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OBJECTIVE CLIMATE COMFORT EVALUATION IN VEHICLES USING DRESSMAN 3.2

EVALUATION OF OVERALL THERMAL COMFORT WITH EXTENDED EQUIVALENT TEMPERATURE

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BACKGROUND

On a cold winter's day at 0 °C, the range of an electric vehicle in urban traffic can halve compared to when the outside temperature is 20 °C *[1]*. It takes significantly more energy to heat or cool the entire vehicle cabin than it does to just control the climate for the occupants. The use of measures close to the body, such as seat or steering wheel heating, are thus on the increase. However, the effectiveness of such measures on thermal comfort can barely be measured using existing methods that measure single points in the vehicle cabin. To further develop climate control in vehicles, a measuring system is called for which can capture both cooling and heating effects both in time and space. Only by using suitable measurement techniques can the effectiveness of vehicle climate control measures and the required duration of the measures on specific areas of the body be assessed and ultimately sound information about thermal comfort be obtained. The measurement system must also be quick and easy to use in practice and must be able to be integrated into a vehicle's CAN bus system.

EQUIVALENT TEMPERATURE

In addition to the four physical indoor climate parameters of air temperature, radiation temperature, air velocity, and relative humidity, two further individual parameters – clothing insulation value and energetic metabolic rate – influence the heat transfer between people and their environment. To gain information about thermal comfort in environments where thermal conditions are inhomogeneous, such as in a vehicle cabin, segmented "thermal manikins" or individually heated sensors on dummies are used. This makes it possible to measure the local heat exchange and calculate the so-called "equivalent temperature" for each part of the body. According to the definition of DIN EN ISO 14505-2 *[2]*, at the same equivalent temperature, a person exchanges the same dry heat through radiation and convection. Following the procedure laid down in the standard, the comfort ranges of the equivalent temperature were defined on 16 specific areas of the body. Heat conduction was not taken into account; the comfort diagrams in the standard do not provide any information about the contact areas on the surface of the seat and on the back.

Literature
[1] Elektroautos im Winter: https://www.adac.de/rund-ums-fahrzeug/elektromobilitaet/info/elektroauto-reichweite-winter/
[2] DIN EN ISO 14505-2: 2007: Beurteilung der thermischen Umgebung in Fahrzeugen – Teil 2: Bestimmung der Äquivalenttemperatur.
[3] Stratbücker, S., Park, S., Pathak, A., Norrefeldt, V., Grün, G.: Concepts for comfortable air-conditioning. Simulation using a zonal cabin model and a metrological evaluation based on equivalent temperature. In: Proceedings of 1st ETA Conference, 2016.
[4] Park, S.; Stratbücker, S., Visser, M., Grün, G.: Thermal comfort measurement methodology during a heat-up or cool-down phase of a vehicle. 3. Tagung Fahrzeugklimatisierung, Essen, 2019.
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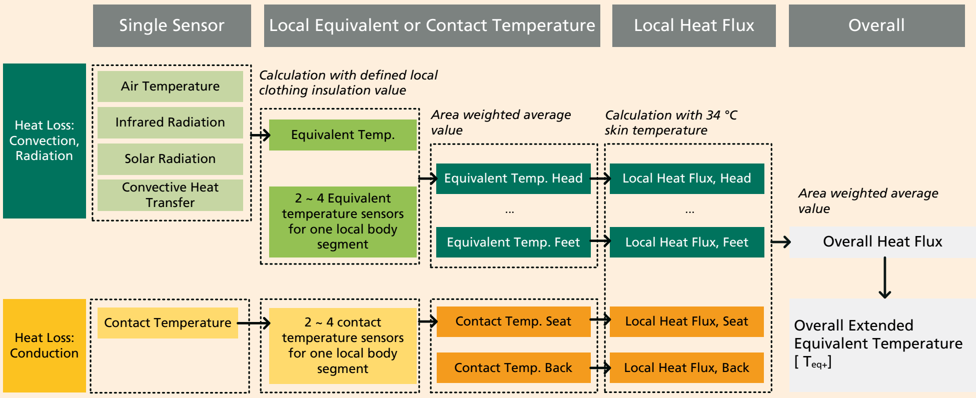

DRESSMAN 3.2

Fraunhofer Institute for Building Physics IBP developed the DressMan (*D*ummy *RE*presenting *S*uit for *S*imulation of hu*MAN* heat loss), to measure thermal comfort in inhomogeneous environments. The first version of the sensor dates back to the 1990s and was developed as a system for measuring the equivalent temperature. It is embedded in the standard DIN EN 14505-2. In 2014, the DressMAN Sensor was further developed in a research project *[3]*. Over the following years, a significantly smaller third version with much lower thermal mass was built. This made it possible to measure the rapidly changing environment of a vehicle cabin during cooling and heating. In addition, data acquisition was realized with wireless sensor technology and data was converted to the CAN protocol. The further developed sensors were then either integrated into a wearable suit *[4]* or attached to 28 defined parts of the body with Velcro fasteners (see Figure 1). The current version 3.2 of DressMAN features new measurement technologies and new sensors. While only heated sensor probes were used for DressMAN in the past, the DressMAN 3.2 features a heated sensor to measure the convective heat transfer coefficient and three further sensors: an air temperature sensor and two thermopile sensors for long-wave and short-wave radiation to calculate the mean radiation temperature. This enables specific variables, such as the intensity of solar radiation or air velocity, to be measured. In addition to the equivalent temperature, the temperature of the contact area is captured so that heat conduction and its impact on overall heat transfer can be taken into account.

CALCULATIONS ON THE BASIS OF INDIVIDUAL PARAMETERS

Eq. 1 expresses the dry heat flux density q_1 of a human in a thermal environment, with h_c being the convective heat transfer coefficient *[W/m²K]*, h_r the radiative heat transfer coefficient *[W/m²K]*, T_a the air temperature *[°C]*, T_r the mean radiation temperature *[°C]* and T_{cl} the surface temperature of the clothing. Following the definition of the equivalent temperature T_{eq} Eq. 1 can also be expressed as Eq. 2. In this case, $h_{c,cal}$ is defined as the convective heat transfer coefficient for air velocities below 0.05 *[m/s]*. Using Eq. 1 and Eq. 2 $(q_1 = q_2)$ the equivalent temperature can be calculated (see Eq. 3).

$$q_1 = h_c\,(T_{cl} - T_a) + h_r\,(T_{cl} - T_r) \tag*{Eq. 1}$$

$$q_2 = h_{c,cal}\,(T_{cl} - T_{eq}) + h_r(T_{cl} - T_{eq}) \tag*{Eq. 2}$$

$$T_{eq} = T_{cl} - \frac{(h_c\,(T_{cl} - T_a) + h_r\,(T_{cl} - T_r))}{(h_{c,cal} + h_r)} \tag*{Eq. 3}$$

DressMAN 3.2 provides data such as air temperature, mean radiation temperature, and the convective heat transfer coefficient. During calibration, $h_{c,cal}$ is determined. The heat flux density of skin to clothing surface can be described by taking into account the clothing insulation value I_{cl} and assuming a skin temperature of 34 °C in the same manner as when the "thermal manikin" is operated in constant temperature mode (Eq. 4). Since this heat flux is the same as the heat flux of clothing surface to the environment $(q_1 = q_3)$, the surface temperature can be calculated with Eq. 5, which is then used to calculate the value for the equivalent temperature in Eq. 3. The DressMAN 3.2 evaluation procedure determines the local equivalent temperatures using clothing insulation values according to Nilsson *[5]* or with a uniform insulation value of 0.8 clo for all local body parts.

$$q_3 = \frac{(34 - t_{cl})}{I_{cl}} \tag*{Eq. 4}$$

$$T_{cl} = \frac{34 + I_{cl}\,(h_c T_a + h_r T_r)}{1 + I_{cl}\,(h_c + h_r)} \tag*{Eq. 5}$$

OVERALL CLIMATE COMFORT RATING WITH EXTENDED EQUIVALENT TEMPERATURE (TEQ+)

The 28 calculated equivalent temperatures are then assigned to 12 parts of the body to determine the local equivalent temperature. These local equivalent temperatures are then compared with the comfort diagram in the standard and used to evaluate the local thermal comfort of each part of the body. For the contact area, the heat flux density is calculated from the contact temperature measurement in Eq. 4, with the measured contact temperature being equated to the clothing temperature in Eq. 4. To evaluate overall thermal comfort on the whole body, local heat flux densities must be calculated with Eq. 2. Together with the heat flux density from the contact area, these can be weighted by area to calculate the overall heat flux density. From this, the extended equivalent temperature, T_{eq+} is calculated using Eq. 4 and Eq. 2). Compared to the definition of equivalent temperature in DIN EN ISO 14505-2 *[2]*, which does not include heat conduction, the impact of seat heating or cooling can be evaluated with help of the equivalent temperature concept. Thus, thermal environmental conditions can be described with a single numerical value and enables different vehicle climate control concepts to be compared.

More information:
https://www.ibp.fraunhofer.de/de/geschaeftsfelder-produkte/produktentwicklungen/dressman.html

1 *DressMAN 3.2 in a vehicle.*

2 *Overall thermal evaluation.*