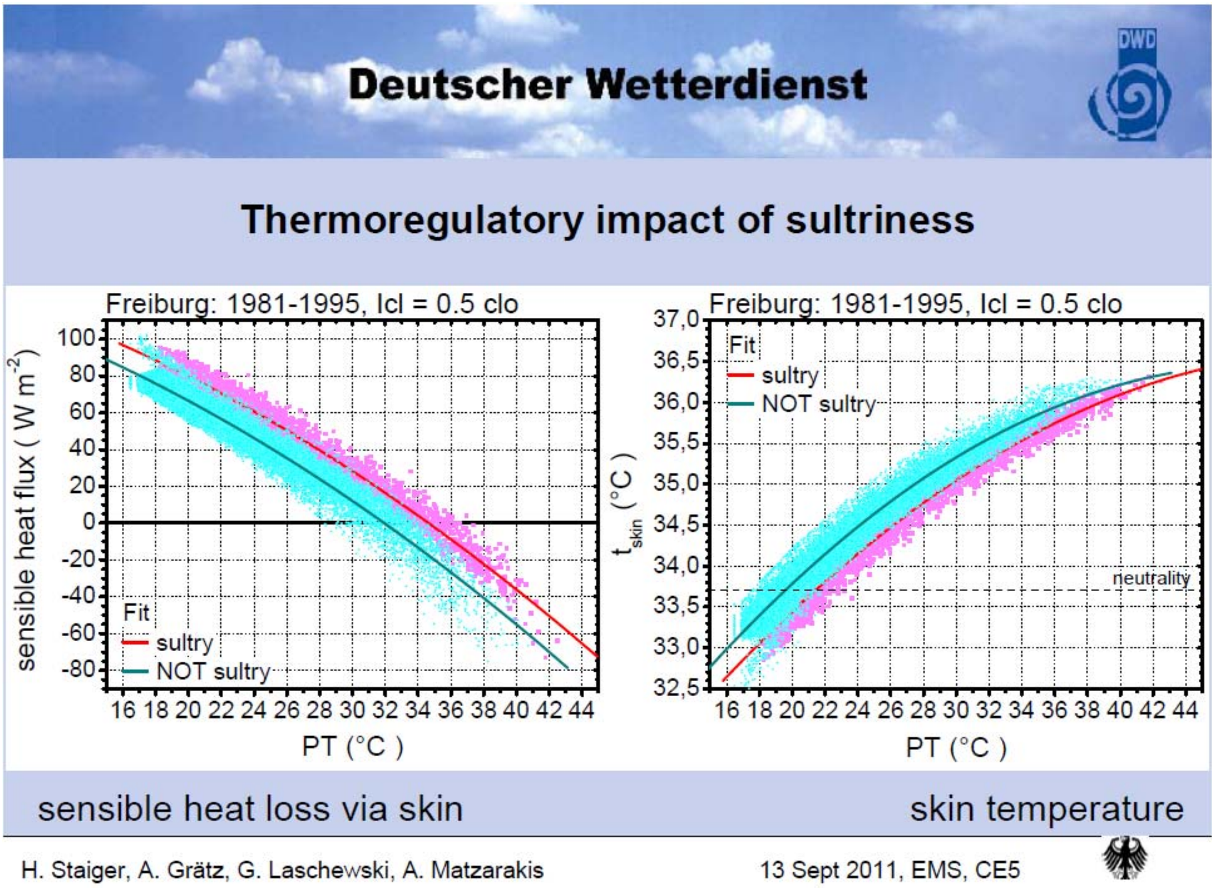


This justifies that for warm conditions the long-term climatology of ΔPMV is calculated at two German lowland sites over bins of Fanger's PMV. Under Central European conditions, Fanger's PMV undergoes an increased reduction by the model extension. The standard deviation in ΔPMV is a measure of typical variations in the interdependency of the meteorological variables determining the climate of Germany.

Hence, for subjects acclimatised to Central European meteorological conditions a PT derived sultriness is defined for such actual conditions that exceed the long-term mean of ΔPMV by more than one standard deviation.



The plot displays the frequency of sultriness for the respective definitions. It is scaled to the frequency of dewpoint temperature. Thus, Scharlau's sultriness, the dark yellow columns is 100 % for dewpoint temperatures greater than 16.5°C and zero below this threshold. In contrast, PT derived sultriness, the magenta coloured columns, can occur for dewpoints less than 16.5°C and it is not in all cases classified for dewpoint temperatures above this threshold. Hence, not only the dewpoint temperature but also other influencing variables can restrict or abet sensible and latent heat flow via the skin, respectively.

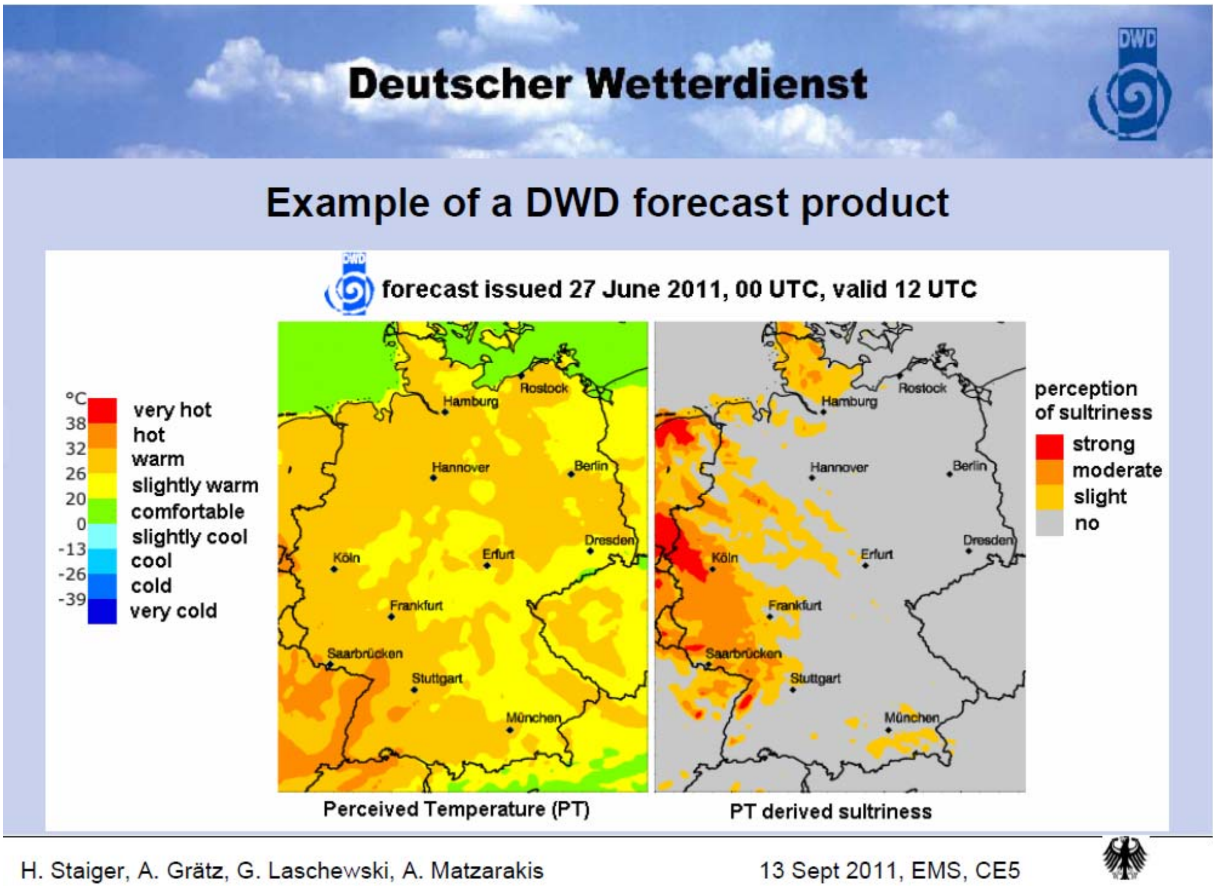


The thermo-physiology inherent the “2-node-model” enables the rationale of sultriness to be elucidated.

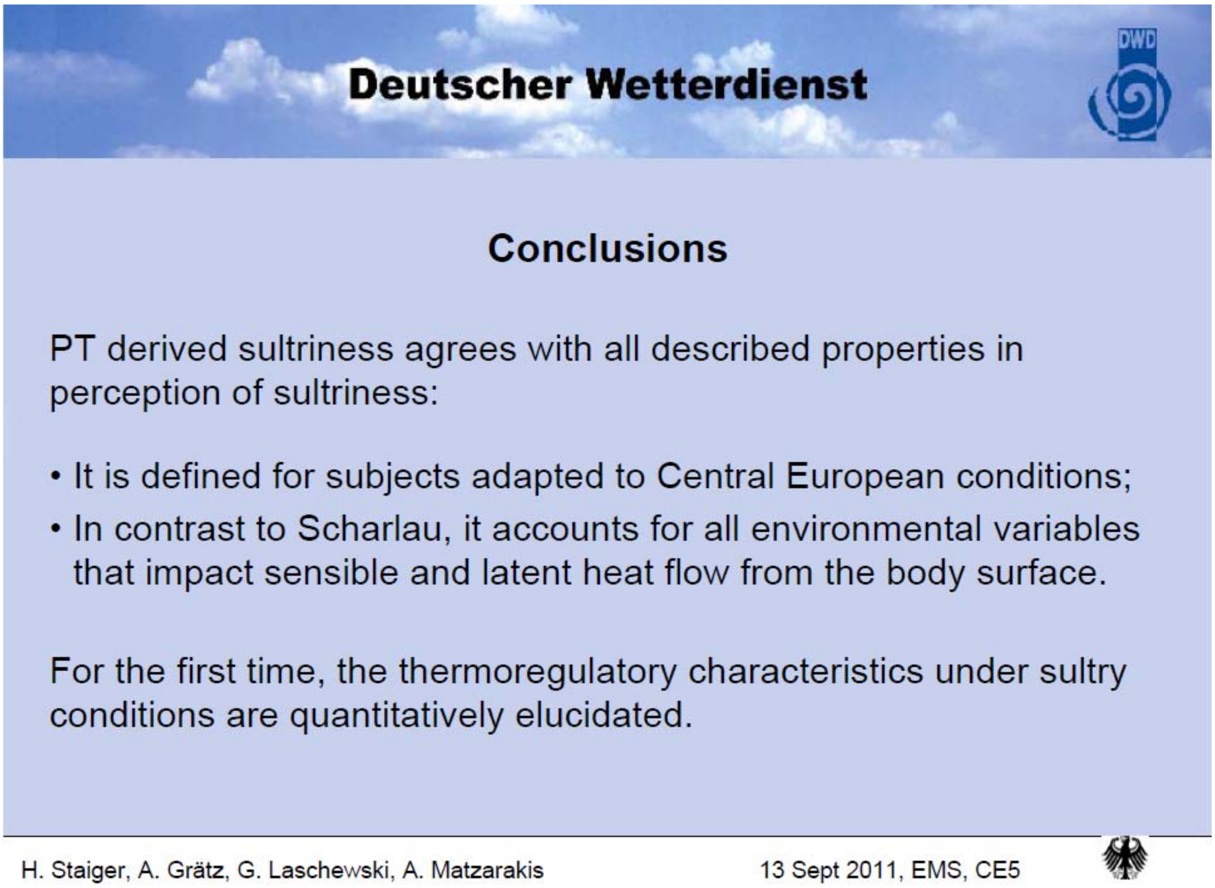
As an example for the passive system, that are the sensible and latent heat fluxes, the left-hand diagram reveals that the sensible heat flux, magenta coloured symbols, is increased under sultry conditions compared to the cases not classified to be sultry and vice-versa for the latent heat flux.

As an example for one of the variables actively regulated by the hypothalamic system, the right-hand plot reveals that the skin temperature is reduced under sultry conditions. That is, the temperature difference between skin and core is increased in maintaining a constant core temperature. However, this requires vasoconstriction that reduces the blood flow to the skin, and thus, the skin temperature must even more be reduced.

Hence, the thermal environment implies a strain on the thermoregulatory system. At least for subjects acclimatised to Central European meteorological conditions, the thermoregulation is outside of optimal responses and the subject is conscious of the adverse environmental impact.



The slide shows a routine forecast product of DWD. The left-hand map displays the spatial distribution of heat load evaluated by PT. This spatial distribution differs markedly from those of PT derived sultriness. E.g., the upper Rhine valley overall shows hot conditions by assessment via PT. However, only the northern parts are classified to be sultry.



Conclusions:

- The PT derived sultriness is in accordance with all described properties in the perception of sultriness.
- For the first time, the thermo-regulatory characteristics of sultriness are quantitatively elucidated.